INTERNSHIP REPORT

BACHELOR OF TECHNOLOGY

in

CIVIL ENGINEERING

by

D. Arjun

2210110245

SHIV NADAR

INSTITUTION OF EMINENCE DEEMED TO BE

UNIVERSITY

DELHI NCR

DEPARTMENT OF CIVIL ENGINEERING

SHIV NADAR UNIVERSITY

DELHI-NCR

201314

STRUCTURAL DESIGN OF UNDERGROUND METRO STRUCTURES

Submitted to

Engineering Design & Research Centre (EDRC)

Heavy Civil Infrastructure IC

L&T Construction

Chennai - 600 089.

An internship report submitted as a part of the training underwent at L&T Construction, Chennai.

………………………..

Mr. Gururajachar S

Senior Chief Engineering Manager (Civil)

Heavy Civil Infrastructure IC

L&T Construction

ACKNOWLEDGEMENT

I thank god almighty for giving me good health and enabling me to complete this internship successfully from **15th MAY to 20th JULY 2025**.

I am deeply thankful to **Mr. Gururajachar S**, the Senior Chief Engineering Manager (Civil), for his immense help and coordination towards the completion of the internship. I am also thankful for **Mr.Sivaraj J and Mr. T Cibin** , for their impeccable guidance and patience in clearing my doubts which helped me much to complete this internship successfully.

This internship was made successfully by the support of all other staff at metro-engineering Design and Research Centre **(EDRC),** L&T Construction HQ, Chennai.

I thank them for allowing me to gain knowledge by providing an affable learning environment, thereby helping me to complete this internship training.

Last but not least, I would like to express my thanks to my dearest parents for their love, constant support, and motivation during my internship period.

INTRODUCTION

Larsen & Toubro Limited (L&T) is one of India's largest and most respected engineering, procurement, and construction (EPC) conglomerates, known for executing complex infrastructure and industrial projects across the globe. Founded in 1938, the company has consistently played a pivotal role in shaping India's infrastructure landscape, with expertise spanning across sectors such as power, transportation, water, hydrocarbons, defence, and heavy civil infrastructure.

As part of its diverse operations, the **Heavy Civil Infrastructure (HCI) division** of L&T is renowned for delivering technically demanding and time-sensitive civil engineering projects. This includes a range of projects such as nuclear power plants, hydroelectric structures, tunnels, ports, marine works, and urban transit systems. The division thrives on its ability to execute high-risk and high-impact projects through advanced engineering, cutting-edge construction techniques, and stringent safety and quality protocols.

Within HCI, the **Metros business vertical** focuses specifically on the design and construction of urban mass rapid transit systems. This includes underground and elevated metro corridors, stations, shafts, and associated civil structures. The Metros team works at the intersection of urban mobility and civil engineering, where innovation, precision, and safety are paramount. The team's responsibilities range from detailed design and structural analysis to planning, execution, and coordination of large-scale construction activities in congested and geologically diverse urban environments.

The internship was undertaken with the Metros team of L&T's Heavy Civil Infrastructure division, which is currently engaged in several key metro projects across the country, including the Bombay metro project. The work covered under this internship involved exposure to both the design and construction aspects of underground metro systems, with a focus on structural analysis, reinforcement detailing, tunnel boring machine (TBM) launch systems, and interaction with field operations. This report presents a comprehensive documentation of the technical learning, site experiences, and design skills acquired during the internship.

TABLE OF CONTENTS

TYPES OF SURVEY

1. Reconnaissance Survey:

The reconnaissance survey is the initial phase of surveying conducted to gather preliminary information about the project area. During this stage, survey team will collect data related to the topography, geology, hydrology, land use, existing infrastructure, and other relevant factors.

From this survey we could assess the feasibility of the metro project and identify potential challenges or constraints that may need to be addressed during the detailed survey phase.

2. Topographic Survey:

A topographic survey is conducted to map the surface features of the project area, including the elevation, contours, natural and man-made features, such as buildings, roads, and water bodies. This survey provides essential information for the design and planning of the metro system, including route alignment, station locations, and construction planning.

3. Geotechnical Survey:

Geotechnical surveying involves assessing the soil and subsurface conditions of the project area. This survey is essential for evaluating the stability and load-bearing capacity of the soil, also it identifies any potential hazards, such as landslides or sinkholes, that may affect the construction of the metro tunnels, stations, and other infrastructure.

4. Utility Survey:

Utility surveying is conducted to identify the location and depth of existing underground utilities, such as water pipes, sewer lines, gas lines, electrical cables, and telecommunications infrastructure. This information is critical for avoiding conflicts during construction and ensuring the safety of the workers and the public.

5. Environmental Survey:

An environmental survey assesses the potential impact of the metro project on the natural and built environment. This includes identifying sensitive habitats, protected species, archaeological sites, and other environmental factors that may be affected by the construction and operation of the metro system. The survey also evaluates measures to minimize or mitigate any adverse effects and ensure compliance with environmental regulations.

6. Traffic Survey:

A traffic survey is conducted to assess the existing traffic conditions in the project area, including traffic volume, patterns, congestion, and safety issues. This information is used to evaluate the potential impact of the metro project on the local transportation network and to develop strategies for managing traffic during construction and operation.

7. Hydrographic Survey:

Hydrographic surveying is conducted to identify the location and depth of existing water bodies, if the metro line crosses or is near water bodies. It also measures underwater features and depths, and assesses the impact on water flow and quality.

TYPES OF METRO BASED ON ALIGNMENT

1. Underground Metro

An underground metro system is constructed beneath the ground surface, typically through tunneling methods such as Tunnel Boring Machines (TBMs) or cut-and-cover techniques. This type of alignment is especially suitable for densely populated urban areas where land acquisition is challenging or surface space is limited. Although underground construction is the most expensive due to excavation, tunneling, waterproofing, and safety requirements, it offers the significant advantage of avoiding interference with road traffic, buildings, and utilities. Underground metros are also less visually intrusive and operate independently from surface conditions like weather or traffic congestion. Examples include the London Underground, New York Subway, and Kolkata Metro Line 1.

2. Elevated Metro

An elevated metro is constructed above ground level, typically using a series of columns and viaducts to support the track. This type of alignment is a cost-effective alternative to underground systems and is often used when surface space is constrained but tunneling is not feasible due to high costs or geological challenges. Elevated metro lines avoid most surface traffic, providing uninterrupted, fast transit service, but can impact the urban landscape visually and contribute to noise pollution. Construction is faster and less disruptive compared to underground systems. Examples include parts of the Delhi Metro, Bangkok Skytrain, and Chennai Metro Phase 1.

3. At-Grade Metro (Surface Metro)

An at-grade or surface metro is built directly on the ground level, usually on dedicated tracks that are separated by fencing or walls to prevent intrusion by vehicles or pedestrians. This alignment is the least expensive to construct, making it a viable option for less crowded or suburban areas where land is more readily available. However, at-grade metros are more vulnerable to level-crossing conflicts, unless adequate measures such as overpasses or underpasses are built at road intersections. While construction is simpler, operational efficiency and safety can be compromised if not properly isolated from surface activities. Examples include portions of the Kochi Metro depot tracks and some sections of Chennai Metro.

METRO PRELIMINARY DESIGN PHASE

The preliminary design phase of Chennai Metro construction involves several critical activities to ensure the project's success. It's activities lay the groundwork for the detailed design and subsequent construction phases of the Chennai Metro, ensuring that the project is well-planned and executable within the set constraints. These preliminary design works typically include:

1. Feasibility Studies:

- Assessment of the project's viability, considering economic, technical, and environmental factors.
- Cost-benefit analysis to determine the financial feasibility.

2. Alignment and Route Selection:

- Identifying potential routes and evaluating them based on technical, environmental, and social criteria.
- Conducting surveys and geotechnical investigations to select the most suitable alignment.

3. Detailed Project Report (DPR) Preparation:

- Compiling comprehensive reports that cover technical, financial, and operational aspects of the project.
- Detailing the proposed alignment, station locations, and facilities.

4. Geotechnical Investigations:

- Conducting soil and rock testing along the proposed route to understand subsurface conditions.
- Gathering data to inform the design of foundations and tunneling methods.

5. Environmental Impact Assessment (EIA):

- Evaluating the potential environmental impacts of the construction and operation of the metro system.
- Proposing mitigation measures to minimize negative effects on the environment.

6. Social Impact Assessment (SIA):

- Assessing the social implications, including displacement of residents, land acquisition, and impacts on local communities.

- Developing strategies for rehabilitation and resettlement of affected people.

7. Land Acquisition Planning:

- Identifying land parcels required for construction.

- Coordinating with government authorities for land acquisition processes.

8. Utility Identification and Relocation:

- Identifying existing utilities (water, sewer, electrical lines, etc.) along the proposed route.

- Planning for their relocation or protection during construction.

9. Design of Major Components:

- Preliminary design of tunnels, elevated sections, stations, and depot facilities.

- Incorporating architectural, structural, and MEP (Mechanical, Electrical, and Plumbing) considerations.

10. Traffic Management Planning:

- Developing strategies to manage traffic during construction to minimize disruptions.
- Planning for alternative routes and traffic diversions.

11. Coordination with Stakeholders:

- Engaging with local authorities, government agencies, and the public to gather input and address concerns.

- Coordinating with utilities and service providers.

12. Regulatory Approvals:

- Securing necessary clearances and approvals from various government bodies and regulatory agencies.

- Ensuring compliance with local, state, and national regulations.

13. Financial Planning and Funding:

- Developing a detailed financial plan, including cost estimates and funding strategies.

- Exploring funding options such as government grants, loans, and public-private partnerships.

14. Risk Assessment and Management:

- Identifying potential risks associated with the project.

- Developing mitigation strategies to address identified risks.

STRUCTURAL COMPONENTS IN METRO

Metro construction involves several structural components that collectively form the infrastructure required for a functioning metro system. These components can be broadly categorized into the following:

1. Substructure Components

a. Foundations:

- **Raft Foundations**: Used for stations or other large structures.
- **Pile Foundations:** Provide deep support where soil conditions are poor.

b. Tunnels:

- **Bored Tunnels**: Created using tunnel boring machines (TBM) for underground metro lines.
- **Cut-and-Cover Tunnels**: Constructed by excavating a trench and covering it over.
- **Immersed Tube Tunnels**: Used for underwater crossings, consisting of pre-fabricated segments sunk into place.

2. Superstructure Components

a. Tracks:

- **Rails and Sleepers:** Steel rails fixed on concrete or wooden sleepers.
- **Ballast:** Crushed stone laid beneath and around the sleepers (in ballasted tracks).
- **Slab Track:** Concrete track bed used in ballast less tracks for stability and low maintenance.

b. Elevated Structures:

- **Viaducts:** Long elevated structures supporting the track over land or water.

- **Bridges:** Shorter spans compared to viaducts, crossing roads, rivers, or other obstacles.
- **Pier**: Support elevated sections of the metro track.

c. **Stations:**

- **Platforms**: Passenger boarding areas, either elevated, at-grade, or underground.
- **Station Buildings:** Contain ticketing, waiting areas, shops, and administrative
  offices..
- **Access Structures**: Stairs, escalators, elevators, and pedestrian bridges for entry and exit.

