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A Case Study of Constraint Cross-Passage Construction in Urban Tunneling

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Abstract: The paper aimed at a detailed case study of cross-passage, which is forced to design and construct by connecting the station box and main tube tunnel of Marol Naka station in Mumbai Metro Line 3, since the marol Naka is densely populated area and elevated metro line is passing over an underground station, therefore further excavation of tunnel is done through the cross-passage. In these station, the cross- passage is constructed for public utilities for connecting the station box to the platform and also for the emergency exit. During tunnel construction, the cross passage is excavated after the main tunnel has been constructed. At the same time, the safety of the cross passage and the stability of the tunnel must be ensured by instrumentation and monitoring. Design of the cross- passage is achieved according to the principles of "New Austrian Tunnelling Method' (NATM) and the composite lining structure is adopted. NATM is used to widen the station platform which is initially tunnelled by the TBM. The dimension of 230m long and 15m wide Marol Naka station has 16 cross-passages which are constructed connecting the station box to the platform; the observations and the designing part- Finite Element method is used in order to evaluate stress deformations induced on the cross-passage.
Keywords: Cross passage, NATM, TBM, Finite element method, Marol Naka station, Emergency exit.

I. INTRODUCTION

Tunnel protection has become more important as road tunnels and city underground tunnels have risen in importance. Since the tunnel space is comparatively small and the tunnel exits are less, a scientific and reasonable escape mechanism is essential to ensure that tunnel users can safely exit the tunnel in the event of any emergency or for other utilities. Around the world, underground metro lines are widely used for transportation purposes. An important element of these underground projects is the building of cross passageways joining the two tunnels for alternative exit. Planning of several project activities and elements is critical for the effective execution of such tunnel projects. These considerations include site, positioning of alignment and its approaches, gradient in order to promote good long term as well as good excavation drainage, among others. At the outset, factors such as accessibility, sustainability, user convenience, and construction and maintenance cost efficiency should be taken into account. Works that are poorly designed take longer to finish, resulting in additional costs. To sufficiently stabilise the land, the cross passages are built using a mixture of structural and geotechnical techniques. These cross passages constitute a significant scheduling and budget jeopardy in underground structures subsequently they are frequently built at conclusion of the project and consists severe practical hurdles in sustaining digging advance and excavation pattern.

Structural approaches are utilized for increasing an ability of an underground excavation to endure the insitu stresses. Some parts of cross sectional planning and design which need to be structured are interim support of excavation, the final liner of the cross-passage and supporting the pre-existing tunnel systems at the time of excavation. A shotcrete lining, is usually used for temporary cross passage protection, with reinforcing materials provided by steel fibres, steel mesh, or lattice girders as per specifications. Liner is constructed behind the advance in steps, requiring several liner of shotcrete is sprayed to achieve a full lining.

Geotechnical techniques are applied to improve the bearing capacity of the soil and reduce risks in the tunnel by promoting load redeployment. Examples of soil enhancement techniques are excavated dewatering, ground freezing, jet grouting, permeation grooves, usage of pipes and pipelines. These techniques can help minimise the stress on the support system described earlier, since it is needed to ensure the integrity of the cross-passage construction in soft strata.

The design and geophysical methods used to construct crossing excavations have been developed very carefully. Reducing the amount of funding needed for construction will have significant benefits, but doing so requires a greater understanding of how loads form during construction. The first stage in this phase will be the analysis, identification and utilisation of ground datasets from various programmes, the mechanisms that influence charging behaviour.

Excavating into an opening provided by dismantling tunnel parts of a finished bored tunnel section is usually how the system is built.

In Singapore, the temporary opening is normally provided by a temporary circular support structure before the cross passage excavation is finished, at which point a permanent lintel is installed (A. Amon, S.S. Agus, N. Enferadi, 2016). A reinforced concrete framework cross-passage was designed constructed between two tunnels. There are two reasons for design: emergency evacuation and repair jobs. Tunnels were built, due to several confluences and horseshoe-shaped cross passages were planned (N. Vignesh, Dr. R. Rajeshguna, J. Saranya, V. Varuna, and Dr. R. Rajeshguna, 2017). For a certain stretch of underground metro tunnels, cross passages must be built to provide emergency and maintenance access. A cross passage is often constructed between two tunnels or between the tunnel and the surface floor, and is also known as an escape tunnel. Construction operations of cross passages should be separated from TBM shafts in order to begin permanent structural work in TBM shafts as soon as possible (B. C. B. Hsiung, Y. Y. Tsai, C. C. Tsai, 2010). The method of excavation for the cross passage building is usually determined by the ground conditions. Dewatering and grouting inside the tunnel would be more successful than dewatering and grouting from the ground in controlling surface ground settlement during NATM construction (especially in highly weathered rock). Because of the successful method of dewatering, grouting inside the tunnel face, the numerical model developed by Finite Element method to capture ground deformation during the construction of cross-passage was significantly higher than the observed magnitude (Harsha G.M., Mahesh H.S., and L. Govindaraju, 2016). Therefore, the learnings from the literature review is that the cross-passage must be built for emergency evacuation and for maintenance purpose. Geological and geotechnical investigations are conducted for determination of suitable construction methodology of cross-passage. Finite element method is used to determine the ground behaviour during the construction. The objective of the study is to design a structurally stable cross-passage with the help of empirical and analytical simulation by two-dimensional model and identify the stress distribution on the cross-passage due to elevated metro pillar with the help of Finite element method.

