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Construction challenges during tunnelling underneath the Mithi river, Mumbai, India

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Abstract

Tunnelling underneath the water body is the most challenging part of the underground project and requires specific study, design, monitoring, and highly skilled professionals that can complete the task with the help of modern and innovative engineering. This paper tried to cover construction challenges faced during the tunnelling underneath the Mithi river at Mumbai Underground Metro Line -3 twin tube, 5.50 m finished diameter (Colaba- Bandra- Seepz) including 152 m NATM tunnel and 4 nos. of cross-passages, which made project more precious and challenging. Apart from tunnelling underneath the river, tunnel alignment was curved also and TBM mining becomes more challenging. In this case study, will discuss the challenges from the geological investigation to the construction of TBM tunnelling, NATM tunnel and cross passage (CP) underneath the Mithi river. As the overburden thickness from the river bed to the tunnel crown portion was about 5 m with weathered basaltic breccia rock; challenges were complete the geological investigation, water seepage, tunnel segment design, tunnel alignment deflection, the opening of cross passage and chances of deflection in the tunnel during CP excavation through NATM methods. This paper would be beneficial for taking precautionary measures during the tunnelling underneath the water body for the future tunnel projects.

Keywords: TBM tunnelling, geological challenges, segment lining, construction challenges, NATM, Water seepage.

Introduction

The tunnel is the best way to utilize the underground space, which is an eco-friendly structure. As per engineering and construction point of view, tunnelling is full of challenges. Tunnelling challenges are faced due to soil and underground lithology, hydrological conditions, geological surprises, ventilation, and others.

Mumbai is the most densely populated city of India, having limited space for the infrastructure development accordingly tunnel is the only best option for the same with various engineering and geological challenges. For a better and more modern transport system in Mumbai, metro rail projects have introduced phase wise and Mumbai underground metro Line -3 twin tube, 5.50 m finished diameter, 33.5 km long (Colaba-Bandra-Seepz) is one of the precious and unique projects, having different challenges during tunnelling such as tunnelling underneath the bridges, highway, river, crossing the railway track.

Mumbai have tropical climatic condition i.e. moderately hot with high humidity. The average temperature is 27-28°C and average annual precipitation varies between 1800mm to 2400 mm. Topographically Mumbai having North- South treading hills, coastal area, and creeks. Mahim river, Mithi river, Polsar, and Dahisar Rivers with Pawai, Vihar, and Tulsi Lakes are major water bodies in Mumbai[1].

Mumbai is made up of basaltic lava flow main rocks are Basalt, Volcanic breccia, Ryolite, Trachite and few shale bands with west direction foliation, belongs to upper Cretaceous to the lower Eocene (60 to 50 million years) as per geological time scale[2]. As per geo-mechanical properties, in situ rock strength varies from very hard to poor (grade 1 to IV).

The following Project components are falling underneath the Mithi river – i. Twin tunnel operated with TBM, ii. Turn back to BKC south NATM tunnel: It is at the south side of Bandra Kurla complex station. It is a Horse shoe type having a base width of 5.5m and a clear height of 6m. The length of this tunnel is 152m falling 100m under the Mithi river and the balance 52m is under the mangrove area[5]. iii. Cross Passage: 4 nos. of passages falling under the Mithi river. 1 no. of cross passage, CP-506 is connecting up and down lines of the main tunnel, and the other 3 nos. CP-04, CP-05, and CP-06 are connecting the turn back BKC south NATM tunnel with up and down lines tunnel. The cross passage is D- shape with a 2.35m width and 2.83m height. iv. Cross-passage with sump.

In this manuscript, try to discuss construction challenges encountered during the tunnelling underneath the Mithi river. As tunnel alignment is curved underneath the Mithi river, TBM mining becomes more challenging. Also discuss in detail about challenges during investigation, tunnelling, segment installation, construction of NATM cross-passage, high water seepage, geotechnical instrumentation installed, and their observation. The studied project alignment is given in Figures-1 to 3.