3. Ancillary Components

a. Depots and Maintenance Facilities:

- **Maintenance Yards:** For storing and servicing trains.
- **Workshops:** Equipped for heavy maintenance and repairs.
- **Operations Control Center (OCC):** Centralized monitoring and control of the metro network.

b. Power Supply Systems:

- **Substations:** Convert and distribute electrical power for train operation.
- **Third Rail or Overhead Catenary:** Methods for delivering power to trains.
- **Backup Power Systems:** Ensure continuous operation in case of power failure.

c. Signalling and Communication Systems:

- **Signalling Equipment:** Automatic Train Control (ATC), Automatic Train Protection (ATP), and Communication-Based Train Control (CBTC) systems.
- Fiber optic cables, radio systems, and public address systems for operational and passenger communication.

4. Safety and Environmental Systems

a. Ventilation Systems:

- For air circulation and comfort for passengers.

b. Fire Safety Systems:

- **Fire Detection and Suppression:** Sprinklers, smoke detectors, and firefighting equipment.
- **Emergency Exits:** Clearly marked and accessible escape routes.

c. Drainage Systems:

- **Track Drainage:** Prevents water accumulation on tracks.
- Manages water ingress and prevents flooding.

METHODS OF UNDERGROUND METRO CONSTRUCTION

1. Cut and Cover Method

The Cut and Cover method is a traditional and straightforward technique used for constructing shallow metro tunnels and stations. In this method, the surface is excavated to the desired depth, the tunnel or box structure is constructed in the open trench, and the trench is then backfilled and the surface restored. This approach is cost-effective and relatively simple, making it suitable for constructing metro stations and short tunnel sections where surface disturbance is manageable. However, it causes significant disruption to surface utilities, roads, and traffic during construction.

Example: In **Delhi Metro Phase 1**, many of the underground stations—such as those on the Yellow Line—were constructed using this method, particularly in areas with available road width for excavation and staging.

2. Tunnel Boring Machine (TBM) Method

The Tunnel Boring Machine (TBM) method uses a large mechanized machine that bores through the ground while simultaneously placing precast concrete segments to form the tunnel lining. It is ideal for long, deep tunnels that must pass beneath densely built-up urban areas with minimal surface disturbance. TBMs provide high-speed, safe, and automated tunnel construction but require high initial investment and careful planning, especially for shaft locations and launching/receiving pits.

Example: The **Mumbai Metro Line 3 (Colaba–Bandra–SEEPZ)** extensively uses TBMs to construct deep tunnels beneath high-density areas like Mahalaxmi, Cuffe Parade, and Churchgate, minimizing surface impact in a congested city.

3. New Austrian Tunneling Method (NATM)

The New Austrian Tunneling Method (NATM), or Sequential Excavation Method, is a flexible construction approach that relies on the natural strength of the surrounding ground to provide tunnel stability. Small sections of the tunnel are excavated, and support systems like shotcrete, steel ribs, and rock bolts are installed immediately. This method is particularly suitable in complex ground conditions or where the geology changes frequently. Although slower than TBM, it allows engineers to respond to ground behavior in real time.

Example: Parts of the **Kolkata Metro East–West Corridor**, which passes under the Hooghly River and through soft silt and clay, have used NATM in transition zones where TBMs were not effective.

4. Box Pushing Method

The Box Pushing method involves hydraulically jacking precast concrete box segments through the ground while soil is removed from the front face inside the box. This trenchless method is highly effective for constructing short underpasses beneath roads or rail lines without disturbing the surface. It is a time-efficient solution where shallow crossings are required but excavation from the top is not possible.

Example: In the **Lucknow Metro**, the box pushing method was employed near Charbagh Railway Station to pass beneath operational rail tracks without disrupting train movement.

5. Drill and Blast Method

In the Drill and Blast method, controlled explosives are used to fracture rock in a planned pattern. The loosened material is then removed, and support systems like rock bolts, mesh, and shotcrete are applied. This method is typically used in mountainous or rocky terrain where TBMs are not practical and where ground vibrations are acceptable.

Example: The **Bangalore Metro (Namma Metro) underground section** near Vidhana Soudha, which passes through hard granite, partially used drill and blast methods due to extremely tough rock formations that were unsuitable for TBM progress.

6. Immersed Tunnel Method

The Immersed Tunnel Method involves floating large precast concrete tunnel segments into a waterbody, lowering them into a pre-dug trench on the riverbed, joining them together underwater, and covering them with backfill material. It is typically used for underwater crossings such as rivers or harbors and is technically demanding and expensive.

Example: Though not yet used in India for metros, this method has been implemented in the **Hong Kong MTR**, the **Bosphorus Tunnel in Istanbul**, and the **Crossrail Thames Tunnel in London**. India may adopt it in future for metro crossings under rivers like the Ganges or Yamuna, should conventional methods be infeasible.

These construction methods are chosen based on several factors such as depth of alignment, soil and rock conditions, environmental sensitivity, urban congestion, tunnel length, and budget constraints. Often, a combination of techniques is used across different parts of the metro alignment to best address varying site conditions.

<u>TYPES OF SOIL RETAINING STURUCTURES</u>

1. Sheet Pile Wall

Sheet pile walls are thin, interlocking steel or vinyl sheets driven vertically into the ground to support soil during excavation. In metro projects, they are typically used for temporary shoring in shallow excavations or cut-and-cover tunnel sections, especially in soft soils or near water bodies, due to their ease of installation and removal.

2. Secant Pile Wall

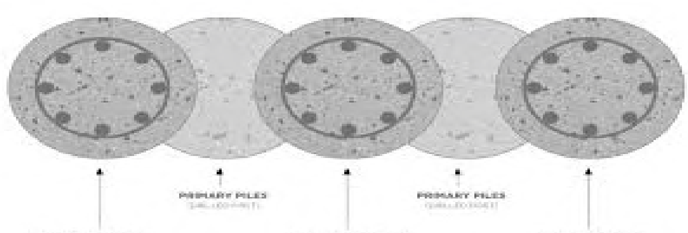
Secant pile walls are formed by drilling overlapping concrete piles, with combinations of soft (unreinforced) and hard (reinforced) piles or both being hard. In metros, they are used for deep excavations in urban areas, such as station boxes and shafts, where space is limited and water seepage control is critical. They create a strong and continuous wall to resist lateral loads and groundwater pressure.

Types of Secant Piles

- **Soft + Hard Secant Pile Wall**

  In this type, primary piles (constructed first) are made of unreinforced, low-strength concrete (soft), and secondary piles (constructed in between) are made of reinforced, high-strength concrete (hard).

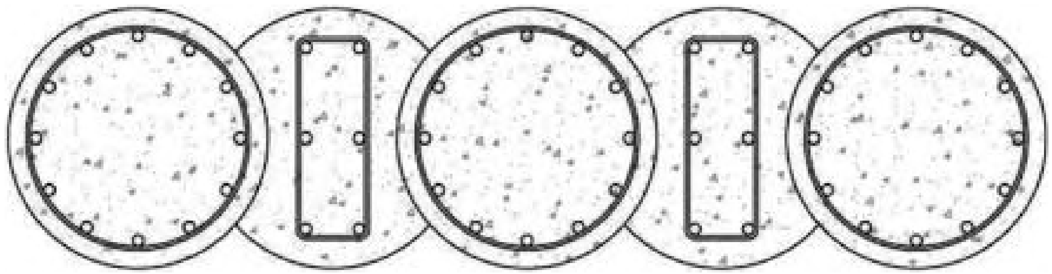
.



- **Hard + Hard Secant Pile Wall**

Both primary and secondary piles are made of reinforced, high-strength concrete.

Provides maximum strength and water tightness, ideal for deep excavations with high lateral loads and groundwater presence.



- **Hard + Structural Secant Pile WalL**

Secondary piles are made with heavily reinforced concrete, often acting as permanent structural walls, while primary piles are still hard but with less reinforcement.

Common in permanent metro station walls where the wall has to carry significant structural loads.

3. Diaphragm Wall (D-Wall)

Diaphragm walls are deep, reinforced concrete walls constructed in slurry-filled trenches before excavation. They serve as both retaining and permanent structural walls in underground metro stations, access shafts, and cut-and-cover tunnels. D-walls are crucial in deep excavations under high groundwater conditions, offering excellent structural stability and water tightness.

4. Contiguous Pile Wall

Contiguous pile walls consist of a series of closely spaced concrete bored piles with small gaps in between. In metro construction, they are used to support excavation for station boxes and shafts, especially where groundwater is low or manageable. These walls are typically used when minimal disturbance to adjacent structures is required and can also act as part of the permanent structure if necessary.

ANCHOR SYSTEM AND REINFORCEMENT DESIGN

(As per AASHTO Code)

During the internship, we were introduced to the design and detailing of **anchor systems** in accordance with **AASHTO (American Association of State Highway and Transportation Officials)** specifications. These systems are commonly used in deep excavations, retaining structures, and support of excavation (SOE) works such as secant pile walls, diaphragm walls, and soldier pile systems. The following concepts were explored and discussed in practice.

1. Anchor Zones – Active and Passive

Anchors used in retaining systems can be classified into two functional zones:

Active Zone: The portion of the anchor where the tension is applied to stabilize the wall.
Passive Zone: The section beyond the potential failure surface in the soil where the anchor is embedded to resist pullout. The bond between the grouted anchor and the surrounding soil provides resistance here.
Anchors can be installed either **inclined** or **horizontal**, depending on the soil profile, working space, and design requirements.

2. Free Length and Fixed Length

Anchors typically consist of two parts:

Free Length: This portion allows the anchor tendon to stretch elastically under tension and does not bond with the surrounding soil.
Fixed (Bonded) Length: This section is grouted into the soil and provides resistance via shear interaction with the surrounding ground. It lies entirely within the passive zone.

Accurate demarcation of these lengths is critical to ensure that the anchor functions as designed.

3.Reinforcement and Cross-Sectional Arrangement

The sketch includes circular cross-sections of drilled anchor holes or micropiles with reinforcement. Key elements include:

- A central tendon or rebar for anchoring or load-bearing.
- A **stiffener ring**, used to keep reinforcement bars spaced uniformly within the circular section.

- Use of **10 mm diameter rebars**, as specified in the sketch, arranged symmetrically around the circumference.
- These bars are embedded within the concrete or grout that fills the borehole.

4.Reinforcement Detailing in Section

The section view shows a rectangular structural element (possibly a pile or pier cap) with vertical reinforcement bars (stirrups or ties) and lateral rebars for confinement. Cover, spacing, and bar placement details are crucial here for ensuring structural performance and durability.

5.Guide Wall Concept

Guide walls are temporary shallow concrete walls used in the construction of diaphragm or secant pile walls. Their purpose is to guide the drilling equipment and ensure alignment of the piles or wall segments.

In the sketch, a top view is shown with a centrally aligned drill rig operating between two guide walls. This setup ensures that the pile remains plumb and is constructed in its intended position.