II. BACKGROUND OF THE LINE 3 MAROL NAKA STATION SITE

Mumbai, India's financial capital has experienced tremendous population and job expansion. The upward trend is predicted to continue. The corridor is completely underground, either on the side of the existing road or in the road's median, and caution must be taken to ensure that existing facilities and traffic flow are not disrupted. Underground systems are designed to withstand Mumbai's harsh coastal climate and increased risk of corrosion, with treatments against corrosion applied to structural steel/strengthening, as well as concrete surfaces in touch with the ground and exposed to the atmosphere. The line is 32,546 kilometres from C/L of Cuffe parade station to SEEPZ station, with a total length of 33.508 kilometres. 27 underground stations have been planned across the whole length of the alignment.

For cities like Mumbai, the Indian Government's emphasis is high on improving conditions for transport owing to traffic congestion. The country is working hard to change itself over the next few decades, particularly with an increasing population. Technology can play a critical role in defining accessibility challenges and improving current transit systems in order to create inclusive, cleaner, and more efficient communities of the future. The importance of a proper transportation infrastructure and its position in the lives of the average earning population cannot be overstated. In Mumbai, the extension and development of bus and rail transportation modes has proved insufficient to keep pace with the city's growing population. Other new modes of transit are being implemented in the region, such as metro rail, monorail, and electric buses, which have lower carbon footprints and offer improved services. That is less noisy, air-conditioned and shorter commute. Two different tunnels are built on two tracks, each one containing a track and platform. These two tunnels are interconnected at periodic cross-passages, allowing both platforms to be accessed by a single set of staircase and escalator sites positioned on two shafts. In fact, the two platforms, interconnected by a number of crossroads, constitute a platform on the island.

A. *Project Specification*

Marol Naka station (25th station) have been proposed at Chainage of 29829 m, with a depth of excavation of 15 m below the ground level. Users will be able to move from this station to Marol Naka station (elevated) on Metro line 1. The planned station is underground and has a platform arrangement that is similar to that of an island. The station is housed in a two-story cut and cover concrete box with dimensions of 256m x 24.2m. The platforms are about 15.4 metres below ground level. The island platform measures 180 metres in length and 10.88 metres in width. Vertical circulation has been provided as 3 suitable sets of steps in the centre of the island platform and escalators to accommodate regular and emergency passenger travel.

The station's catchment area includes both public and semi-public areas, as well as residential and industrial areas. This station is very difficult to navigate since it has 16 cross passages that lead to the main tunnel.

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Figure 1. Project Alignment of Mumbai Metro Line 3 showing Marol naka station

B. 2 Regional Geology

Since adverse and volatile geological conditions will result in loss of life, increased construction time, and increased project costs, geology plays a critical role. One of the most important considerations in determining the form of tunnel cross section and construction sequence is the type of terrain along the alignment.

The Reduced Level along the route ranges from 1.730 to 64.20 m overhead mean sea level, which is a broad physiographic characteristic and climate of the Mumbai area. From Colaba to Mahim, a distance of 18.475 km, and from Mahim to SEEPZ, a distance of 15.033 km, geological site investigations were carried out. The Mumbai area is part of the Deccan Plateau's great volcanic formation. The region protected by Deccan trap Basalts contains a large range of Basalts and related rocks such as volcanic breccia, black tachylytic Basalts, red tachylytic Basalts, and so on.

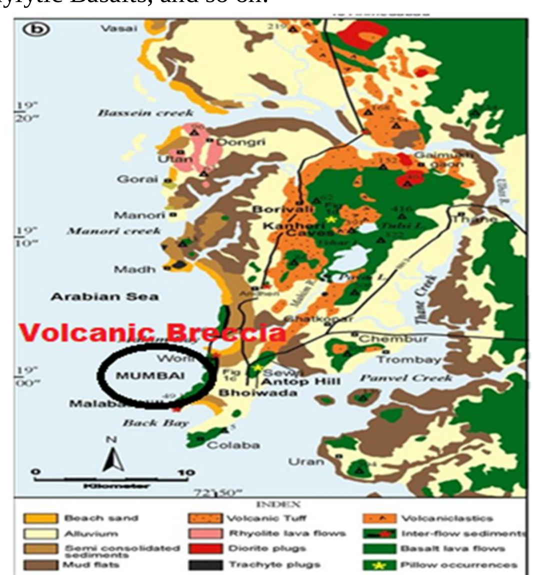

Figure 2. Geological Map of Mumbai

Geology encountered at the Marol Naka station is Fill soil, clay, Breccia Grade IV and Breccia Grade III, Breccia Grade II.

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III. CROSS-PASSAGE (CP-1), MAROL NAKA STATION

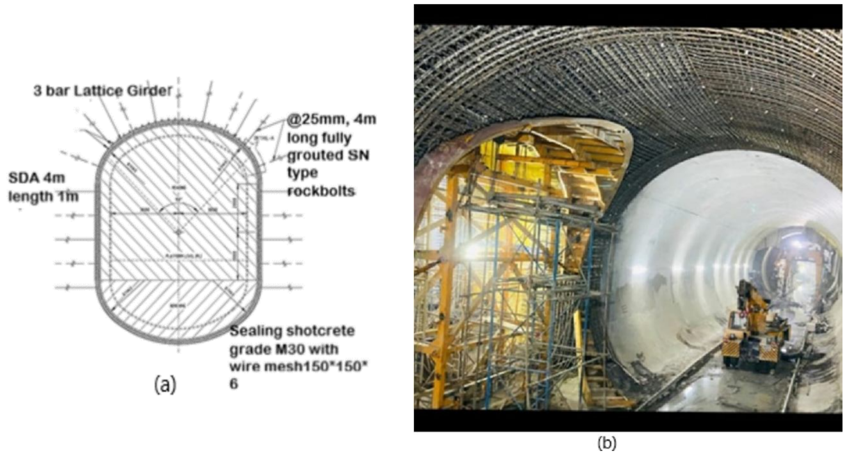

Figure 3 (a) Cross section drawing of cross-passage (b) Site visual of cross-passage

Figure 3 (a) depicts the original cross-sectional drawing of CP-1 (6m× 8m). There are total 16 cross-passages (CP) in Marol Naka station of varying dimensions. Out of these 16 cross-passages, CP-1 as shown in figure 3.4, has radius of 3 m, total height of the CP-1 is 8m and 6m wide, radius of the invert dish is 1.96 m. CP-1 has a overburden of about 15m. Since, an elevated metro line is passing above the Marol Naka station, CP-1 is subjected to the load of elevated metro pillar of about 200 KN/m^2.