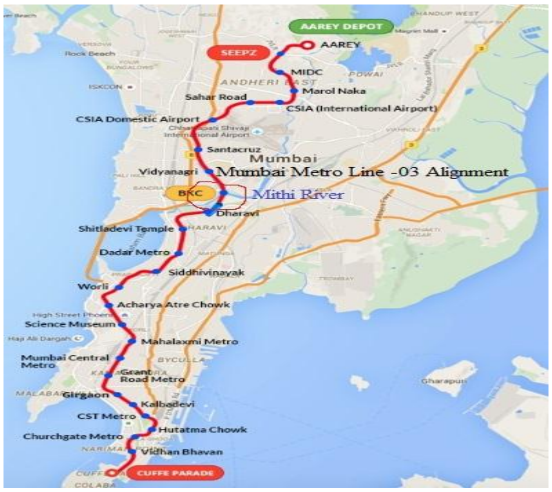

Figure-1: Mumbai metro line 03 alignment and studyarea[6].

Figure-2: Google earth image of the studied area[7].

Due to marshy land, mangrove area, tidal impact, poor geology were main challenges during completing the pre investigation along the tunnel alignment.

Investigation and Construction challenges

Tunnelling underneath the Mithi river falling under civil construction package 05 (Dharavi station to Santacruz station) between the Dharavi station to BKC station,1.80km long section consisting of 980m mangrove area and 200m Mithi river. The tidal water level varies in the river and mangrove area from 3 m high to 1.5m low from normal river water level during the high tide and low tide respectively. The twin tube tunnel underneath the Mithi river is 200m long with tunnel curvature is 230m radius as well as four numbers of cross-passage having length around 10.60m.

Pre-construction challengers: The construction team had faced the following main challenges for tunnelling underneath the Mithi river and mangrove area: i. Poor geology- As overburden thickness between river bottom levels to tunnel, top is only 5 m with highly weathered basaltic breccia rock. ii. Chances of high water seepage, iii. Tunnel lining segment should be of high strength and water proof, iv. Construction of turn back tunnel (NATM Tunnel) on the south side of BKC station, v. Construction of cross-passage underneath the Mithi river and mangrove area, vi. Selection of tunnel boring machine (TBM), vii. Selection of instrument monitoring system during the tunnelling operation. viii. TBM tunnel alignment deflection from permissible limit

Apart from the above-mentioned challenges there would be chances of geological surprises and maintaining the project's progress was also a great challenge.

Site studies and precautionary measures: From day one, tunnelling underneath the Mithi river was a challenge, and the civil team, as well as the design consultant and project government authorities, had considered the best precautionary measures based on the world's other underwater tunnels case studies.

During the site geological investigation stage, only three boreholes were possible along the Mithi river tunnel alignment. The core recovery was very poor. As rock condition was very poor belongs to grades IV and V and bedrock alignment varies drastically as shown in the geological section given in Figure-4 and core boxes photographs shown in Figure-5.

Precautionary measures: Based on geological observation and river water level variation due to tide, the design team tried to insure the tunnelling without any problems. The team proposed the best engineering measures based on similar projects worldwide. The first challenge was the selection of the TBM operation mode and recommended for earth pressure balance (EPB) TBM operates with close mode to counterbalance water pressure at the tunnel face and periphery for control of gravity-driven failure and settlement. TBM face pressure is recommended at 1.8 bar for nominal conditions and 2.3 bar if soil formation is encountered at the tunnel face.

Apart from the TBM operation mode, geotechnical instrumentations (surface settlement monitoring, vibration wire piezometer, standpipe piezometer, deep settlement marker, optical target, etc) were recommended to measure the ground and tunnel settlement.

Construction challenges: In the present case study, will discuss the construction challenges step by step from segment strength, tunnel segment gasket, tunnel alignment deflection, construction of BKC south NATM tunnel, cross-passage, instrumentation monitoring, safety, and environmental aspect underneath the Mithi river.