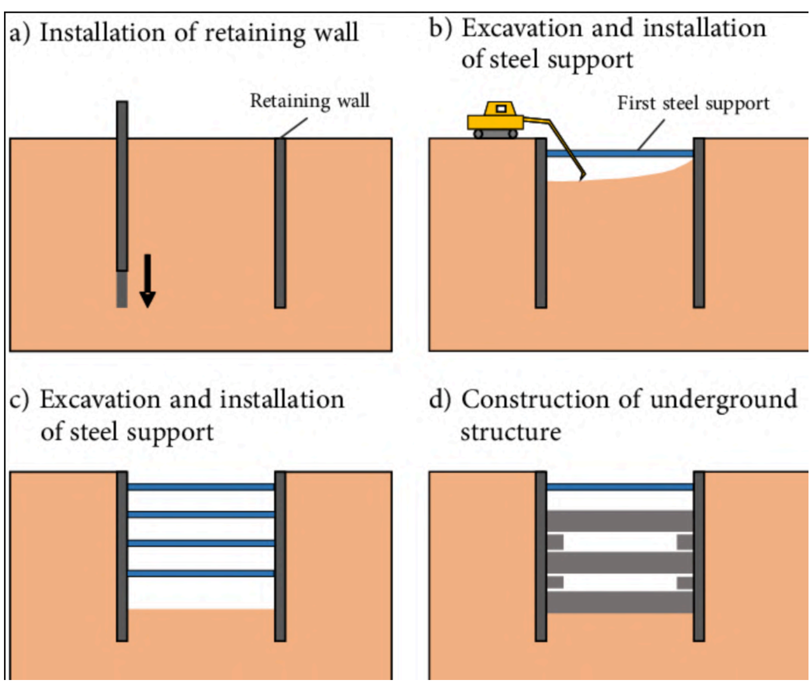
6. AASHTO Code Reference

The detailing and anchoring concepts discussed are based on AASHTO LRFD Bridge Design Specifications, which provide guidelines for geotechnical anchoring systems, soil-structure interaction, and reinforcement detailing. Adherence to such codes ensures safety, reliability, and standardization across infrastructure projects.

CONSTRUCTION OF UNDERGROUND METRO STATIONS

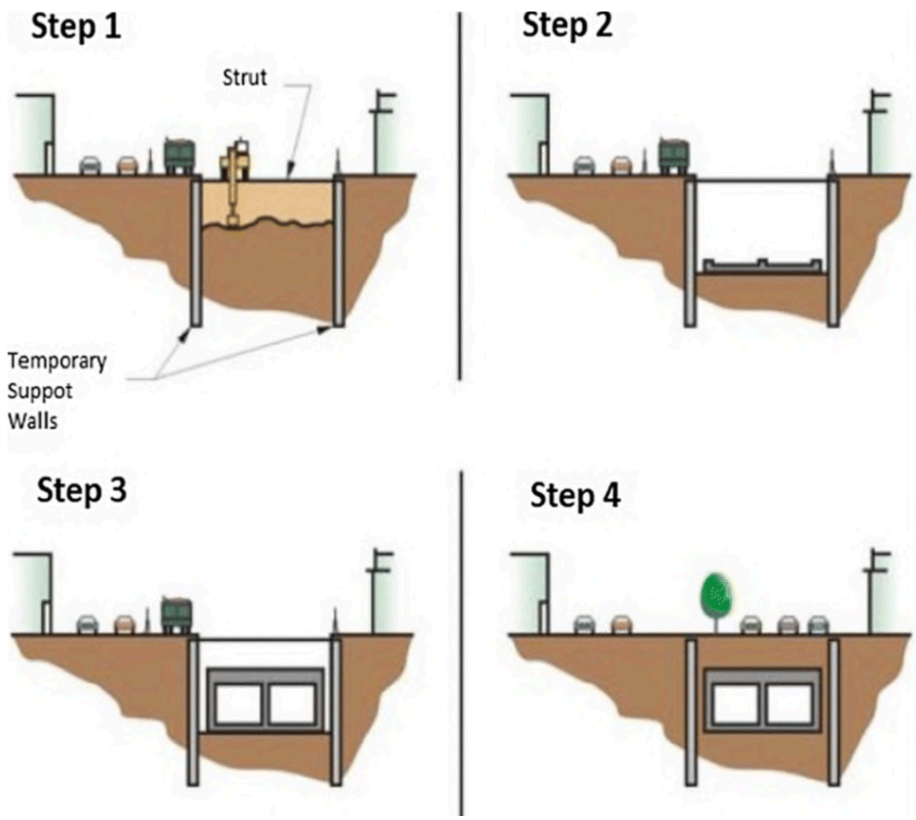
TOP -DOWN APPROACH

The top-down method of metro station construction involves building the permanent structure from the ground level downwards. Initially, retaining structures such as diaphragm walls or secant piles are installed around the perimeter. Then, the ground-level slab (roof slab) is constructed, followed by excavation below it through temporary openings. As the excavation progresses downward, intermediate floor slabs are constructed sequentially until reaching the final depth where the base slab is laid. This method allows simultaneous excavation and structural work, making it especially suitable for congested urban areas where minimizing surface disruption is essential. The top slab can be completed early, allowing above-ground traffic or activities to resume while work continues below.



BOTTOM UP APPROACH

In contrast, the bottom-up method is a traditional approach where excavation is carried out entirely to the required depth before beginning structural construction. Once the excavation is complete, the construction of the metro station starts from the base slab and proceeds upward through the various structural levels until reaching the roof slab. After the structure is complete, the site is typically backfilled. This method is straightforward and offers open access to the excavation, which facilitates the use of large construction equipment. It is generally more suited to open or less congested environments where there are fewer constraints at the surface level.



LEVELS IN UNDERGROUND METRO STATION

1. Street Level (Ground Level)

The **street level** is the interface between the metro station and the city surface. It serves as the entry and exit point for passengers. This level typically includes station entrances/exits with staircases, escalators, and elevators leading down to the concourse. It may have canopies, entrance pavilions, signage, and connections to nearby roads, footpaths, bus stops, auto/taxi stands, or pedestrian crossings. Street-level planning is essential to integrate the station into the urban fabric and provide seamless connectivity for commuters.

2. Concourse Level

Located just below the street level, the **concourse level** functions as the main circulation and control area of the station. It houses **ticketing facilities** like manual counters and Automatic Ticket Vending Machines (TVMs), **AFC (Automatic Fare Collection) gates** for entry and exit, and **security screening zones** with baggage scanners and metal detectors. It also includes **customer care centers**, **retail shops**, **washrooms**, and **emergency services** like first-aid rooms. This level helps regulate the movement of passengers and provides access to the platform via escalators, stairways, or elevators. In interchange stations, multiple concourse levels may exist to connect different lines.

3. Platform Level

The **platform level** is where passengers **board and alight from the trains**. It is the lowest public level in the station and directly interfaces with the rail tracks. Stations may have **island**

platforms (a single central platform serving both directions) or **side platforms** (separate platforms on either side of the tracks). The platform is equipped with **signage**, **display boards**, **CCTV cameras**, **public announcement systems**, **platform screen doors** (in some systems), and **tactile paving** for the visually impaired. The design ensures safe, fast, and organized boarding and alighting of passengers.

4. Service or Utility Levels (if present)

Some underground metro stations, especially deep-level ones, have additional **sub-platform or intermediate levels** dedicated to **services and utilities**. These levels house **electrical panels, ventilation equipment, sump pumps, fire protection systems**, and **communication control rooms**. They are typically not accessible to the public and are used by maintenance and operational staff to manage the station's infrastructure systems. In some designs, these may also include **evacuation passages** or **tunnels** for emergency use.

ARCHITECTURAL CONSIDERATIONS FOR UNDERGROUND METRO STATIONS

1. **Street Level** – Entry point of the station with access via staircases, escalators, and elevators from the road.

2. **Entrance Canopy/Structure** – Covered structure at the entrance protecting passengers and marking station access.

3. **Security Check Area** – Zone with metal detectors, baggage scanners, and security personnel for screening passengers.

4. **Unpaid Area** – Publicly accessible area before ticket validation, containing ticket counters, TVMs, and information boards.

5. **Ticket Counter –** Manual facility where passengers can buy tokens or recharge smart cards.

6. **Ticket Vending Machine (TVM)** – Automated machine for fast and self-service purchase of metro tokens or card top-up.

7. **Smart Card Recharge Point –** Dedicated kiosk or machine where passengers recharge their metro cards.

8. **Customer Help Desk –** Assistance point for resolving passenger issues, lost items, or general queries.

9. **Paid Area** – Restricted access area after ticket validation, leading to platforms and train boarding zones.

10. **AFC Gates (Automatic Fare Collection Gates)** – Electronic gates that validate tickets or smart cards to enter/exit paid areas.

11. **Concourse Level** – Intermediate level between street and platform used for passenger circulation, retail, and services.

12. **Escalators** – Moving stairways that transport passengers between street, concourse, and platform levels efficiently.

13. **Elevators/Lifts** – Vertical transport for elderly, disabled, or passengers with luggage across different levels.

14. **Staircases** – Fixed steps for access between station levels during normal or emergency conditions.

15. Platform Level – The train boarding area where passengers wait and enter or exit the metro coaches.

16. Side/Island Platforms – Passenger waiting zones designed based on track layout, either on one or both sides of the train.

17. Platform Screen Doors – Safety barriers on platforms that open only when trains arrive (used in modern systems).

18. Tactile Tiles/Guidance Paths – Surface tiles that guide visually impaired passengers safely across the station.

19. Public Announcement (PA) System – Audio system used for train updates, safety messages, and passenger information.

20. Signage and Maps – Visual boards showing directions, platform numbers, exits, and metro route maps.

21. CCTV Surveillance – Security camera system for real-time monitoring of all areas in the station.

22. Fire Alarm System – Detection and alert mechanism for smoke or fire incidents inside the station.

23. Firefighting Equipment – Includes extinguishers, hydrants, hoses, and sprinklers for fire control and safety.

24. Emergency Exit Routes – Clearly marked paths and staircases for safe evacuation during emergencies.

25. Ventilation System (TVS) – Tunnel Ventilation System that maintains air circulation and removes smoke during fire.

26. Air Conditioning System (HVAC) – Provides thermal comfort and fresh air supply in concourse and platform areas.

27. Lighting System – Adequate artificial lighting throughout all levels for safety, visibility, and aesthetics.

28. Power Supply Room – Station area housing transformers and panels supplying power to all systems.

29. Backup Generators – Diesel generators that supply electricity in case of main power failure.

30. UPS (Uninterrupted Power Supply) – Backup system that keeps critical services running during power outages.

31. Drainage and Dewatering System – Network of sumps and pumps that prevent water logging and maintain dry conditions.

32. Control and Communication Room – Secure area for monitoring station operations, alarms, and communication systems.

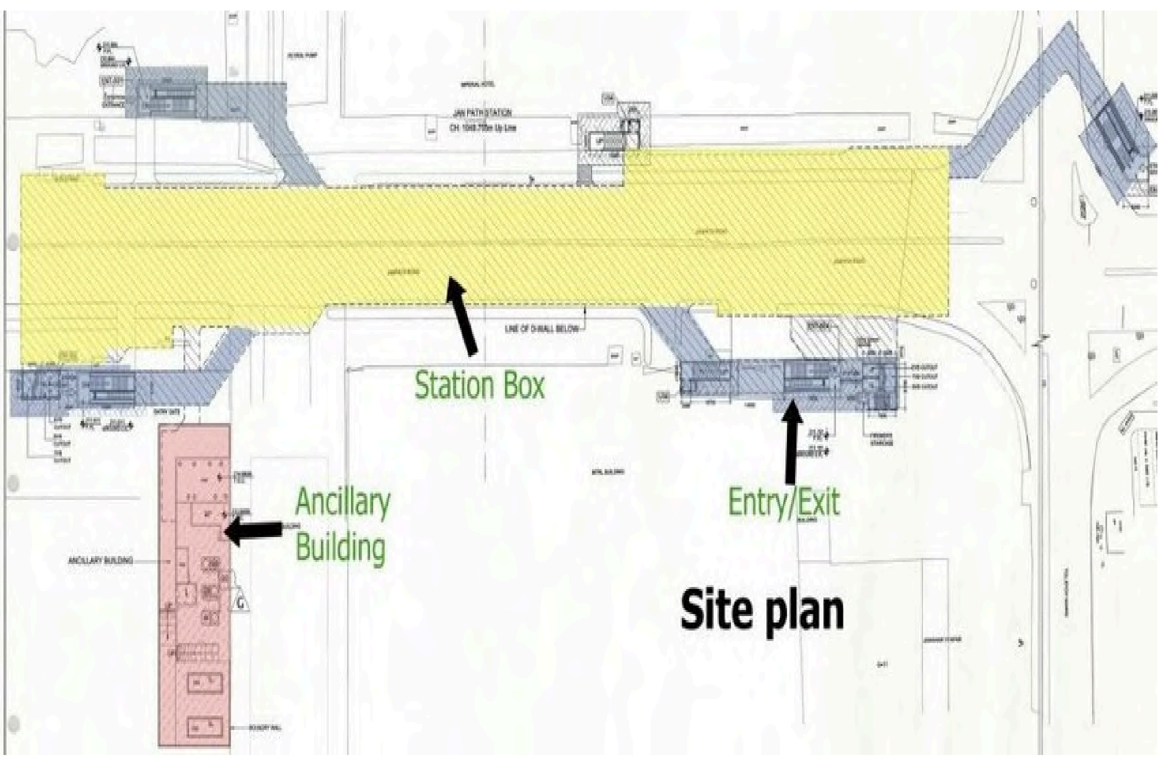
33. Retail Shops/Kiosks – Commercial outlets inside the station offering food, beverages, magazines, or convenience items.

