High Water Ingress during TBM Tunneling under Andheri Kurla Road, Marol Naka, Mumbai, India

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Abstract—For surface space limitations in metro cities, tunnel is the best option worldwide for the development of modern transport system, utilities and other infrastructures. But tunneling is full of surprises depending on geological and hydrological factors. Underground Mumbai Metro line -03 is also full of surprises. In this paper we are going to discuss the encountered high water pressure during the Up line mining underneath the Andheri – Kurla road & elevated Mumbai Metro line -01 at Marol Naka. Pressure of water was observed to be 4.5 bars to 5 bars, geotechnical instruments showing no settlement but tunnel always filled with muck and progress were affected badly apart from taking precautions during the mining. As per geology, grade III basal and breccia were encountered. Team tried to find out the source/causes of this high water ingress but even after searching various options such as utility damage, recharging with water body, geological & geophysical investigation options, it was unable to conclude the confirm source. It was very astounding that no high water ingress was observed during the down line TBM mining. In this paper, all options have been discussed in details and also suggesting for taking high precautions during construction of cross passage in this area.

Index Terms—Geological Challenges, High Water Ingress, Instrumentation, Muck, TBM Mining.

I. INTRODUCTION

Tunnel is the best way to utilize the underground space, which is an eco-friendly structure. From the earlier age of human civilization, tunnel is part of social development. There are various old underground large structures present in every parts of the world such as Derinkyu underground city, Turkey; Naours underground city, Northen France; Lalibela, New Jerusalem and others. As per engineering & construction point of view, tunneling is full of challenges. Tunneling challenges are faced due to soil & underground lithology, hydrological condition, sudden geological challenges, ventilations and others.

India is a developing country and infrastructure projects are going in full swing like the highway project, metro rail project, hydro-power project, Coastal area development. As Mumbai is the most populated & highest dense populated city in India. For providing basic amenities to local public; government had started the various road, railway & water tunnel projects in Mumbai. Urban areas have very limited surface space and it necessary to utilize the underground space but tunnelling in urban areas has many engineering challenges. Major Engineering challenges in urban area has been given in table 1

| Challenges during tunnelling in Urban area | Sub surface | Surface |
|--------------------------------------------|-------------|---------|
| Flooding & Water Seepage                   | Tunnelling ground settlement | Finalization of Alignment of Construction using Spacing of present civil structures | Site of disposal of Muck | Geophysical & Instrumentation | Utilities & Overburden |

In this paper we will discuss the challenges faced during the Mumbai Metro line -03 (MML-03) underground projects tunneling underneath the Andheri – Kurla road at Marol Naka, Andheri (East), Mumbai. Tunneling underneath the Andheri- Kurla road was very challenging due to space, traffic & utilities; major utilities was elevated Mumbai Metro Line -01 (MML-01), three piers are situated near the tunnel and high water seepage observed during the upline tunnel of MML-03, geologically area in makeup of alternate bands of volcanic breccia and basalt. We will discuss in details about geology of area, quantity of high water seepage, water pressure observed during tunnelling, muck condition, water chemical test report, geological instrumentation installed and their observation and concluded the most probable causes for high water ingress underneath the Andheri- Kurla road.

II. PHYSIOGRAPHY AND GEOLOGY OF PROJECT AREA

A. Physiography:

Mumbai (old name Bombay) is one of the oldest, highly populated, dense city as well as economical capital of India. Before 18th century, it was seven Island, i.e. Colaba, Little Colaba (Old Woman’s island), Island of Bombay, Mazagaon, Parel, Worli and Mahim [2], which were connected under the Hornby Vellard project [3], for business from western & gulf countries and joined all the seven island by filling of sea [4] during the mid-18th century.

Climatically, Mumbai is falling under tropical zone, having wet, dry & hot weather with high humidity. The average temperature is about 27-28° C and normal annual rainfall varies between 1800 millimetre (mm) to 2400 mm. Mumbai has varying topographical features, most of the area is flat and Mumbai is surrounded by north-south trending hill range, coastal area and sea creeks. Mahim river, Mithi River, Poisar and Dahisar river with Pawai, Vihar & Tulsi lake are major water bodies in Mumbai. Apart from these water bodies Thane creek, Manori, Malad & Mahim creek are present which increases the mud flanges and swamps at main land area [1].