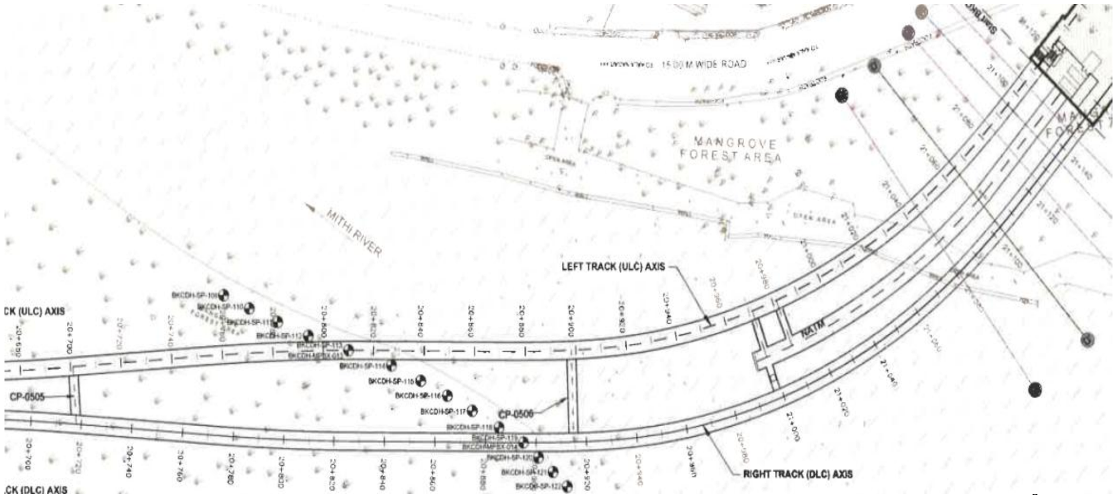

Figure-3: Project component, alignment with instrumentation installed at the studied area[8].

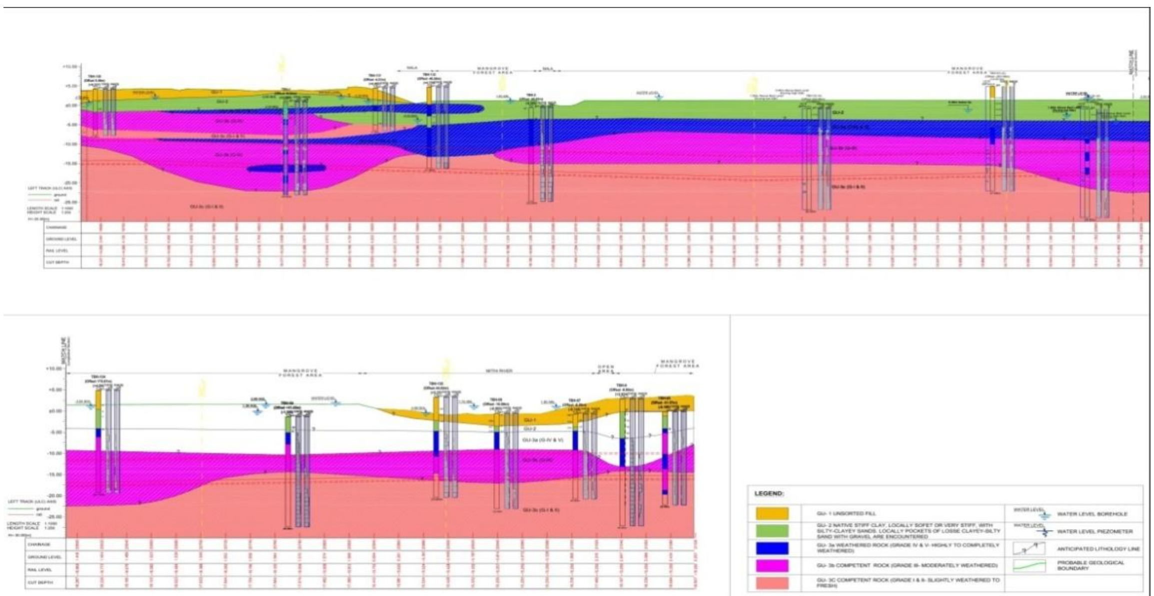

Figure-4: Geological section along Mithi river and mangrove area[8].

Figure-5: Core recovery underneath the Mithi river during a geological investigation[8].

Segment strength, tunnel segment gasket: For avoiding water seepage and strengthening the tunnel segment, throughout the project life, were recommended to increase the reinforcement strength of the segment by about 1.5 times of normal segment strength. For the packing of two segments proposed a special type of tunnel segment gasket for avoiding the water seepage during the high flood as well as protect the tunnel segment from any crack or deflection or tunnel settlement. For the most effective water locking in the tunnel followed the internationally recognized standards such as EN681-1, Elastomeric (rubber) gaskets were used during the tunnel lining. Details diagram of the gasket is given in Figure-6.

Design of special segment in cross passage: In the cross-passage location, a temporary steel frame was applied before the removal of the tunnel segment panel for protecting the balance portion of the segment panels from collapse. This process was time-consuming and increased the cost project. Three nos. of special segments have been applied in the vicinity of the cross passage. Cross-passage segment location and section of a cross-passage are shown in Figure-7 and Figure-8. California crossing was also there in the TBM tunnel as shown in Figure-9.