34. ATM Machines – Cash withdrawal facility available at the concourse or entrance for passenger convenience.

35. Drinking Water Facility – Free or coin-operated units for passengers to access drinking water.

36. Public Toilets – Washroom facilities located at the concourse level for passenger use.

37. Seating Areas – Benches or resting spots at concourse and platform levels for waiting passengers.



Site Visit to Royapettah Station – Chennai Metro (TBM Bhavani Launching Shaft)

As part of our structural engineering internship, we actively sought on-site learning opportunities to complement our office-based experience. With the support of the project team, we were granted permission to visit one of the key underground construction sites of the **Chennai Metro Rail Project**—the **Royapettah Station** site, which forms a part of the extensive Phase II metro corridor development.

This particular visit was centered around the **launching shaft of Tunnel Boring Machine (TBM) "Bhavani"**, a critical component in the execution of underground metro tunnels. The site is strategically located in a dense urban zone, making the engineering and logistical aspects of tunneling particularly challenging and impressive.

Upon arrival, we were briefed on the overall layout and structural systems involved in the station and tunnel development. The **launching shaft**, which serves as the entry point for TBMs, was a reinforced concrete vertical structure with sufficient dimensions to lower and assemble the TBM. We observed the heavy-duty gantry systems, segment stacking areas, muck handling systems, and other peripheral installations that support TBM operations. The structural detailing, such as wall thickness, anchoring mechanisms, and shaft depth, were aligned with the guidelines outlined in **IS codes** and **AASHTO specifications**, especially for deep excavations and soil-structure interaction.

A key highlight of the visit was the opportunity to **descend into the shaft and walk inside the actual tunnel**. Proper safety briefings, PPE protocols, and confined space entry regulations were followed. Inside the tunnel, we were introduced to **TBM Bhavani**, a state-of-the-art Earth Pressure Balance (EPB) machine used for soft ground tunneling. Engineers on-site explained the working principles of the TBM, which include the rotation of the cutter head, controlled excavation of soil, simultaneous installation of **precast concrete segment linings**, and the management of thrust and steering. We were shown the various segments of the TBM, including the shield, backup gantries, screw conveyor, and segment erector.

From a structural engineering perspective, this site visit helped us understand the critical importance of **tunnel lining design**, segment joint detailing, **grouting procedures**, and the interface between civil and mechanical systems in tunneling. It also emphasized how site constraints, ground conditions, and construction methodology shape the structural solutions adopted in such projects.

Moreover, we learned about **safety management**, **quality assurance**, and **real-time monitoring systems** employed in tunneling operations, particularly within a congested urban context. The coordination required between the design, execution, and project management teams to ensure alignment, settlement control, and timely progress was clearly evident.

This visit provided an invaluable bridge between theoretical learning and practical application. Witnessing the TBM in action and the structural systems surrounding its operation deepened our appreciation for large-scale infrastructure work and the role of structural engineers in ensuring the safety, durability, and efficiency of underground metro systems.

Fig:TBM head

Fig:TBM Control Software

T

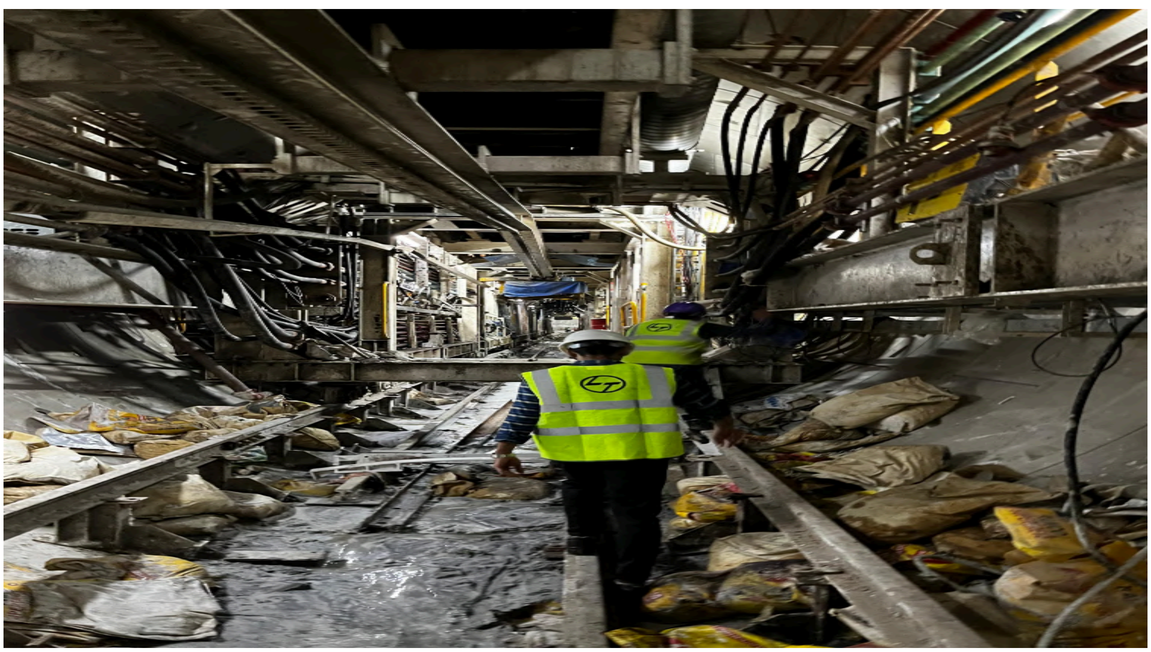


Fig:TBM Body

DESIGN ASPECTS RELATED TO METROS:

Working stress method vs limit state method:

1. Working Stress Method (WSM)

🔹 Definition

Working Stress Method is a design philosophy where structural members are analyzed and designed assuming materials behave elastically, and the actual stresses under service loads are kept below permissible (working) stresses.

🔹 Concept

- Assumes linear stress-strain behavior (Hooke's law) for both steel and concrete up to the service load.
- Uses a global factor of safety (FoS) applied to material strengths (not to loads).
- The structure is designed to remain in the elastic range without cracking or permanent deformation.
- Stresses are calculated for actual (unfactored) loads like dead load, live load, etc.

🔹 Features

- Ensures structure behaves safely under service loads.
- Cracking and deflection are controlled by keeping stress low.
- More conservative and results in heavier sections.
- Does not account for ultimate failure or collapse mechanisms.

🔹 Example

Design of a circular overhead water tank using WSM ensures that internal water pressure does not lead to cracks, keeping the structure watertight. Here, stresses in concrete are limited to safe permissible values.

2. Limit State Method (LSM)

◆ Definition

Limit State Method is a design approach where structures are designed to satisfy both safety (strength) and serviceability (comfort, appearance) under the action of factored (increased) loads.

◆ Concept

- Recognizes that materials have non-linear behavior, especially near failure.
- Applies partial safety factors separately to loads and material strengths.
- Designs are checked for two conditions:
    - Ultimate Limit State (ULS): safety against collapse, overturning, and rupture.
    - Serviceability Limit State (SLS): control of deflection, cracking, vibration, etc.

◆ Features

- Uses factored loads (e.g., 1.5 × live load + 1.5 × dead load) for safety.
- More realistic and material-efficient, leading to economical designs.
- Adopted by all modern design codes (IS 456:2000, Eurocode, ACI, etc.).
- Can easily handle different types of loading scenarios and limit checks.

◆ Example

Design of a multi-storey concrete building using LSM involves checking for bending, shear, and axial load under various load combinations. It ensures that under worst-case loading, the building won't collapse and will remain comfortable for users.

P-M CURVE

One of the critical aspects of column design that we encountered during our internship is the use of the **P–M interaction curve**, which governs the behavior of columns under **combined axial load (P)** and **uniaxial or biaxial bending moment (M)**. This is especially relevant for columns in underground metro structures, which are seldom subjected to purely axial compression due to real-world loading conditions like lateral earth pressure, unbalanced thrust, or eccentricity.

Understanding the P–M Curve

The **P–M interaction curve** is a graphical representation of all combinations of axial load and bending moment that a reinforced concrete section can safely carry. It helps determine whether a column section will **fail in compression**, **fail in bending**, or be **safe** under combined action.

The key idea is that **increased axial compression** reduces the section's ability to carry moment, and **increased bending** reduces axial capacity. These combinations form a curved boundary, which can be divided into three zones:

1. **Pure Axial Compression Zone** (Max P, M = 0)
2. **Balanced Failure Point** (Concrete reaches crushing strain, steel yields simultaneously)
3. **Pure Flexural Zone** (P → 0, max M, tension failure)

Mathematical Representation

As per **IS 456:2000**, Clause 39.6 and **SP:16**, interaction is often simplified through non-dimensional parameters:

Let:

- Pu= Ultimate axial load
- Mu = Ultimate moment

- fck= Characteristic compressive strength of concrete (MPa)
- fy = Yield strength of steel (MPa)
- b = Width of the column
- D = Depth of the column
- Ac=b · D=Gross cross-sectional area
- Asc = Area of longitudinal reinforcement

Non-dimensional Parameters:

$$\frac{P_u}{f_{ck} \cdot b \cdot D} \quad \text{and} \quad \frac{M_u}{f_{ck} \cdot b \cdot D^2}$$

These parameters are used to plot or reference interaction curves from **SP:16**, which account for different reinforcement ratios and effective cover.

Design Check – Interaction Equation (IS 456:2000)

For simplicity, IS 456 provides an approximate **interaction equation** for design:

$$\frac{P_u}{P_{uz}} + \frac{M_u}{M_{uz}} \leq 1.0$$

Where:

- Puz = Axial load capacity with zero moment
- Muz = Moment capacity with zero axial load

This equation helps check whether a given design point lies **within the safe interaction domain**.

Balanced Failure and Limit States

The **balanced point** on the curve corresponds to a condition where:

- **Concrete** strain reaches $\varepsilon cu=0.0035$ in compression
- **Steel** strain reaches yield strain $\varepsilon y=fy/Es\approx0.00207$ for Fe500

If P is higher, the section will **crush** in compression. If M is higher, the section will **fail in tension**.