For transportation facility government body had proposed

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various Metro lines which connect the various part of Mumbai. In this proposed metro, one fully underground metro line -03 (MML-3), passing the heart of Mumbai and connect the most important locations of Mumbai i.e. Colaba- Bandra- Seepz and construction work was started in year 2016. Total 33.5 km long, 5.8 m finished diameter twin tube tunnel including 26 underground station in MML-03. It was divided into seven construction packages for construction feasibility. MML-03 is crossing underneath the Methi River, Western Railway track, Western express highway, bridges and other major utilities, which will require extra precautions during tunneling.

B. Geology of Area

Geologically Mumbai is made up of Basaltic lava flow, which is dipping towards west about 10°-20°. Mr Sethna S F (1999) [5] has identified seven distinct lava flows at different time period from Upper Cretaceous to lower Eocene (60 to 50 million years). Basalt, Volcanic breccia, Rhyolite, Trachytes, shales are the main rocks exposed at various location in Mumbai. As per geotechnical & geological parameters insitu rock strength varies from very hard to poor (grade 1 to IV) in nature.

The Mumbai and nearby Islands landmass comprises a linear depression bounded by easterly and westerly ridges [6]. Muddy sediments deposited in the central lowland dip 12°–158° west, and lavas up to 258° West [7].

1) Project Geology

To know the subsurface geology of proposed underground station Marol Naka including Andheri- Kurla road (falling mid of proposed station), ten boreholes were done and on the basis of core recovery, RQD and geo-mechanical parameters; classify the rock grade. Volcanic breccia and basalt with rock grade V to I (rock grade increases with depth) recovered during the borehole. Due to space limitations & heavy traffic, proposed underground Marol Naka station has been divided into two parts Box A & B, total length of station is 270 m and no borehole was done on Andheri – Kurla road. Based on borehole data, geological cross section has been prepared and given below in fig 3.

III. CASE STUDY: - TUNNELING UNDERNEATH THE ANDHERI – KURLA ROAD, ANDHERI EAST

After the completion of field investigation and construction of launching shaft at Pali Ground, Marol village (Ch. 30062 m); civil construction team had launched EPB (Earth Pressure Balance) Tunnel Boring Machine (TBM-01) in Up-line towards CSIA station on Jan 08, 2018. Major Utility /Structure along this alignment were Metro-1 flyover, which passes at along the Andheri Kurla Road at mid of proposed Marol Naka Station MML-03. Tunneling team had installed various instruments for safe mining, main instruments, like online tilt meter & vibration monitoring at each pier of MML-01 apart from 3 deep settlement marker, one stand pipe piezometer, 5 Surface settlement marker, pavement marker, various optical target for safe monitoring of tunnel (Refer fig 4). From Ch 29700 m, TBM encountered water with low pressure but from Ch 29680 m to Ch. 29610 m, high water pressure was encountered. Mining progress was badly affected. Mucking comes out in the form of sludge and tunnel filled with muck. During segment erection, water pressure reaches up to 4.5 bar at TBM chamber and as chamber opened for mucking, muck floated in tunnel. The water discharge was 60000-80000 litter/hr observed. Cleaning the muck & face pressure were critical issue and tunneling team suffered a lot. Tunneling team checked the pressure bar but it was showing actual reading.

A. Discussion

Water encountered during the Tunneling is normal phenomena but encountering the high-water pressure makes it surprise and poor quality breccia rock works as Cartelist
as more sludge were generated in the presence of water. Geologically grade III & IV rock, we expected but high pressure water was geological surprise for all. For identification of source of high- water pressure, tunnel team tried to know the possible causes, characteristics and precautionary measures; discussed below accordingly:

1) Recharging from water body or ground water:

Mithi River is near the area but had less water in normal season; did not have high level difference which can create the water head flow. After that tunnel team checked the draw down in water table by installed piezometer but no draw down was observed. As mining was going on and water seepages continuously increases, tunneling team thought that water table must be recharging from surface water body and tried to find out the other source of water and got the two large water bodies nearby the area. First is Pawai lake (ground El is 36 m) and Vihar Lake (ground El is 52m) and areal distance were 2600 m & 4300 m respectively. Google earth image and cross section of level difference is displayed in fig 5 & 6. If high water ingress were connected by these water bodies then we defined get high water ingress before these areas, but did not get previous water ingress. So it’s very difficult to fix the direct link with these water bodies. As we reached Ch 29680 km, TBM face pressure reaches 4.5 bar continuously and indicated that water head is minimum 45 m. This face pressures indicated that we must find out some other source of water ingress in tunnel.