Tunnel alignment deviation: During the TBM advancement, there was some deviation from the final alignment in the curved portion under the Mithi river. This was properly detected in the as-built survey report. For maintaining the design speed the curve portion re-alignment was done in which the radius of curvature was changed from 230m to 228.5m. During construction the maximum horizontal deviation was 170mm observed against the permissible limit of 100mm. The location of alignment deflection is shown in Figure-10.

Typical section details were prepared with space-proofing drawings of tunnel services and checked whether any of the services infringes a kinematic envelope of the train. It was observed that no services were infringing on the kinematic envelope of the train.

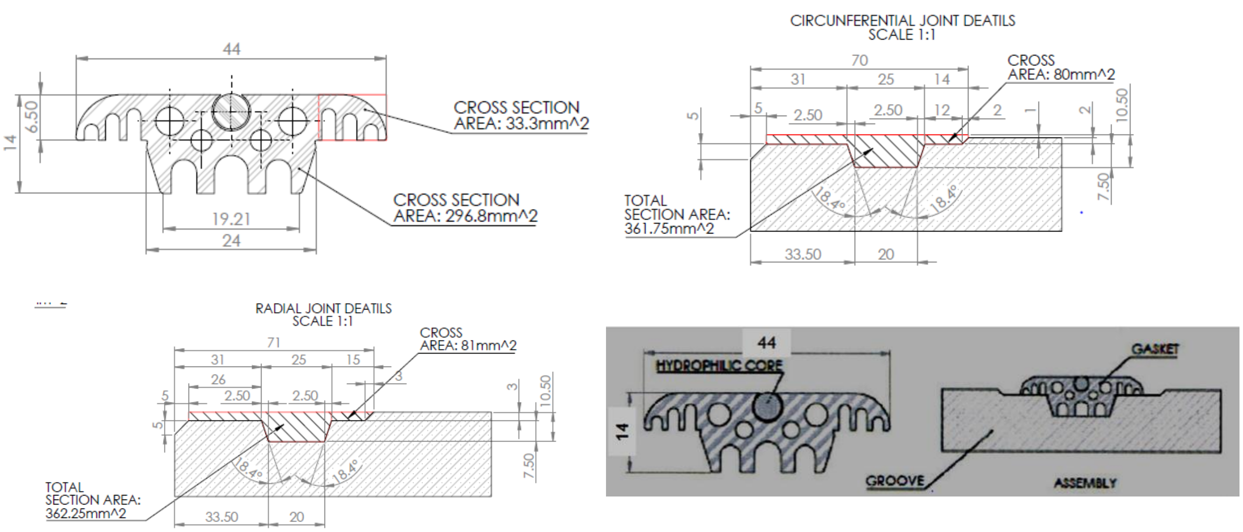

Figure-6: Tunnel segment gasket (Mushroom gasket)[9].

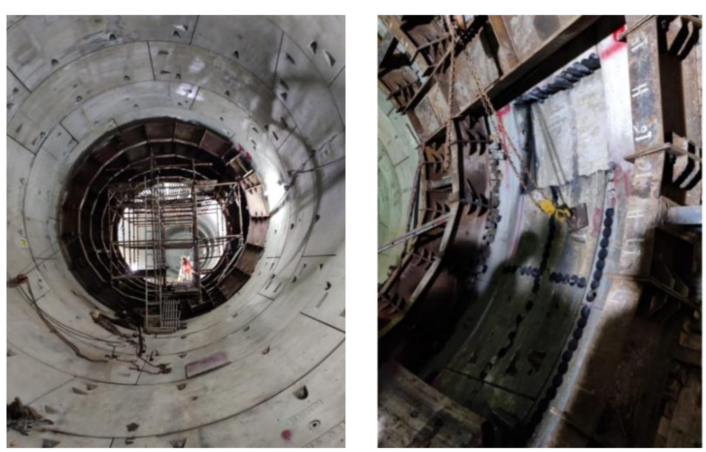

Figure-7: Cross-passage location and opening.