Application to Metro Construction

In our internship and during the site visit to **Royapettah Station (Chennai Metro)**, we observed structures such as:

- **TBM launching shaft walls**
- **Retaining diaphragm walls**
- **Deep columns and piles**

These elements are not purely compression members; they resist complex load combinations, including **bending due to soil pressure** or **machine loads**, and therefore must be checked for interaction.

For example, a pile wall may resist:

$P=1800\,kN, M=90\,kNm$

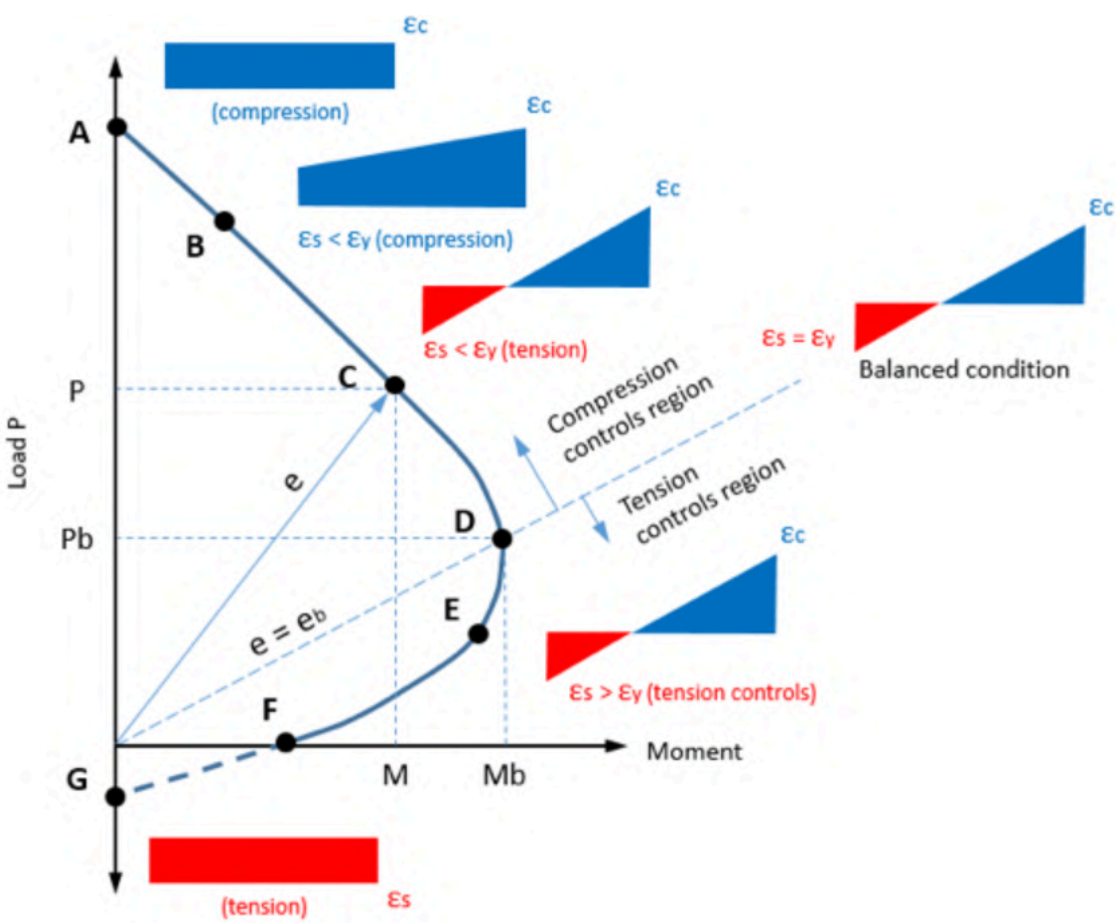
and must be checked against the curve for:

$$\frac{P}{f_{ck} \cdot b \cdot D}, \quad \frac{M}{f_{ck} \cdot b \cdot D^2}$$

to ensure it lies inside the safe zone. This is often done using **SP:16 charts** (Charts 32 to 44 for rectangular sections).

Software and Graphical Representation

During the internship, software tools like **ETABS** or **STAAD Pro** were also used to generate real-time interaction diagrams. These tools take into account biaxial bending (Mx–My) and generate **3D interaction surfaces** for more accurate capacity checks.



BEAM DESIGN

BEAM DESIGN
USING IS 456-2000

Beam Design

1	**Input Data**			
		BEAM =	Beam	
		Width of Support	200	mm
		clear span =	6300	mm
		effective cover/d' =	40	mm
		Working Load	40	KN/m
		Self Weight of Beam	1.75	KN/m
		Dsign load=wu	62.625	KN/m
	Design constant			
		pt-lim%	0.57	
		q=	0.133	
		Xu max Constant=q''=	0.46	⇒
		fck=	25	M15(eg)
		fy=	500	Fe500
	Size of Beam			
		b =	200	mm
		Take D=(Span /12)=	525	mm
		i.e D=	350	mm
		d=	310	mm d=D-d'
2	**Effective Span**			
		c/c distance of support =	6500	mm
		Clear Span+d/2=	6455	mm
		Le=	6455	mm
		Le=	6.455	m
3	**Factored Bending Moment=**			
		Mu =(wu x Le^2)/8 =	326.17468	KN.M
4	**Ultimate /moment of Resistance=**			
		Mur=q x fck x b x d^2	63.9065	KN.m
		Xu max=q'' x d=	142.6	mm
		As Mu < Mur Need to design as Doubly R. S.		
5	**Find Ast1 Area of Tensile Steel**			
		pt lim=	0.57	%
		Ast1=(pt lim x 100)/(b x d)=	353.4	mm^2

Mu for Asc=Mu-Mur 262.26818 KN.m

for fsc & fcc

d'= 40 < 61.318 (0.43 x Xu r

Calculate Fsc from IS :456

fy	fcc in mpa d'/d			
	0.05	0.1	0.15	0.2
500	424	412	395	370
415	355	353	342	329

d'/d= 0.07692308

Fsc= 353.92 mpa

Fcc=0.446 x fck= 6.69 mpa

6 Find Asc Area of compression Steel

Mu1for Asc=Mu-Mur 262.26818 KN.m

Mu1=Asc(fsc-fcc)x(d-d')

From that Asc= 2797.46459 mm^2

But for balance secton Find Ast2 for Asc

Asc(fsc-fcc)=ast2(0.87 x fy)

Ast2= 2233.019839 mm^2

Total Ast=Ast1+Ast3	2586.419839	mm^2
Asc=	2797.464591	mm^2

Provide,

	Ast req	Dia of bar	No of Bar(Ast req/area of one bar	i.e No of bar	Ast provided
	1086.89	20	8.229517669	9	2828.571429 mm^2
	Asc req	Dia of bar	No of Bar(Ast req/area of one bar	i.e No of bar	Asc provided
2	897.4654	16	13.90784953	14	2816 mm^2

Cheks

1 Check for Ast

1 Ast Min= 105.4 mm^2 0.85 b d/fy

1 Ast Max= 2800 mm^2 0.04 x b D

Mu for Asc=Mu-Mur 262.26818 KN.m

for fsc & fcc

d'= 40 < 61.318 (0.43 x Xu

Calculate Fsc from IS :456

fy	fcc in mpa d'/d 0.05	0.1	0.15	0.2
500	424	412	395	370
415	355	353	342	329

d'/d= 0.07692308

Fsc= 353.92 mpa

Fcc=0.446 x fck= 6.69 mpa

6 **Find Asc Area of compression Steel**

Mu1for Asc=Mu-Mur 262.26818 KN.m

Mu1=Asc(fsc-fcc)x(d-d')

From that Asc= 2797.46459 mm^2

But for balance secton Find Ast2 for Asc

Asc(fsc-fcc)=ast2(0.87 x fy)

Ast2= 2233.019839 mm^2

Total Ast=Ast1+Ast3 2586.419839 mm^2

Asc= 2797.464591 mm^2

Provide,

Ast req	Dia of bar	No of Bar(Ast req/area of one bar	i.e No of bar	Ast provided
1086.89	**20**	**8.229517669**	**9**	**2828.571429 mm^2**

	Asc req	Dia of bar	No of Bar(Ast req/area of one bar	i.e No of bar	Asc provided
2	**897.4654**	**16**	**13.90784953**	**14**	**2816 mm^2**

Cheks

1 Check for Ast

1 Ast Min= 105.4 mm^2 0.85 b d/fy

1 Ast Max= 2800 mm^2 0.04 x b D

1	300 mm	300 mm		
2	0.75d	232.5 mm		
3	Sv Min=(0.87 x fy x As))/(0.4b)	1063.348664 mm		
	Take Spacing lesser of above	170.9222459	170	mm

Pro vid	**Dia of Stirrups**	**Leggs**	**Spacing**	**GRADE**
	10	**3**	**170**	**415**

COLUMN DESIGN

Design of Axially Loaded Column

1) Input Data

Unfactored axial load	Pu	3000	KN
Unsupported length	L	3.2	m
Grade of concrete	fck	25	N/mm2
Grade of steel	fy	415	N/mm2
Restrained conditions		3	(Refer to sheet on "effective length")
	K	1	
effective length	Le =	3.2	m

2) Determine the size of the column

factored load		4500	KN	
Self wt. of column		45	KN	(1% of factored load on column)
Total Factored Load	Pu	4545	KN	
	pt	3	%	(Assume value between 0.8% to 4%)
	Arequired	247798.70	mm2	Use, Pu = /
Assume	b	450	mm	
	D	600	mm	
	Aprovided	270000	mm2	OK

3) Check for slenderness ratio

Le/b	7.11
Le/D	5.33

HENCE DESIGN AS SHORT COLUMN

4) Estimate Longitudinal Reinforcement

	Asc,requir	6635.4972							
	Ast,min	2160	mm2	OK					
provide	6	bars of	28	mm dia. &	4	bars of	32	mm dia	
	Asc,prov.	6911.5038	mm2	OK					

5) Check for minimum eccentricity

ex,min	21.4	mm	OK
ey,min	26.4	mm	OK

emin should be less than 0.05*D and 0.05*b respectively

6) Design of lateral ties

dia. of ties φties 8 mm

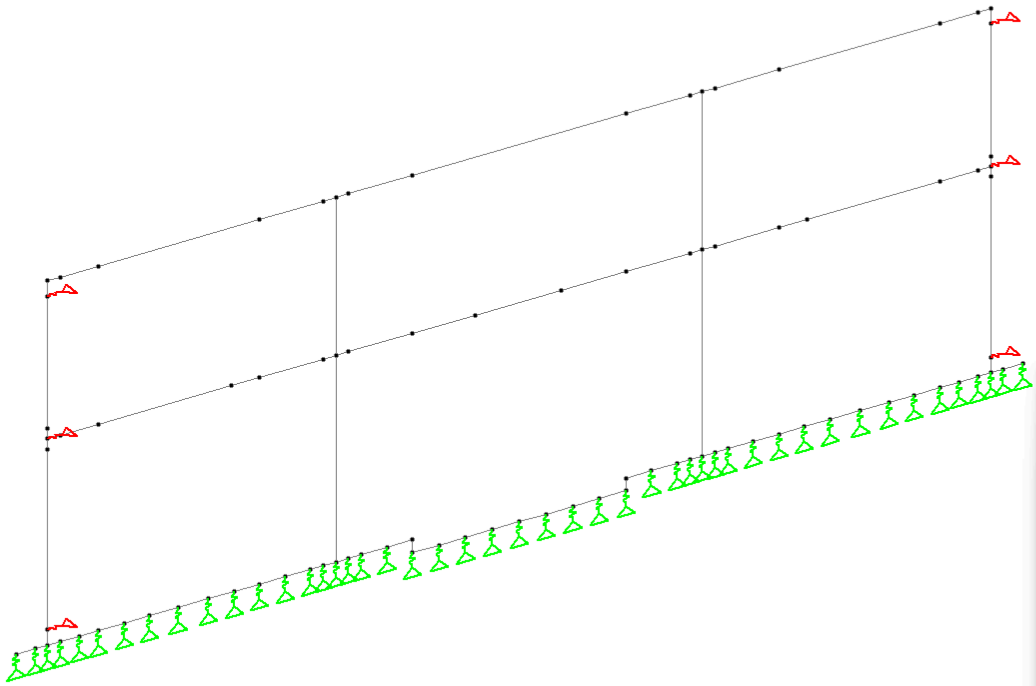
Pitch is taken smaller of the following:

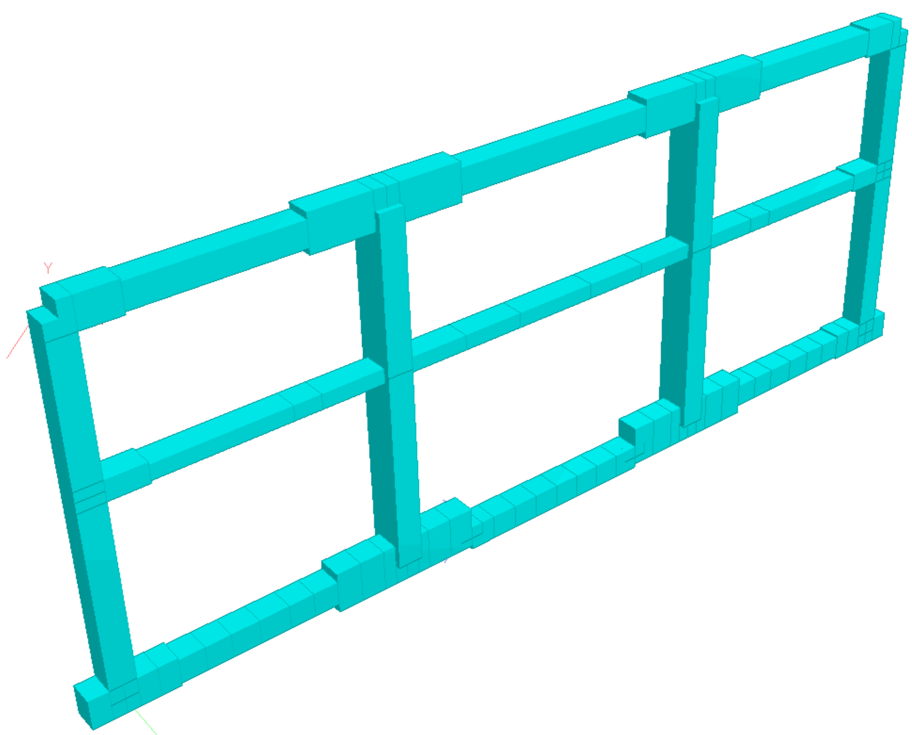
a)	LLD =	450	mm
b)	16*φSL =	448	mm
c)	300 mm	300	mm

pitch provided = 300 mm

Design Summary	
b	450 mm
D	600 mm
Longitudinal bar details	6-28 mm & 4-32 mm
Asc,provided	6911.50 mm2
Dia. Of ties	8 mm
Pitch of ties	300 mm

DESIGN OF BOX STRUCTURE





INPUT DATA

- **M35 grade**: Beam , RCC wall
- **M60 grade:** coloumn
- **Elastic modulus of concrete Ec** 29580 N/mm2
- **Poisson ratio ν (concrete)** 0.15
- **Elastic modulus of steel Es** 200000 N/mm2
- **Poisson ratio ν (steel)** 0.3
- **Grade of steel for shear reinforcement** Fe 415
- **Density of RCC (ODS**) 24 kN/m³
- **Density of PCC (ODS)** 23 kN/m3
- **Density of blockwork** 18.85 kN/m3
- **Density of dry soil (Compacted/consolidated)** 20 kN/m3
- **Density of saturated soil** 20 kN/m3
- **Density of submerged soil** 10 kN/m3
- **Density of water** 10 kN/m3
- **Coeff. of lateral earth pressure at rest** 0.5
- **Coeff. of lateral active earth pressure** 0.3
- **Coeff. of lateral passive earth pressure** 3

LOAD CALCULATION ON BOX STRUCTURE

Section	Parameter	Value	Units
Levels	Ground level (GL)	902.335	m
	Rail level (RL)	885.8	m
	Max High Flood level (HFL)	902.335	m
	Existing ground water level (EWT)	899.335	m
	Top of undercroft level	885.8	m
	Top of platform level	886.785	m
	Top of concourse level	892.685	m
	Top of roof level	898.885	m
		898.485	m
Materials and Constants	Grade of concrete (ODS)	M 35	
	Elastic modulus of concrete Ec (IS 456 Cl 6.2.3.1)	29580	N/mm2
	Poisson ratio v (concrete)	0.15	
	Grade of steel (OCS)	Fe 500	
	Elastic modulus of steel Es (IS 456 Cl 6.2.3.1)	200000	N/mm2
	Poisson ratio v (steel)	0.3	
	Grade of steel for shear reinforcement (IS 456 Cl 40.4)	Fe 415	
	Density of RCC (ODS)	24	kN/m^3
	Density of PCC (ODS)	23	kN/m3
	Density of blockwork (IS 875 burnt brick)	18.85	kN/m3
	Density of dry soil (Compacted/consolidated)	20	kN/m3
	Density of saturated soil	20	kN/m3
	Density of submerged soil	10	kN/m3
	Density of water	10	kN/m3
	Coeff. of lateral earth pressure at rest	0.5	
	Coeff. of lateral active earth pressure	0.3	
Geometry of Station	Coeff. of lateral passive earth pressure	3	
	Length of station (To inner edge of wall)	210	m
	Width of station (To inner edge of wall)	36.02	m
	Width of station at BOH (To inner edge of wall)	31.92	m
	Height between TOC of base slab and TOC of platform	2	m
	Height between TOC of platform and TOC of concourse	5.9	m
	Height between TOC of concourse and TOC of roof	6.2	m
	Soil fill between TOC of roof and GL	3.45	m

D imensions of Structural Element	Thickness	Unit
Thickness of wall	1	m
Thickness of wall of entry/exit/ TSS	1	m
Thickness of base slab	1	m
Thickness of base slab at wall edge	1.2	m
Thickness of base slab at column dro	1.7	m
Thickness of platform slab	0.2	m
Thickness of concourse slab	0.6	m
Thickness of concourse at wall edge	0.8	m
Thickness of concourse slab drop	0.8	m
Thickness of roof slab	1	m

Thickness of roof slab at wall edge	1.2	m	
Thickness of roof slab at column dro	1.7	m	

Load cases	parameters	value	unit
general data	ground level	902.335	m
	water level	899.335	m
	top/roof level	898.885	m
Load Case 11 (Self-Weight)	density of reinf. concrete	24	kN/mm2
	density of plain concrete	23	kN/mm2
	wall and slab thickness	0.2	m
	overhand projection	0.6	m
	R1	9.32	kN
	R1	25	kN
	R3	15	kN
	M2Z	1.475	kN
	M3Z	0.75	kN
	thickness of OTE duct wall	0.15	m
	R5	12.708	kN
	R6	12.708	kN
Load Case 12 (SIDL)			
	Load due to finish (100 mm thickness)	2.3	kN/m2
	Load of ceiling and services	1	kN/m2
	Total SIDL on Roof Slab	3.3	kN/m2
	Load due to finish (200 mm thickness)	4.6	kN/m2
	Load of ceiling and service	1	kN/m2
	Load of partition walls	1	kN/m2
	Total SIDL on Concourse Slab	6.6	kN/m2
	Load due to finish (100 mm thickness)	2.3	kN/m2
	Load of partition walls	1	kN/m2
	Total SIDL on Platform	3.3	kN/m2
	Load due to track bed (770 mm thickness)	18.48	kN/m2
	Total SIDL on Base Slab	18.48	kN/m2
	Escalator laod for lifting(point load,R1)	80	KN
	Lift load(load on pit,P1)	240	KN
Load case13: vertical earth load on roof			
	Thickness of back fill (Ground Level - Top of Roof Level)	3.45	
	Density of back fill	20	
	Load intensity of soil fill on Roof Level (Thickness × Density of back fill)	69	
LOAD CASE 14: Live Load			
	Live Load at Concourse level	5	kN/m2
	Live load on Platform Slab & UPE Wall (refer UPE wall STAAD file		
	Live Load at Platform level	5	kN/m2

UPE Wall & Platform Slab thickness	0.2	m
The overhang/projection of the platform slab	0.6	m
R1	9.708	KN
R2	13.5	KN
Mz	2	KNm
R3	13.5	KN
Mz	1.6	KNm

Live Load on Staircase Table

Description	Main Staircase	Emergency Escape Stairs	Fireman Staircase
Grid No.	**Grid 5–7 & 13–15**	**Grid 4–5& 15–16**	**Grid 4–5 & 15–16**
Staircase connects slab	**Concourse to platform**	**Concourse to platform**	**Concourse to platform**
Height between floor (m)	5.9	2.85	2.55
Length of stairs in plan (m)	16.8	10.2	5.7
Length of stairs (m)	17.61	10.59	6.29
Width of stairs (m)	3.5	1.5	1.5
Landing slab area (m²)	-	-	-
Live load on Staircase (kN/m²)	5	5	5
Reaction on concourse per unit width (kN/m)	44.51	26.5	15.71
Reaction on base per unit width (kN/m)	44.51	26.5	15.71
Reaction on wall per unit width (kN/m)	-	26.5	15.71

LOAD CASE 15 : Train live load on b	axle load, W	160	kN
	Rail gauge distance	1.51	m
	depth of base slab	1	m
	impact factor	1.67	
	total dispersion width (b)	4.55	m
	load intensity without impact (2W)/(b*b)	15.4570704	kN/m2
	load intensity with impact I*(2W)/(b*b)	25.81330757	kN/m2
	train live load on base slab level	**30**	**kN/m2**
LOAD CASE 21-26: Lateral earth pre	**Data**		
	Ground level	902.335	m
	water level 3m below GL	899.335	m
	concourse level	892.685	m
	density as per ODS		

density of RCC	24	kN/m3
density of saturated soil	20	kN/m3
density of water	10	kN/m3
density of submerged soil	10	kN/m3
static lateral earth pressure		
K0	0.5	
Ka	0.3	
angle of friction	30	degree