IV. EMPIRICAL DESIGN

In rock engineering, rock mass classification system are widely used and served as the foundation for analytical design approaches. The classification of rock masses has become very common, and it is now being used in feasibility studies. When used properly, rock mass can be an effective design instrument, as many people have discovered. The classification method is the only functional framework for the construction of complicated underground systems on a number of projects. Because of its flexibility and ability to handle ambiguity in an analytical way when constructing a tunnel support system, Rock mass classification system is considered.
Both rock mass grading schemes assign a low rating to the worst rock mass and the maximum rating to the highest rock mass. Rock Quality Designation (RQD), Rock Mass Rating (RMR), Q-system, Geological strength Index (GSI) etc. are the parameters considered for rock mass classification.

A. Rock Mass Rating (RMR)

Bieniawski introduced this classification system in 1973 and which uses the following rock parameters: Intact rock material's uniaxial compressive strength (UCS); Rock Quality Designation (RQD); the spacing between discontinuities; discontinuity conditions, signified by length and persistence, separation, smoothness, infilling, weathering / Alteration, condition of the groundwater and Orientation of discontinuities. All of these parameters can be measured in the field, and data from boreholes also could be collected. The ratings for each of these parameters are added together to provide an RMR rating.

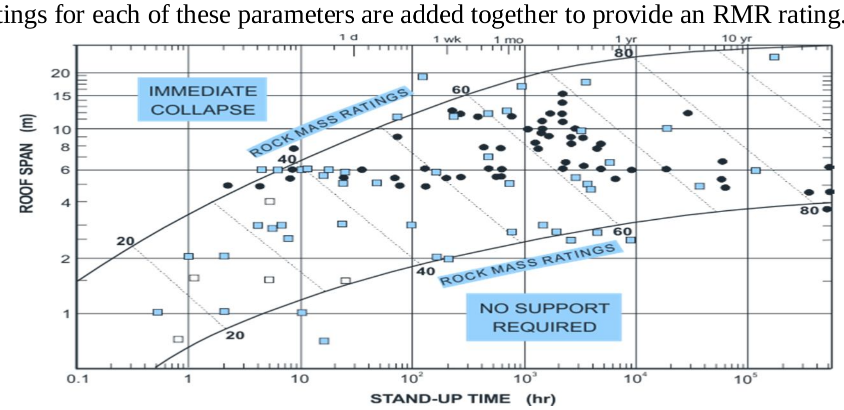

Figure 4. RMR classification of rock masses (Bieniawski)

Thus, the RMR value obtained is 48 which are in the range between 41-60. Therefore, the primarily the nature of rock can be considered as Fair (Class III), according to the classification of rock based in its RMR values (IS: 13365, Part 1) as shown in Table 4.2. The RMR value of the rock can also be used to calculate the support load needed to reinforce the tunnel's surrounding rock, the support load as:

$$P = \frac{100-RMR}{100} \times \gamma B \qquad \text{Equation (1)}$$

Where, P= support load (KN), B= width of the tunnel (m); γ = density of rock (kg/m^3)

$$P = \frac{(100-48)}{100} \times 2535 \times 6$$

Support load = 7909.2 kg/m^2

Support pressure, P = 77.51 KPa or 77.51 KN/m^2

Therefore, support load and support pressure is calculated as 7909.2 kg/m^2 and 77.51 KN/m^2 respectively.

B. Rock Mass Quality (Q- System)

The Q-system is a grading system for rock masses in terms of underwater opening stability. Cantered on around 200 case histories of tunnels and caverns, Barton suggested the Tunnelling Quality Index (Q). The value of Q ranges logarithmically from 0.001 to 1000, but it usually falls between 0.01 and 100. The Q-system was created to identify rock masses in the vicinity of an underground opening and for field mapping. A Q-value for a rock mass can be determined based on the calculation of six rock mass parameters. This value describes the consistency of the rock mass. The Q-value is not an independent characterisation of the rock mass since it is based on the underground opening and its geometry. In an undisturbed rock mass, the Q-value can be different.

The following equation can be used to calculate the rock mass quality (Q).

$$Q = \left(\frac{RQD}{Jn}\right) \times \left(\frac{Jr}{Ja}\right) \times \left(\frac{Jw}{SRF}\right) \qquad \text{Equation (2)}$$

$$= \frac{45}{4} \times \frac{3}{0.75} \times \frac{1.0}{5}$$

$$= 9$$

Where,

RQD denotes the Rock Quality Designation = 45; J_n is the number of the joint set = 4 (Two joint set); J_r stands for Joint Roughness Number = 3 (Slightly rough); J_a is the Joint Alteration Number = 0.75 (rock wall contact is hard); J_w represents Joint Water Reduction Factor = 1.0 (dry excavation or minor inflow); SRF = Stress Reduction Factor, which takes into account in-situ stresses (single weakness zone containing clay, depth of excavation 15m).