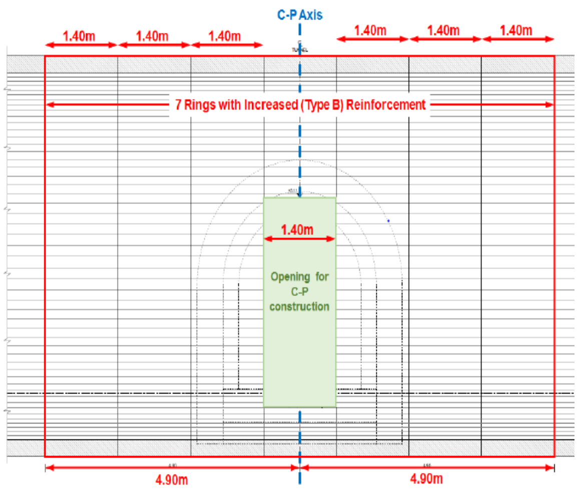

Figure-8: Typical section of cross-passage[9].

Figure-9: California Crossing.

Construction of BKC south side turn back NATM tunnel: As the rock belongs to grade IV to lower grade III, heading and benching NATM methods were applied, sequence of excavation is discussed below and the cross section and site photos are given in Figure-11 and12 respectively:

Construction Sequence for the top heading – i. Installation of grouting of pipe roofing umbrella. Repeated this process up to 6 rounds. ii. Installation of fiberglass bolt at the face. iii. Mechanical scaling of unstable blocks, iv. Apply a minimum of 50 mm thick 1st layer of shotcrete in the excavated portion including the tunnel face. v. Installation of 150 x 150 x 6 mm steel mesh and erects the lattice girder and distance keeper. vi. Application of 80mm thick 2nd layer shotcrete. vii. Application of 80mm thick 3rd layer shotcrete. viii. Installation of pair rock bolts and 150 x 150 x 6mm steel mesh. ix. Application of 40mm thick 4th layer shotcrete, x. Excavation of temporary invert (round length 1.6m) at a distance two round lengths behind the face. Application 100mm thick shotcrete in two layers. xi. Application 150 x 150 x 6mm steel mesh and 50 mm thick shotcrete.

Construction sequence for benching – i. Excavation of full round length (1.6m) benching with the demolition of temporary invert. ii. Mechanical scaling of the temporary block. iii. Application 50mm thick 1st layer of shotcrete. iv. Installation 150 x 150 x 6mm steel mesh and lattice girder. v. Application of 2ndand 3rd round shotcrete 80mm thick each layer. vi. Installation of rock bolt and 150x150x6mm steel mesh and 40mm thick final layer shotcrete. vii. The final layer of invert with 250mm shotcrete and 150x150x6mm two-layer steel mesh. viii. Modulation of the temporary working level of the bench by filling the inverted area of the region with aggregate.

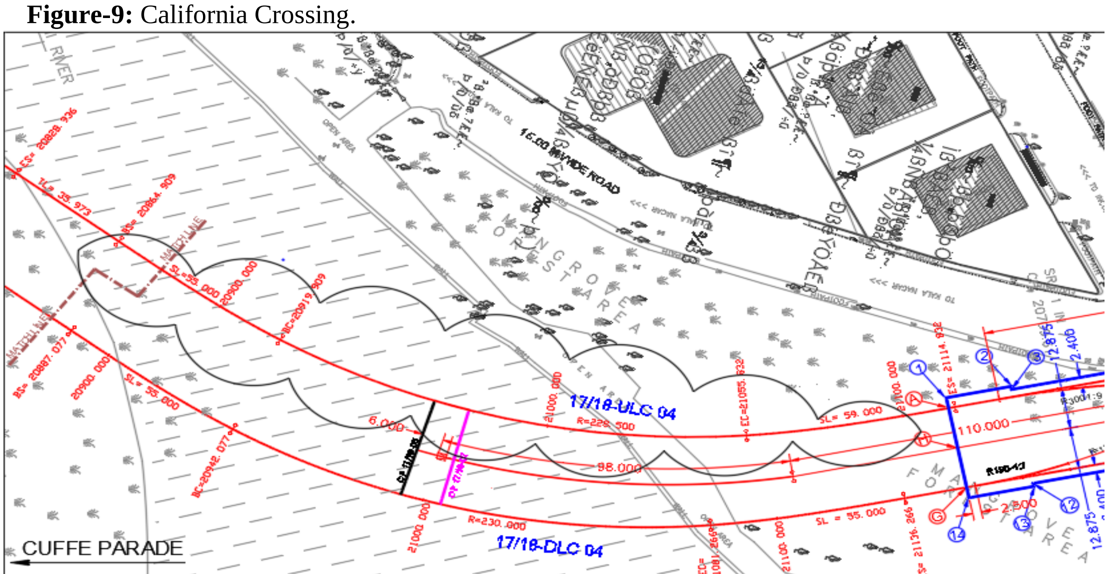

Figure-10: Location of alignment deflection[9].