2) Utility damage

Chances of utilities damage cannot be ruled out. Tunnel team did approach government authorities Municipal Corporation of Greater Mumbai (MCGM) for utilities and checking of water losses. Local government body informed that there is about 40% water loss and it is impossible to identify these losses due to old pipe lines of water & sewer. Available utility drawing showing one 1050 mm diameter sewer pipe line is 3 m below the ground, but damage of utility yet to be confirmed. However, it cannot create 4.5 bar pressure, so it may not be probable causes for high water ingress in tunnel.

3) Water Chemical Analysis

To know the type of water source, tunnel team approached the MCGM to check whether it is domestic water or not. Representative of MCGM took the water sample and checked the Chloride content but did not get the connection. They also inform that when fresh water is mixed with pollutant, detecting Chloride content is not possible and suggested for chemical test of water.

Tunnel team sent the water sample for chemical analysis and the report displayed a high PH value 10.64, Total suspended solid, chemical oxygen demand and other parameters are higher side. Water test report indicated that it was chemical and sewer waste water mixture. By chemical analysis, it was confirmed that seepage water is not ground water but TBM facing water pressure was still mystery.

4) Explore the Possibilities of Investigations

Apart from heavy traffic road and unfavourable condition for investigation, tunnel team explored the possibilities of conducting the Geophysical/Geological test in this area and accordingly discussed with professionals and concluded that concrete road has limitation for conducting the geophysical test; only Multi Spectral Wave Analysis might be useful but that has possibilities for shallow depth only. TBM passes 16m below the ground, so testing will not be fruitful. This possibility for causes behind the high water ingress was also ruled out.

5) Discussed with Local Public

Marol village is situated at the bank of river Mithi and development activities had occupied the river low line catchment area and constructed Andheri- Kurla road, elevated Metro line -01 and high rise buildings. But in every monsoon, this area is heavily flooded; government authorities increased the road level for avoiding the flood.
but not efficient result during the monsoon. It was also confirmed by local public that some water issue was also observed during construction of piers of elevated Metro line -01.

Due to continue flooding and river catchment area, chances of underground water channel/ stored water body cannot be ruled out in this area. But it is still hypothesis, as no evidence worked out.

B. Precautions Taken During Mining

Mining in this problematic zone was a big challenge, TBM were operated in closed mode and as we open the TBM chamber for mucking, tunnel was filled with sludge and cleaning the sludge was also challenge as water entered in tunnel too. Muck pit were filled with sludge and transportation of mucking was not possible. Tunneling team and other MMRCL professionals did close monitoring and tried to minimise the sludge factor but nothing happened. Tunneling team used high pressure grout, water proofing gel to solidify the muck but ultimate result was nil. TBM pressures bar was checked by TBM engineer various times but it was showing actual reading. Mining progresses was very slow and hardly install one ring segment in a one day. After crossing this zone (about 70m) water seepage stopped naturally. After that, tunnel team was ready to take all precaution measures for mining in down-line after the unsuccessful attempt of investigation and without causes of high water seepage, but it was big surprised that no high water seepage had encountered during down line mining in this zone.

IV. CONCLUSION

Tunneling is always full of geological surprises and water encountered during mining is normal event and every geological problem have some solution based on facts/ different studies, finalized the main causes. In high water ingress, the present case study becomes mystery due to high water pressure (45-50m water head) and no large water body evidence/direct link were observed. Chemical analysis of water indicated the mixture of various chemicals, which directly indicates the damaged utilities but such a high water head is not possible from leakage of utilities. One more possibility is that water which was taken for chemical analysis could have been already mixed with TBM machinery oil, griss and other impurities; so value of PH was high & various parameters were above limit.

Due to space & utility limitations, no geological investigations were done. Old topographical setting of this area might be possible but as such no prove exists. During installation of deep settlement marker on Andheri – Kurla road at down-line, no high water seepage encountered, as well as TBM mining.

Reviewing all the facts and no fluctuation in present water table, it seems that affected area was pocket of water storage which was surrounded by impervious layers and TBM had puncher this zone due to which the force of water had created such high water head. Physical evidence is yet to be confirmed for this hypothesis.

In other words, it can be concluded that high water ingress is still unsolved mystery and we hope that during excavation of cross passage in this area, construction team have to be careful and take instrumentation reading very carefully as well as proper construction methodology has to be followed.

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