				Submerged soil upto GL	
Load case (LC)	**Column 1**	**Column 2**	**Column 4**	**Pressure at Rest ($K_0\gamma H$)**	**Active Pressure ($K_a\gamma H$)**
Lateral earth pressure at level	**(presure coeff*soil density*depth from ground**	**Depth (m)**	**Difference between lev**	**Value**	**Value**
Ground Level (GL)		902.335	0	0	0
Roof Level (RL)	(K0 or Ka)*soil density*(GL-RL)	898.885	3.45	17.25	10.35
Concourse Level (CL)	(K0 or Ka)*soil density*(RL-CL)+P at RL	892.685	6.2	48.25	28.95
Toe level 1 (TL1)	(K0 or Ka)*soil density*(CL-TL1)+P at CL	884.185	8.5	90.75	54.45
Toe level 2(TL2)(Bell mouth area)	(K0 or Ka)*soil density*(CL-TL2)+P at CL	883.685	9	93.25	55.95
Councourse Bottom to Base (TL1)	(K0 or Ka)*soil density*(CL-TL1)	884.185	8.5	90.75	54.45
Councourse Bottom to Base (TL2)(Bell mouth)	(K0 or Ka)*soil density*(CL-TL2)	883.685	9	93.25	55.95
Cable Gallery (TL3)	(K0 or Ka)*soil density*(TL1-TL3)	880.685	3.5	108.25	64.95
Slump area (TL4)	(K0 or Ka)*soil density*(TL1-TL4)	880.985	3.2	106.75	64.05

				Submerged soil upto GL-3 or HRL	
Load case (LC)	**Column 1**	**Column 2**	**Column 3**	**Column 5**	**Active Pressure ($K_a\gamma H$)**
Lateral earth pressure at level	**(presure coeff*soil density*depth from ground**	**Depth (m)**	**Difference between lev**	**Value**	**Value**
Ground Level (GL)		902.335	0	0	0
Ground level-3m (HRL)	(K0 or Ka)*soil density*(GL-HRL)	899.335	3	30	18
Roof Level (RL)	(K0 or Ka)*soil density*(GL-RL)	898.885	0.45	32.25	19.35
Concourse Level (CL)	(K0 or Ka)*soil density*(RL-CL)+P at RL	892.685	6.2	63.25	37.95
Toe level 1 (TL1)	(K0 or Ka)*soil density*(CL-TL1)+P at CL	884.185	8.5	105.75	63.45
Toe level 2(TL2)(Bell mouth area)	(K0 or Ka)*soil density*(CL-TL2)+P at CL	883.685	9	108.25	91.95
Councourse Bottom to Base (TL1)	(K0 or Ka)*soil density*(CL-TL1)	884.185	8.5	105.75	63.45
Councourse Bottom to Base (TL2)(Bell mouth)	(K0 or Ka)*soil density*(CL-TL2)	883.685	9	108.25	
Cable Gallery (TL3)	(K0 or Ka)*soil density*(TL1-TL3)	880.685	3.5	123.25	
Slump area (TL4)	(K0 or Ka)*soil density*(TL1-TL4)	880.985	3.2	121.75	73.05

				Saturated soil upto GL	
Load case (LC)	**Column 1**	**Column 2**	**Column 3**	**Pressure at Rest ($K_0\gamma H$)**	**Active Pressure ($K_a\gamma H$)**
Lateral earth pressure at level	**(presure coeff*soil density*depth from ground**	**Depth (m)**	**Difference between lev**	**Value**	**Value**

	Ground Level (GL)		902.335	0	0	0
	Roof Level (RL)	(K0 or Ka)*soil density*(GL-RL)	898.885	3.45	34.5	
	Concourse Level (CL)	(K0 or Ka)*soil density*(RL-CL)+P at RL	892.685	6.2	96.5	
	Toe level 1 (TL1)	(K0 or Ka)*soil density*(CL-TL1)+P at CL	884.185	8.5		
	Toe level 2(TL2)(Bell mouth area)	(K0 or Ka)*soil density*(CL-TL2)+P at CL	883.685	9		
	Councourse Bottom to Base (TL1)	(K0 or Ka)*soil density*(CL-TL1)	884.185	8.5		
	Councourse Bottom to Base (TL2)(Bell mouth)	(K0 or Ka)*soil density*(CL-TL2)	883.685	9		
	Cable Gallery (TL3)	(K0 or Ka)*soil density*(TL1-TL3)	880.685	3.5		
	Slump area (TL4)	(K0 or Ka)*soil density*(TL1-TL4)	880.985	3.2		

LOAD CASE 31 (Vertical surcharge (	surcharge load on roof as per ODS	60	kN/m2
LOAD CASE 32	**Horizontal surcharge load on normal ground from left to right**		
	uniformly distributed surcharge on ground level, q	60	kN/m2
	lateral earth pressure on wall (k0*q)	30	kN/m2
LOAD CASE 34	**Horizontal surcharge load on normal ground level from right to left**		
	uniformly distributed surcharge on ground level, q	60	kN/m2
	lateral earth pressure on wall (k0*q)	30	kN/m2

LOAD CASE 41 & 42 (Seismic load (	**Parameter**	**Symbol**	**Value**	**Unit**
	Moment Magnitude	Mw	4.3	
	Source to Site Distance	-	35	km
	Density of soil	γ	20	kN/m2
	Height of the cut and cover	H	15.2	m
	Max Design Earthquake (MDE)	Z`	0.1	g
	Operating Design Earthquake (ODE)	Z/2	0.05	g
	Peak Ground acceleration at surface for MDE	amax	0.1	g
	Depth factor	-	1	
	Peak ground acceleration at depth	as	0.1	g
	Importance factor	I	1.5	
	Horizontal seismic co-efficient	A	0.08	
	Type of soil layer	-	Rock	
	Ratio of Peak ground velocity / peak ground acceleration	Vs / amax	1.01	m/s
	Peak particle velocity	Vs	0.08	m/s
	Apparent velocity of shear wave propagation in soil	Cm	250	m/s
	Maximum free field strain of soil	Ymax	0.0003	
	Racking displacement of the structure	Dstructure	4.61	mm

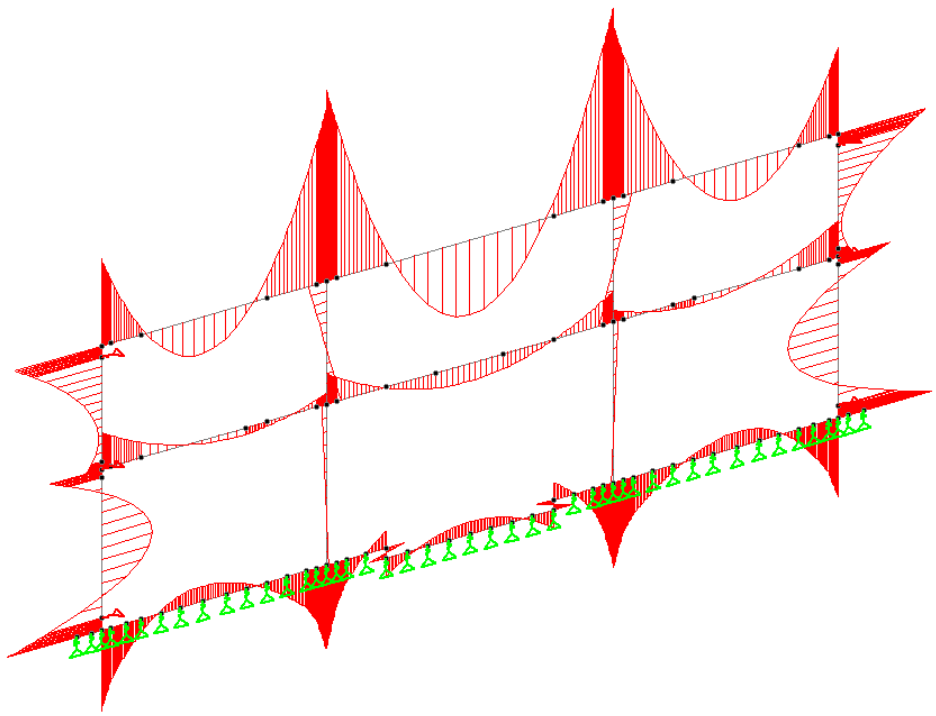
LOAD CASE 51 - 54 (Hydrostatic pre	ground level	902.335	m
	water level 3m below GL (HRL)	899.335	m
	concourse level	892.685	m
	density of water	10	kN/m3

					Water level upto GL	
	Load case (LC)	**Column 1**	**Column 2**	**Column 4**	**Pressure at Rest ($K_0\gamma H$)**	**Active Pressure ($K_a\gamma H$)**
	Lateral earth pressure at level	**(presure coeff*soil density*depth from ground (**	**Level (m)**	**Depth (H)**	**Value**	**Value**
	Ground Level (GL)		902.335	0	0	0
	Roof Level (RL)	(K0 or Ka)*soil density*(GL-RL)	898.885	3.45	34.5	-
	Toe level 1 (TL1)	(K0 or Ka)*soil density*(CL-TL1)+P at CL	884.185	18.15	181.5	-
	Toe level 2(TL2)(Bell mouth area)	(K0 or Ka)*soil density*(CL-TL2)+P at CL	883.685	18.65	186.5	-
	Councourse Bottom to Base (TL1)	(K0 or Ka)*soil density*(CL-TL1)	884.185	8.5	-	-
	Councourse Bottom to Base (TL2)(Bell mouth)	(K0 or Ka)*soil density*(CL-TL2)	883.685	9	-	-
	Cable Gallery (TL3)	(K0 or Ka)*soil density*(TL1-TL3)	880.685	3.5	-	-
	Slump area (TL4)	(K0 or Ka)*soil density*(TL1-TL4)	880.985	3.2	-	-
	Base level 1 (BL1)	water density*(GL-BL1)	884.185	18.15	181.5	181.5
	Base Level 2 (BL2) (Bell mouth area)	water density*(GL-BL2)	883.685	18.65	186.5	186.5
	Cable gallery base (BL3)	water density*(GL-BL3)	880.685	21.65	216.5	216.5
	Slump area base (BL4)	water density*(GL-BL4)	880.985	21.35	213.5	213.5
	Entry or exit base level	water density*(GL-EL)	892.685	9.65	96.5	96.5

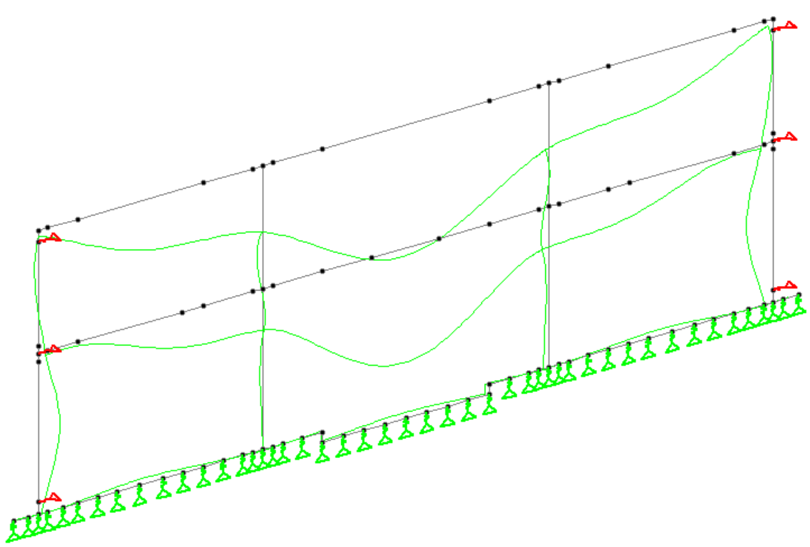
					Water level upto GL-3 or HRL	
	Load case (LC)	**Column 1**	**Column 2**	**Column 4**	**Pressure at Rest ($K_0\gamma H$)**	**Active Pressure ($K_a\gamma H$)**
	Lateral earth pressure at level	**(presure coeff*soil density*depth from ground (**	**Level (m)**	**Depth (H)**	**Value**	**Value**
	Ground Level-3 (HRL)		899.335	0	0	0
	Roof Level (RL)	(K0 or Ka)*soil density*(GL-RL)	898.885	0.45	4.5	-
	Toe level 1 (TL1)	(K0 or Ka)*soil density*(CL-TL1)+P at CL	884.185	15.15	151.5	-
	Toe level 2(TL2)(Bell mouth area)	(K0 or Ka)*soil density*(CL-TL2)+P at CL	883.685	15.65	156.5	-
	Councourse Bottom to Base (TL1)	(K0 or Ka)*soil density*(CL-TL1)	884.185	8.5	-	-
	Councourse Bottom to Base (TL2)(Bell mouth)	(K0 or Ka)*soil density*(CL-TL2)	883.685	9	-	-
	Cable Gallery (TL3)	(K0 or Ka)*soil density*(TL1-TL3)	880.685	3.5	-	-
	Slump area (TL4)	(K0 or Ka)*soil density*(TL1-TL4)	880.985	3.2	-	-
	Base level 1 (BL1)	water density*(GL-BL1)	884.185	15.15	151.5	151.5
	Base Level 2 (BL2) (Bell mouth area)	water density*(GL-BL2)	883.685	15.65	156.5	156.5
	Cable gallery base (BL3)	water density*(GL-BL3)	880.685	18.65	186.5	186.5
	Slump area base (BL4)	water density*(GL-BL4)	880.985	18.35	183.5	183.5
	Entry or exit base level	water density*(GL-EL)	892.685	6.65	66.5	66.5