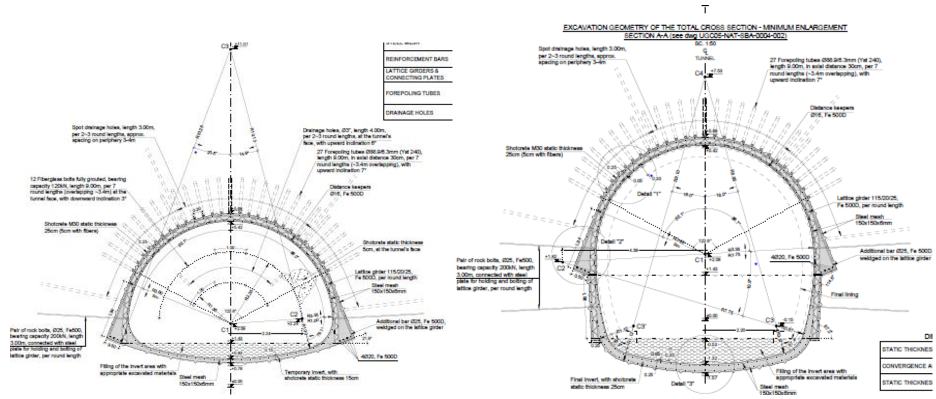

Figure-11: Conceptual cross-section of BKC south NATM tunnel excavation (heading and benching)[9].

Figure-12: Heading and benching excavation under BKC south NATM tunnel.

Figure-13: Rock face and water seepage during construction of cross-passage underneath the Mithi river.

Cross passage –Undercutting and overcutting in excavation work: During excavation centre line alignment of the main NATM and cross passages was maintained properly. In one of the cross passages, CP- 05 which was connecting the south side turn back NATM tunnel and TBM tunnel, excavation and temporary lining work was started at both ends of the cross passage and there was some deviation happened in alignment. It was observed after the completion of temporary lining work that there was an undercuton one side of the wall face. The new scheme was prepared for dismantling and maintaining the correct alignment.

Instrument monitoring system applied during tunnelling operation: During the tunnelling operation, many safety instruments need to be installed for monitoring the behaviour of the mining operation on the tunnel and its impact on the surrounding structures. It requires controlling the adverse impact, doing preventive action on time, and the tunnelling operation as per design. The instrument monitoring systems were following types – i. Surface monitoring system such as settlement marker, inclinometer, etc. These instruments were installed on the ground surface in the array. ii. Inner instruments such as Bi-reflex target, MPBX, pressure cell, strain gauge, etc. These instruments were installed inside the tunnel.

The installation of a surface monitoring instrumentation system was not possible due to the tidal water and mangrove area. Hence only inner instrument monitoring systems were installed. Instrumentation installed under the TBM tunnel, BKC south NATM tunnel, and cross-passage are given in Figure-15-17.

Figure-14: Repair of undercutting work.

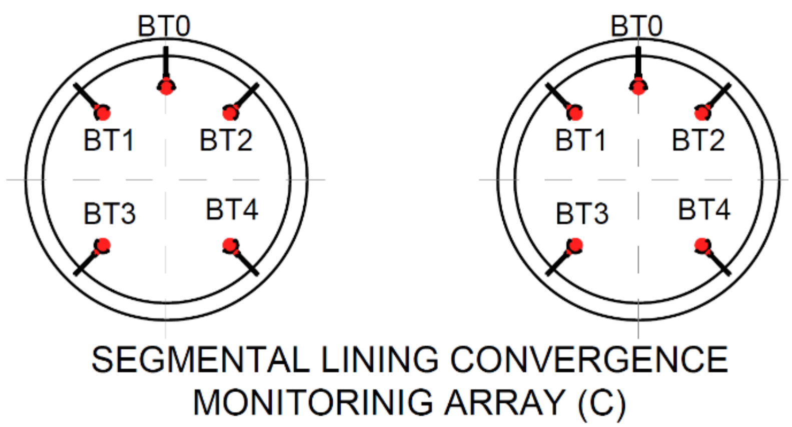

Figure-15: Instrument installed inside TBM tunnel[11].