Therefore, Q-value on the basis of calculation is 9. Based on the Q- value, one can predict the type of rock mass. Based on rock environments, numerical scores are assigned to the above six criteria.

C. Rock Quality Designation

RQD is a measurement of the quality of a borehole rock core. RQD is a statistic that indicates the degree of jointing or fracturing in a rock mass, with RQD of 75 percent or above indicating high quality hard rock and less than 50 percent indicating poor quality weathered rocks. A rock core sample is taken from a borehole, and the lengths of all sound rock fragments that are at least 100 mm long are added together and separated by the duration of the core run.

The following formula is used to measure core recovery:

$$Core\ recovery = \frac{Total\ length\ of\ the\ rock\ recovered}{Total\ core\ run\ length} \times 100 \qquad \text{Equation (3)}$$

$$Total\ length\ of\ recovered\ rock = 250 + 250 + 200 + 190 + 80 + 60 + 120$$

$$= 1150\ mm \approx 1200 mm$$

$$\therefore Core\ recovery = \left(\frac{1150}{1200}\right) \times 100$$

$$= 96\%$$

$$Length\ of\ sound\ pieces = 540\ mm$$

$$\therefore RQD = \frac{Sum\ of\ Length\ of\ sound\ pieces > 100mm}{Total\ core\ run\ length} \times 100 \qquad \text{Equation (4)}$$

$$= \left(\frac{540}{1200}\right) \times 100$$

***RQD*= 45 %,** Fair-quality rocks are those that have been mildly weathered.

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V. CONSTRUCTION OF CROSS PASSAGE

Excavation of Cross passage shall be carried out either by breaker or controlled blasting depending on rock strata. Excavation of cross passage will be carried out in below mentioned steps:

A. Fore Polling

Before initiating drilling, fore poling is a form of rock support. The following is a summary of the fore poling procedure: A drill jumbo will be mounted on the excavation's face. The fore pole elements will be mounted at an angle of 5 to 10 degrees upwards as per authorised sketches, at the spacing specified in the drawing, over the perimeter of the face towards the direction of advance. The fore pole components will be grouted with cement grout/mortar according to the applicable requirements. The water-to-cement ratio is 0.4.Jute bags can be used to fill the holes. Once the grouting is completed, flush the pump, hoses, and accessories, as well as clean the appliances.

B. Excavation (Drilling, Loading, Blasting)

A double-boom Jumbo drill rig would be used to drill. At the face, the drilling boom will be set up and positioned. After that, the drill holes will be drilled according to the drilling pattern drawn on the face/surface. Depending on the rock strata, these holes would be 1.5-2.8 m deep. During blasting activities, competent site safety staff, including an accredited blaster with a licence, must be present. The explosive will be shipped in separate holding boxes that have been approved by the explosives chief controller. The cartridge would be prepared by injecting the detonator at a remote location on the surface and transported to the site by blasting in-charge at the time of filling the holes in the carrying boxes. Blasting in-charge, Tunnel in-charge, and Safety in-charge are responsible for the storage, handling, and unpacking of explosive materials.

C. Ventilation (De-Fuming Following Blasting And Shotcreting)

After firing the round, the blast area will be de-fumed with sufficient ventilation fans to enable the gases and dust produced by the blast to dissipate. The blasting engineer would then inspect the blast field, looking for misfires in particular. If any misfires are discovered, the blaster will handle them right away, either by re-blasting or flushing the misfire with water to destroy any residual explosive content. The blasting engineer will send the all-clear signal to resume operation and begin mucking until the field has been tested and cleaned. In the event of a misfire, the cavity can be cleaned with a wooden or plastic rod and water jetted

D. Spoil or Muck Removal

After scaling is completed, the muck will be transported by loader/truck from the tunnel to a temporary storage area near the portal in the box, then raised by gantry crane from the box to the muck pit, loaded into dumpers, and transported to the specified muck disposal site.

E. Scaling of Loose Blocks

Scaling is the process of removing loose rock fragments that were not entirely released from the rock during the blasting process. A strong tunnel excavator will be used to complete this task. After drilling, the loose substance can be scaled and collected using a swivelling bucket excavator. The same excavator will also remove/trim off any undercuts. Any dangerous noticeable fractures that may result in rock falling can be cut with the aid of an excavator.

F. Survey and Face Mapping

After removing the excavated muck, the crew will examine the cut surface with the help of a geologist and remove any suspended material. A geologist will map out the area and then prepare a face log for each draw. The surveyor can keep track of the excavation profile.

In conjunction with the Engineer, any inevitable overbreak will be identified. After gathering and analysing current geologic charts, aerial photographs, sources, and the findings of a preliminary site reconnaissance, an experienced engineering geologist can conduct survey geological mapping of available rock outcrops to acquire accurate, site-specific information on rock quality and structure. Geologic mapping is a method of collecting local, detailed geologic data that is used to characterise and document the condition of a rock mass or outcrop in order to classify it.

G. Primary Lining (Sealing Shotcrete, Erection Of Lattice Girder, Final Shotcrete)

At the batching plant, all materials and water without accelerators will be properly weighed, batched, and blended to create the shotcrete blend, which will then be transported by transit mixture from the batching plant to the site/box top (road level). Two transit mixtures will be stored in the bottom of the tub, and concrete will be poured from top to bottom of the box using a 200 mm diameter MS pump, with a funnel attached to the top of the pipe with the other end going to the transit mixture hopper.

H. Rock Bolting

SN-type rock-bolt/SDA is placed in an opening into the roof or into the walls of a rock structure for the roof of the cavity in tunnelling and underground works. In any excavated geometry that is easy and rapid to add, rock bolt strengthening may be used.