RESULT

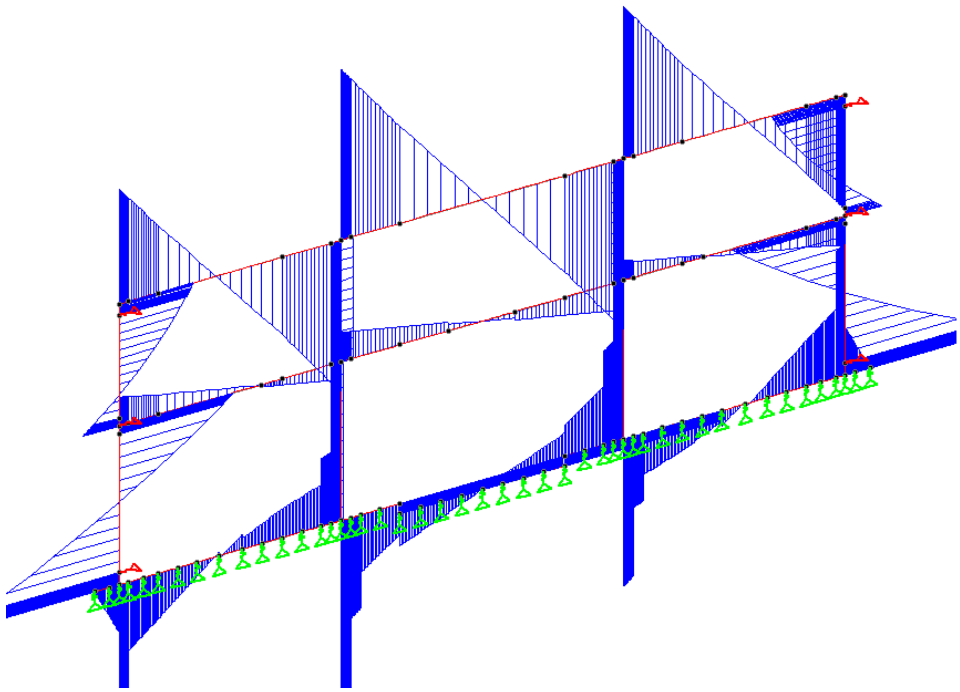
BENDING MOMENT



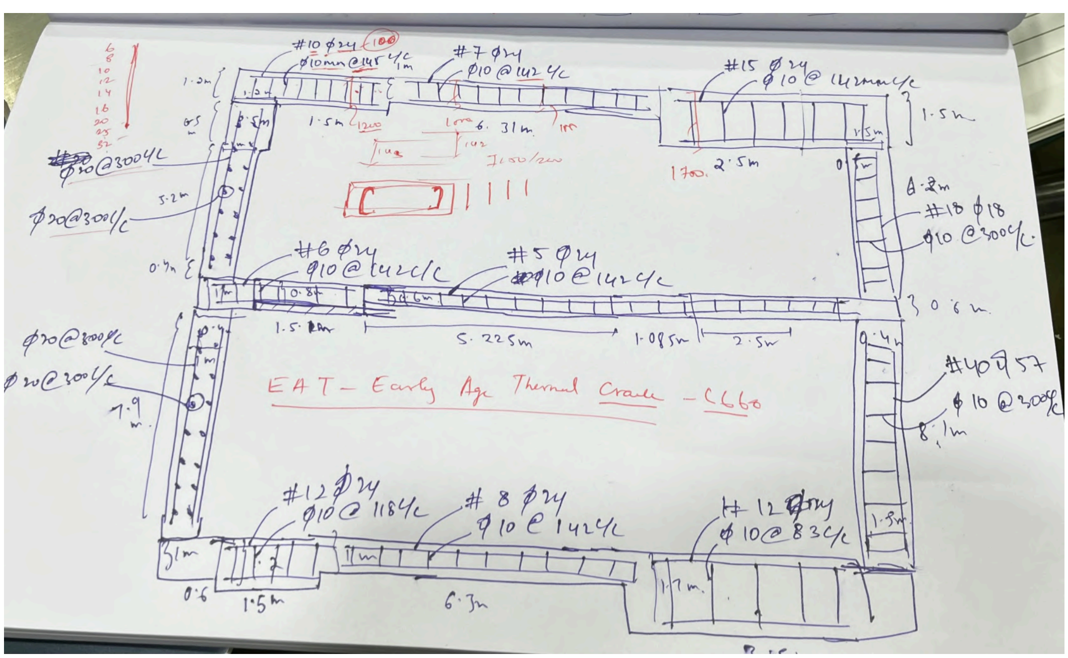
DEFLECTION DIAGRAM



SHEAR DIAGRAM



DETAILING



CONCLUSION

This internship has been a transformative learning experience, allowing me to bridge the gap between academic knowledge and its practical application in the field of structural and metro infrastructure engineering. Through a combination of office-based design exposure and valuable site visits, particularly at the Royapettah Station construction site under the Chennai Metro Rail Project, I gained a deeper understanding of both the conceptual and executional aspects of underground metro systems.

The report begins by outlining the theoretical foundations of metro design, including various types of alignment, surveys, and structural components essential in underground construction. A comprehensive study of tunnel construction methods—including cut and cover, TBM, and NATM—provided insight into the decision-making involved in choosing appropriate excavation techniques based on site-specific constraints. Learning about retaining systems, anchor mechanisms, and underground station design further highlighted the complexity of these massive infrastructure projects, where geotechnical, architectural, and structural disciplines must work in harmony.

The structural design portion of the internship was particularly enriching. By engaging with both the Working Stress Method (WSM) and Limit State Method (LSM), and exploring detailed topics such as the P–M interaction curve, beam and column design, and underground box structure analysis, I was able to connect classroom theory with real-world design requirements. Calculating loads, interpreting design charts, and preparing reinforcement layouts using various codes.

The hands-on exposure to tunnel boring operations, including the functioning of TBM Bhavani and the design features of its launching shaft, enriched my appreciation for the integration of mechanical and civil systems in underground construction.

A critical aspect of this learning experience was the direct and consistent application of various structural and geotechnical codes. The **IS 456:2000** code formed the backbone of our reinforced concrete design work, guiding beam, column, and box structure calculations under both Working

Stress and Limit State Methods. It was supported by **SP:16**, which provided essential interaction diagrams and design aids, especially in understanding the axial-moment behavior of columns. The **IS 800:2007** code, though focused on steel design, was relevant in areas like stiffener ring detailing and secondary steel structures associated with anchorage systems.

Furthermore, the **AASHTO LRFD Bridge Design Specifications** proved instrumental in our understanding of anchor design, seismic load considerations, and performance-based checks for soil–structure interaction—particularly relevant during our study of deep shaft and retaining systems. Similarly, **CIRIA C760** offered guidance on embedded retaining wall design, adding practical depth to our understanding of shoring, diaphragm walls, and guide wall systems observed on site.

Seismic design, which is particularly critical for underground metro infrastructure, was approached using both **IS 1893** and research-based references such as **Youssef M.A. Hashash et al.** This allowed us to evaluate parameters like peak ground acceleration, displacement, and the response of buried structures under dynamic loading—critical for tunnel safety and segment ring behavior during TBM operations.

By integrating these codes into design exercises, calculations, and technical decisions, the internship not only enhanced my theoretical foundation but also gave me the confidence to read, interpret, and apply complex design standards in real engineering contexts. It reinforced the idea that structural safety and constructability are not achieved through calculations alone, but through a deep understanding of applicable codes, thoughtful detailing, and coordination with on-site execution.

In conclusion, this internship has not only enhanced my technical competence but has also developed my understanding of project coordination, safety standards, construction sequencing, and structural detailing in the context of urban metro systems. It has reinforced my interest in the field of infrastructure and transportation engineering and has provided a strong foundation for my future academic and professional pursuits.

REFERENCES / CODES

- **AASHTO LRFD Bridge Design Specifications**, 4th Edition, SI Units, 2007
  Standard adopted in the U.S. for the design of bridges, including ground anchors and retaining structures. Used in this report for anchorage zone detailing and seismic load considerations.

- **CIRIA C760: Guidance on Embedded Retaining Wall Design**, 2015
  A comprehensive design manual for retaining walls in deep excavations, considering soil–structure interaction, wall deflections, and embedment criteria. Referred to for diaphragm wall behavior and design checks.

- **IS 456:2000 – Plain and Reinforced Concrete – Code of Practice**
  The foundational Indian code for structural concrete design under limit state and working stress methods. Used extensively in the beam, column, and box structure design chapters.

- **SP 16 – Design Aids for Reinforced Concrete to IS 456**
  A supplement to IS 456 providing charts and formulas for column interaction curves, reinforcement design, and simplified checks. Used in the P–M interaction curve section and column capacity evaluation.

- **IS 800:2007 – General Construction in Steel – Code of Practice**
  Guidelines for structural steel design. Referenced during analysis of stiffener rings and anchor casing reinforcement (where applicable).

- **IS 1893 (Part 1):2016 – Criteria for Earthquake Resistant Design of Structures**
  Used for understanding seismic zones, design horizontal acceleration spectrum, and base shear calculations. Applicable in interpreting seismic displacement and acceleration

parameters.

- **IS 2911 (Part 1/Sec 1):2010 – Design and Construction of Pile Foundations (Driven Cast In-situ Concrete Piles)**
  Relevant for understanding pile interaction, detailing, and anchorage length requirements for shaft and foundation piles in metro stations.

- **Seismic Design and Analysis of Underground Structures**
  Youssef M.A. Hashash, Jeffrey J. Hook, Birger Schmidt, John I-Chiang Yao
  A research-based reference that explains the seismic behavior of underground structures including racking displacement, soil layering effects, and structural response. Used while studying TBM tunnel design and soil–structure interaction.

- **IRC:6-2017 – Standard Specifications and Code of Practice for Road Bridges, Section II (Loads and Stresses)**
  Used as a supplementary reference for load combinations in underground box-type structures under traffic loads.