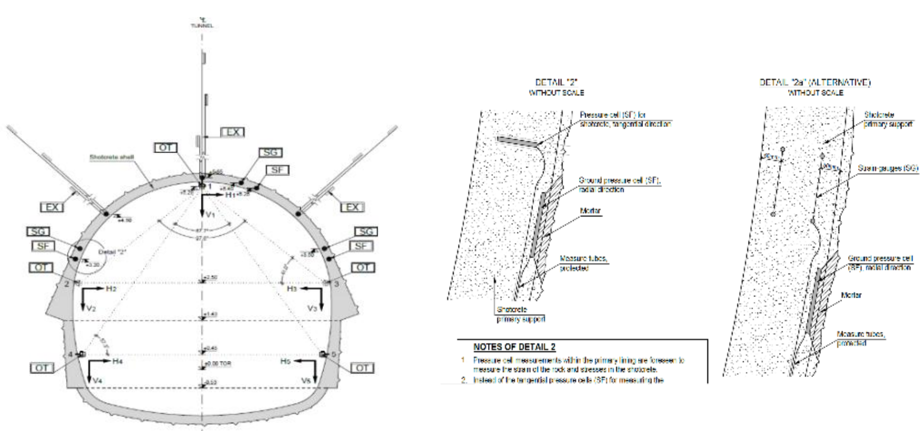

Figure-16: Conceptual plan for Instrumentation inside BKC south side turn back NATM tunnel[9].

The function of the instrument installed inside the tunnel[10] under the Mithi river – i. Pressure cell install in the tangential direction in the primary lining measures the stain in the rock mass and stress in the shotcrete, ii. Pressure cell installed in the radial direction measures the hoop stress in the primary lining of shotcrete. iii. Strain gauges (SG) – Measures the compression and tension in the lattice girder of the primary lining. iv. Bi-reflex target (BRT) –Measures deflection, and settlement and was used in traversing. v. Multipoint rod extensometer (MPBX) – used for measuring differential settlement.

All instrumentation readings were under control due to safe mining practices and competent rock mass. The instrumentation reading graph is given below for reference Figure-18; where no deflection was observed.

Safety and environmental aspect: i. Emergency preparation plan- This plan includes all emergency procedures followed at the time of emergency. ii. Fire hydrant system: Proper fire hydrant system[12] has been implemented in the tunnel. iii. Proper access and egress were maintained for tunnel operation. iv. Signage – Proper signage has been displayed for the hazardous operation. v. Air quality monitoring–Measurement of hazardous gases was done through a portable gas meter which measures the level of oxygen (O_2), hydrogen sulphide (H_2S), methane (CH_4), carbon monoxide (CO), vi. Ventilation–Proper ventilation (fresh air) circulated.

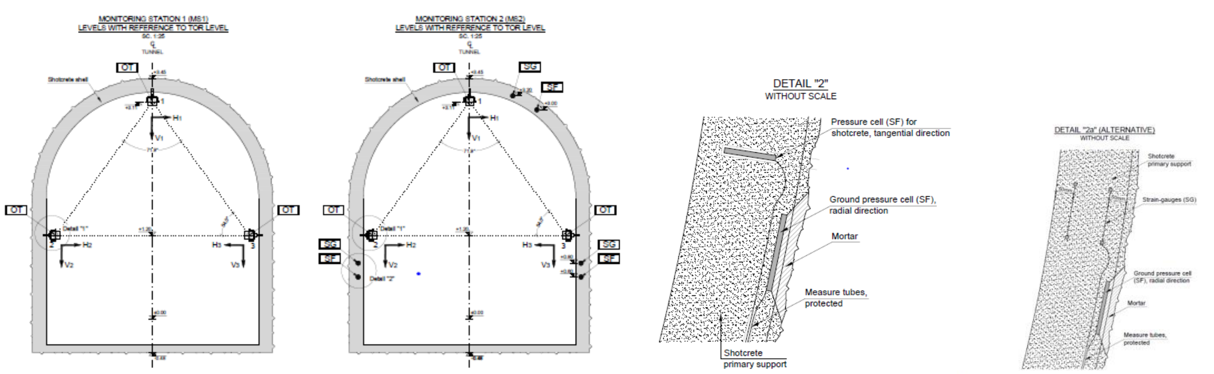

Figure-17: Conceptual plan for Instrument installed under cross-passage[9].