I. Secondary Lining (Permanent lining)

Permanent lining will begin after the cross-passage excavation leading, benching, and other excavation works are completed. Invert, kerb, and overt are the three phases of our cross-passage permanent lining operation. For kerb and overt concrete, two sets of traditional type work have been used. Hydraulic basics can be used to power the gantry shutter. Each period, the shutter must be cleaned and oiled. Concrete will be shipped from the batching plant to the job site in transit mixtures. Concrete can be poured from top to bottom in the package using a concrete pump/concrete boom placer. A concrete pump would be attached to the formwork via a window for concrete work. Pre-determined connecting points will be used. From the sides to the crown, the concrete will be poured.

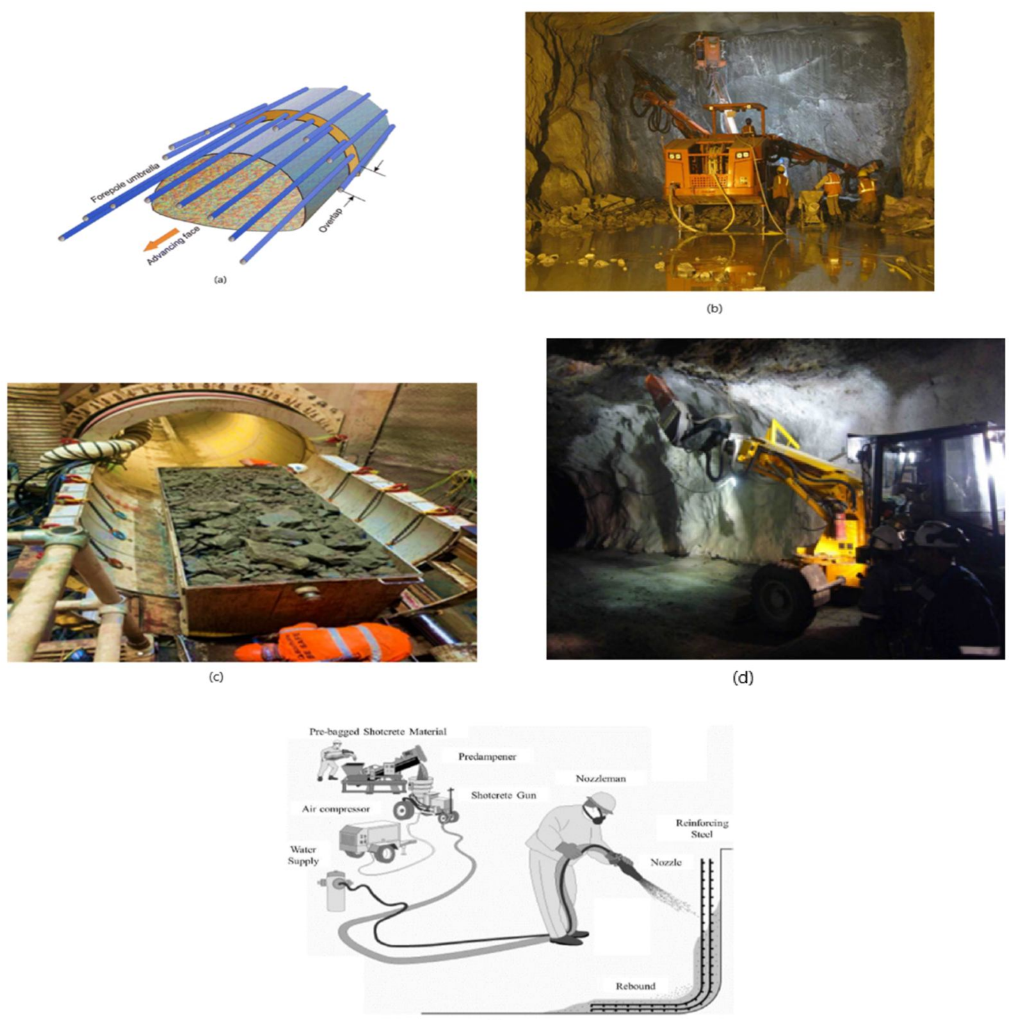

Figure 5 (a) Fore polling (b) Drilling (c) Mucking (d) Scaling (e) Shotcreting

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VI. FINITE ELEMENT ANALYSIS OF CROSS- PASSAGE (CP-1)

Design of Cross-passage (CP-1), Marol Naka station, MML-3 is done using FEM modelling software. A horseshoe shaped cross-passage is excavated if radius 3m, having width of 6m and overall height of 8m, invert dish is of 1.96 m long. Types of rocks encountered at the site are Fill soil, Clay soil, Volcanic Breccia Grade IV, III and II. Cross-passage excavation is done in mainly Volcanic Breccia Grade III. Overburden here is minimal of 15m. CP-1 out of 16 cross- passages in total, is subjected to an elevated metro pillar having load of 50 KN/m^2. Thus, analysing the impact of overburden and load of elevated metro pillar above the CP-1 is needful to know the stress distribution and the displacements that could take place during construction of cross-passage. By determining the above parameters, suitable support systems are also provided in order to stabilise the cross-passage as well as tunnel. In RS2, the generalised Hoek-Brown criteria is used for modelling.

A. Geological Profile

Following will be the derived geological profile: Soil/ Fill from GL: 2m, Clay/ residual soil layer: 2m- 6m deep, Breccia grade IV: 6.00- 13.50m deep, Breccia Grade III: 13.50-30 m deep.

Figure 6. Geological profile

B. Design Parameters for different layers at the site (Data courtesy L& T)

MATERIAL TYPE	Filled Soil	Clay/ Residual soil
Unit weight	19 KN/m^3	19 KN/m^3
Youngs's Modulus	10000 KPa	10000 KPa
Poisson's Ratio	0.3	0.4
Failure Criteria	Mohr- Coulomb	Mohr- Coulomb
Peak Tensile Strength	0 KPa	0 KPa
Residual Tensile Strength	0 KPa	0 KPa
Peak Friction Angle	30°	32°
Peak Cohesion	0 KPa	10 KPa
Material Type	Plastic	Plastic
Residual Friction Angle	30°	32°
Residual Cohesion	0 KPa	10 KPa
Hydraulic Permeability	1e-06 m/s	1e-06 m/s
K2/K1	1	1

Table 1. Design parameters for filled soil and clay soil

MATERIAL TYPE	Breccia Grade III	Breccia Grade IV
Unit weight	23 KN/m^3	22 KN/m^3
Youngs's Modulus	200000 KPa	195719 KPa
Poisson's Ratio	0.25	0.25
Failure Criteria	Generalized Hoek- Brown	Generalized Hoek- Brown
GSI	46	19
m_i	17	14
m_b	2.471	0.7758
s	0.002479	0.000123
a	0.5	0.54
Material Type	Plastic	Plastic
Hydraulic Permeability	1e-06 m/s	1e-06 m/s
K2/K1	1	1

Table 2. Design parameters for Breccia Grade III and Breccia Grade IV

Table no. 1 and 2 illustrates the design parameters for modelling of the horseshoe shaped cross-passage model of radius 3m, having width of 6m and overall height of 8m, with overburden of 15m. The results of the stress distribution are obtained after computing the RS2 model. Modelling is done in nine stages in total. In the first stage, in-situ conditions of the cross-passage are modelled i.e. geometry of the cross-passage, materials are assigned as per the geological conditions encountered at the site. The geology taken for modelling is taken as per the Marol Naka station which is fill soil, clay soil, Breccia Grade IV, Breccia Grade III, . Cross-passage (CP-1) is excavated in Breccia Grade III. In modelling, material properties are assigned.

The proposed cross-passage is excavated in stages. Excavation is done by Sequential Excavation method such as heading excavation i.e. crown portion of the cross-passage is excavated in second stage. After excavating the crown portion, immediate primary support is installed in the form of M30 grade of sealing shotcrete of thickness 50mm. Wire mesh is installed of (150mm×150mm× 6mm) having 6mm section depth of thickness of 200mm. Rock bolts are installed of diameter 19m normal to the boundary. Length of the rock bolts is 4m and are installed at the spacing of 1m. 3-bar lattice girder is installed of bar size 20 and 30mm of 200mm thickness. Shotcrete layer of 100 mm is applied of M30 grade. Heading primary support is installed in stage 3.

After installation of heading primary lining, benching excavation is modelled in stage 4. After excavating benching portion of the cross-passage, same immediate primary support is applied in the stage 5 as installed in the heading portion. In the stage 6, invert portion of the cross-passage is excavated. After excavation of the invert section, composite liner is installed comprising of lattice girder of 200mm thick and shotcrete (M30) of 100mm in stage 7. In stage 8, final lining of the invert is installed by applying 400mm, M40 grade of shotcrete lining. Finally, in stage 9, Heading and benching final lining by using M40 shotcrete of 350mm thick is applied.

After excavation of cross-passage by heading, benching and invert excavation, stress distribution is observed to be 1329.79 KPa, by using numerical approach. Graphical representation of stress distribution on the cross-passage before and after the excavation is shown in Figure 6.1 (b).

Figure 6.1 (b) represents the Distance (m) i.e. periphery of the tunnel on X-axis and stress (Sigma one) on Y-axis. Therefore, as shown in the Graph 1, the maximum stress at the 15m to 20m periphery of the tunnel will be 1329.79 KPa. After the excavation, the stress is maximum at the invert portion of the cross-passage.

In figure 6.2 (a), it is observed that after installation of supports such as sealing shotcrere of thickness 50mm is applied, Rockbolts having diameter of 25mm and length 4m is installed at the crown and side wall of the cross-passage, 3-bar PENTAX Lattice Girder of 95×25×20 mm is installed as a composite liner, Wire mesh of 150×150×6 mm, concrete final lining of 400 mm thick is applied as the permanent lining. After installation of supports, Stress distribution has increased to 1389.52 KPa. Similarly, graphical representation of the same is shown in Graph 2 which has Distance (m) i.e periphery of the tunnel on X-axis and Sigma one (KPa) on Y-axis. As shown in the figure 6.2 (b), maximum stress distribution after installation of supports is 1389.52 kPa.