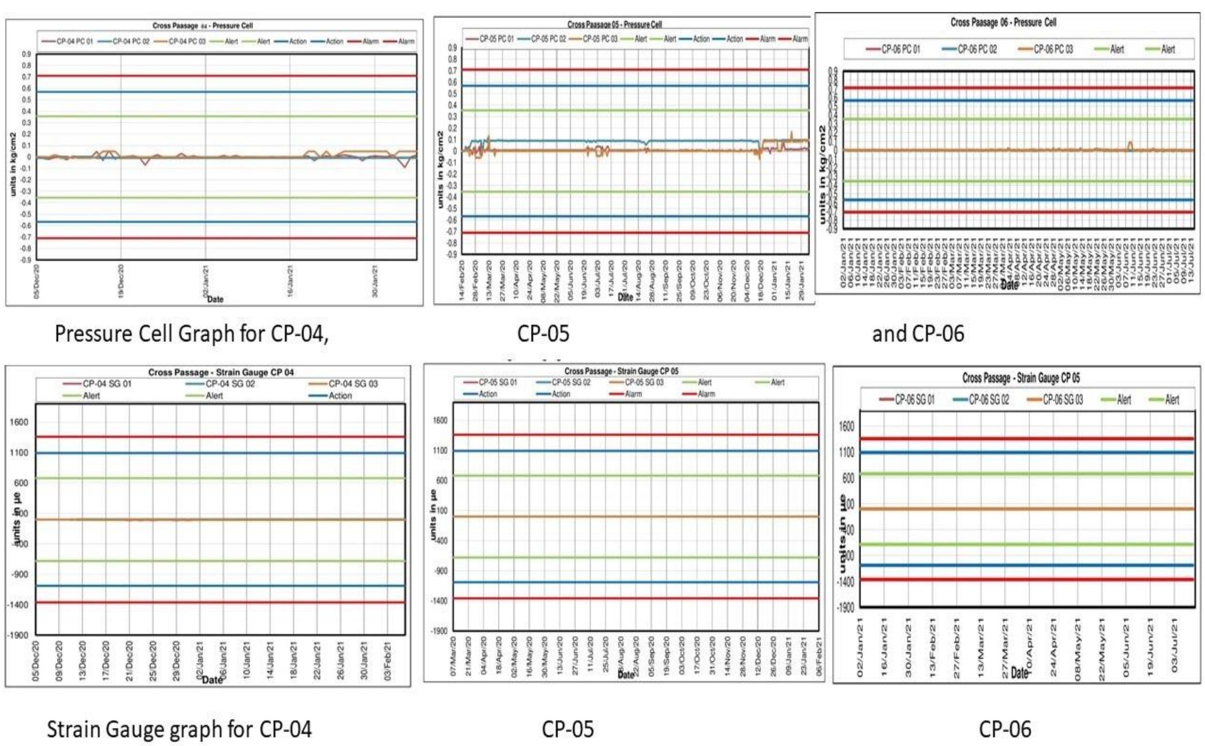

Figure-18: Instrumentation reading graph[11].

Figure-19: Air quality measurement inside the tunnel.

Other construction challengers: A part from high precautionary measures taken, the following construction challenges were faced by the construction team: i. During TBM mining, the tunnel team faced high water discharge (20-30 litter/per minute) during the segment building. Dewatering and removal of sludge was an issue but due to team hard work and good management of muck removal team, achieved average progress of 10 m mining per day. ii. Due to poor and variable geological strata with water ingress, maintaining the tunnel face pressure was an issue. iii. High quantity of primary and secondary grout also was a concern. iv. During the construction of the cross passage, grade III and IV volcanic breccia rock was encountered with an average RMR varies between 35-55 water seepage was an issue and well managed by the team. The site photo is given in Figure-13.

Conclusion

Tunnelling underneath the Mithi river was a big challenge. Apart from poor geology, less overburden, tidal impact on water level, water ingress, segment strengthen, alignment deflection, cross passage, and NATM tunnel and packing were major challenges. Accordingly, the design, as well as the construction team, had managed well based on international similar projects. Safely completing tunnelling underneath the Mithi river including the mangrove area gave us more confidence regarding the tunnelling and cross-passage construction. The planning, design, and construction process adopted for this section will be helpful for future tunnelling underneath the water body in an urban area.

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