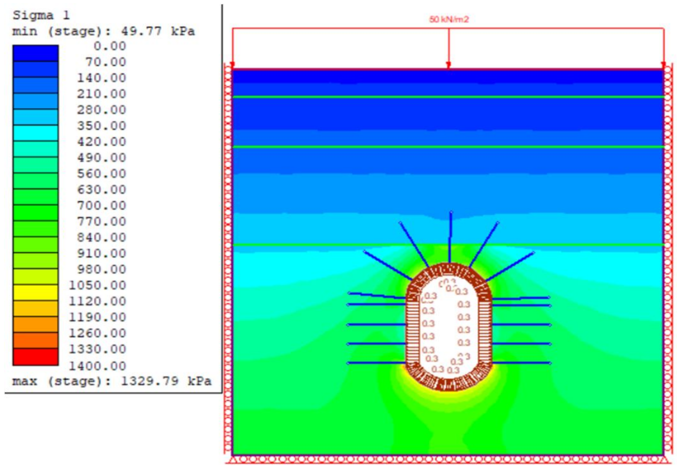

Figure 6.1 (a) Stress distribution after excavation of Cross-passage

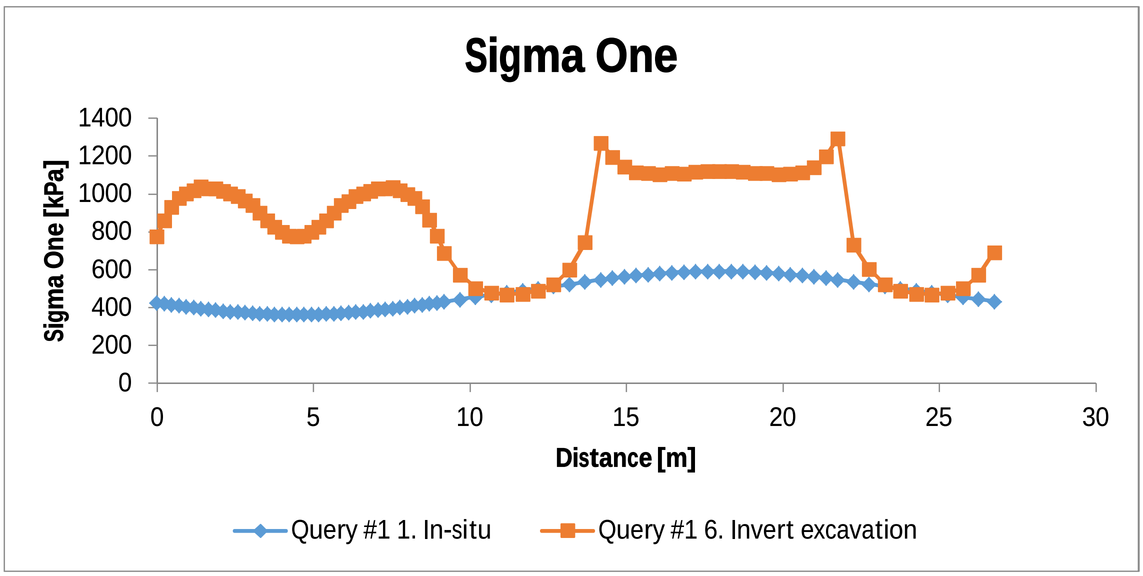

Figure 6.1 (b) Graphical representation of Stress distribution after excavation of Cross-passage

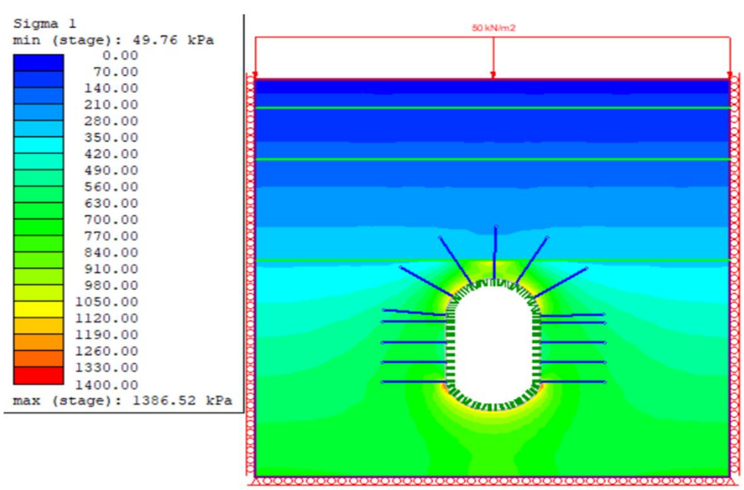

Figure 6.2 (a) Stress distribution after installation of Final lining.

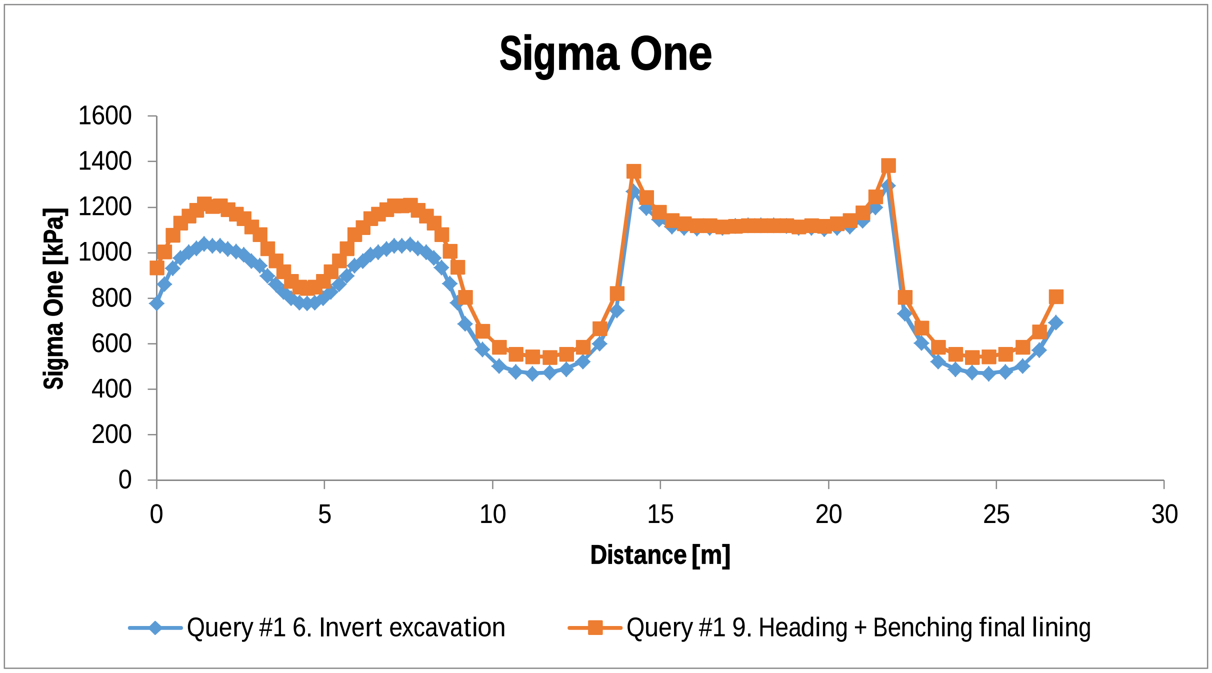

Figure 6.2 (b) Graphical representation of Stress distribution after installation of supports

VII. CONCLUSION

Aspects related to the design of cross-passage have been presented. The following are the conclusion taken from the discussion that has been given in this paper:

A. Planning and design aspects to be considered for the cross-passage excavation includes face stability, ground improvement requirement, construction sequence, primary support, temporary support.
B. Empirical analysis is done Rock Mass Classification system such as Rock Mass rating (RMR), Rock Quality system (Q-system) and Rock Quality Designation (RQD). Using RMR, support pressure is calculated as 77.51 KN/m^2.
C. Based on the analysis of the geological conditions along the Marol Naka station, package 07, Mumbai Metro Line 3, the ground strata in the tunnel section is simplified into four layers. In addition, the surface settlement, stress distribution along the section of the tunnel before and after installation of the support are simulated and analysed by using the Finite Element Method.
D. Using the Finite Element Method, stress distribution after the excavation of cross-passage is observed to be as 1329.79 KPa. After installation of final lining, the stress distribution is observed to be 1389.52 KPa.

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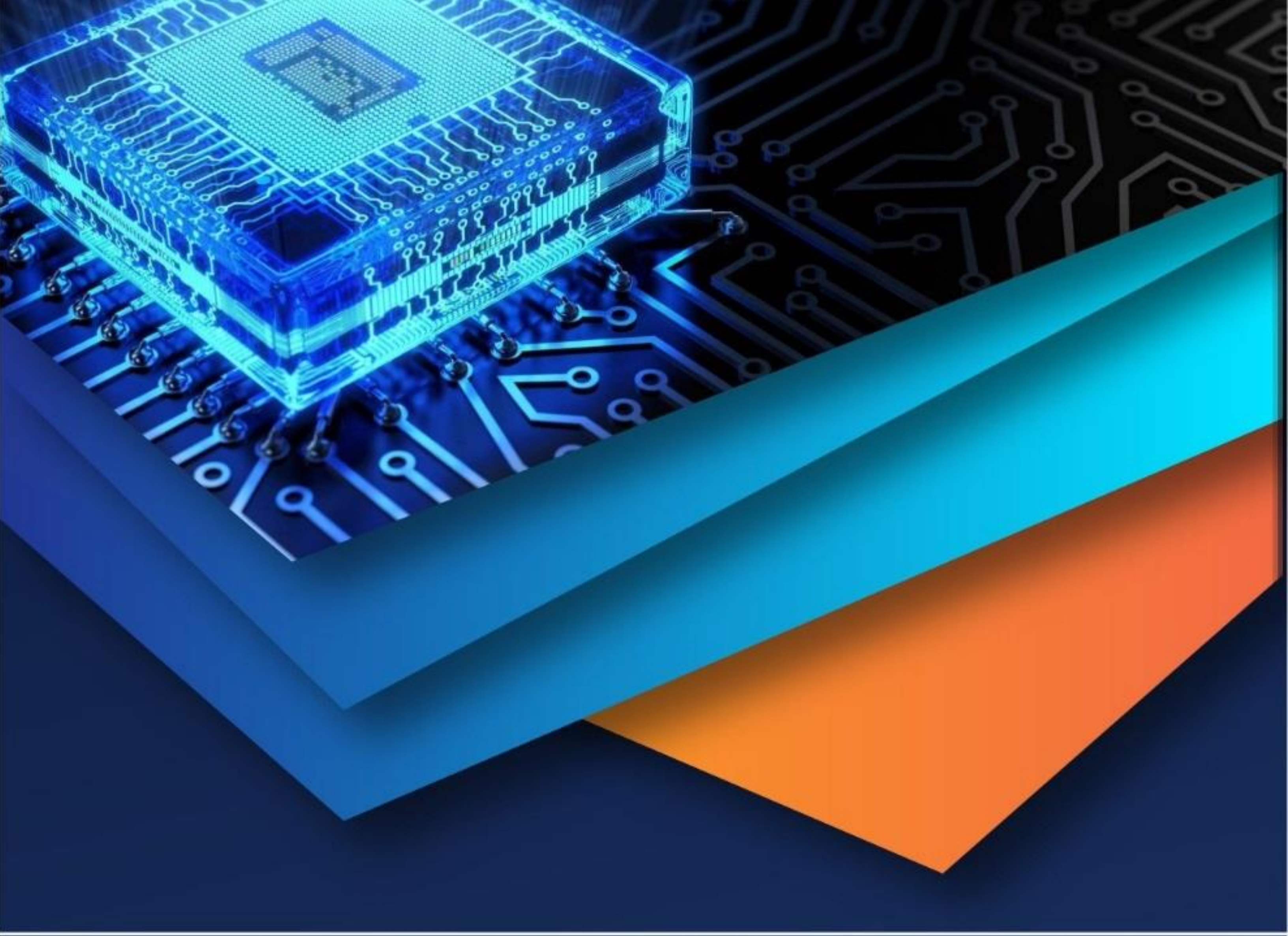

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