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Metro Tunnelling - A Challenge

POL V R AND RANADIVE M S
College of Engineering, Pune
Email: *vikram.pol@gmail.com, msr.civil@coep.ac.in*

Abstract: Due to continuous and fast growth of population, people demand more and more transportation facilities. There can be no doubt that the requirement of tunnels also increases. We all know that there is less space available for surface transportation in cities. Metro tunnel construction is one of the best solutions to fulfill the transportation need of growing population. Metro Tunneling is complex, time consuming project in which Engineers have to think at every part of its execution such projects involve new challenges and problems at every point of its progress. During constructional phase problems like Land acquisition, High water table, Breakdown of TBM, Drainage problem etc. affect the project cost, time of completion and quality of work. Some of the problems which have been faced during the construction of Metro Tunnel in our country and their remedial measures are discussed in this paper.

Keywords: *TBM, Ground water Table, Water Seepage, Grouting, Gasket, Shotcrete.*

1. Introduction

To cater the need of transportation in cities, construction of roads and railways has already been built. But due to higher growth of cities and their increasing population, these modes of transportation are not sufficient now a day. So a new concept has arises and that is Metro railways. But in cities like Mumbai and Delhi, people even don't have sufficient space for building houses and residential complexes. Construction of Elevated Metros requires large space which is not available so underground metro is one of the best solutions. In some of the cities work has already been started. Construction of underground metro tunnels is not an easy task. People have to face various problems while constructing it. There is need to identify the problems and find the solution on it.

We can identify number of problems faced by Engineers in metro tunnel construction. We can find out some problems in many international journal papers. One of the problems is settlement of the overlying tunnel has to be reduced.

This happens in Shenzen Metro construction, China. The new tunnels and the existing tunnels are located at the curves of 350-m radius, and the intersection angle between the new tunnels and the existing tunnels in plane is 20°–23°. The vertical distance between two tunnel lines is 2132 mm and ground is made of gravelly clay.

Settlement of overlying tunnel is a complex problem. They have reduced this settlement by using grouting in various phases. The grout proportion used was different for different phases.

Another problem that has to be considered is from Izmir Metro Tunnel, Turkey. A fault zone was occurred during construction. A study of influence of fault zone on metro tunnel was carried out and results were interpreted. In this study, influence of deformations in and around a metro tunnel constructed as part of the 2nd Stage of Izmir Metro Project, in two different tunnel cross sections and in weak and faulted rock mass was investigated on the surface structures along the tunnel route. Therefore, detailed geological explorations and based on which computer modeling studies were conducted prior to the excavation. Following the excavation, the results obtained from computer models were compared with the deformations measured in the tunnel and on the ground surface and accordingly, it was suggested that excavation and support systems in original project be re-evaluated

In metro tunnel construction we come across number of problems related to constructional phase. These problems can be classified on the basis of some categories. These categories can be grouped as follows.

1. Human Related problems.
2. Technical Problems
3. Operational Problems
4. Quality and Safety related Problems
5. Miscellaneous Problems.

One problem may fit in to more than one category but mainly above said groups can explain it. In the

following sections the problems and the remedial measures have been discussed at greater length.

2. Human Related Problems

In this type of problem land acquisition is a major issue, which has been discussed here.

2.1. Land Acquisition

For any project in India of metro tunnel construction, metro rail corporation has to acquire the land and should be handed over to the contractor. Contractor has no role in acquiring the land. The land has to be acquired from Municipal Corporation, governmental agency or private owner.

For example, while constructing Delhi metro, land has been acquired from Municipal Corporation Delhi (MCD) or Delhi Development Authority (DDA). The land which has used for public gardens or parks comes under the MCD whereas roads are under the jurisdiction of the DDA. If the required land has not handed over to the contractor on time then there may be delay in work and that suffers lot while planning the work. So this problem can be solved by proper co-ordination between the client and various governmental agencies.

3. Technical Problems

Technical problems like high ground water table, supply of electricity, TBM operation& breakdown, seepage and settlement of overlying tunnel have been discussed below.

3.1. High Ground Water table

Generally Metro tunnels are constructed between 15m to 25m depth from ground level. While constructing tunnels at deep level may be obstructed by some problem like high water table. Then there is need of lowering the water table so that machineries can excavate the station area. In Delhi at some places we can find the water table is at the depth of 10 m below ground level.

So due to high water table, construction of station may take long time. There may be delay of more than one month also. During excavation of Metro Tunnel station, required depth cannot be achieved due to the high water table so following remedial measure can be applied.

Suppose required depth of excavation is 17m then contractor may take bore wells at points situated 10m x 10m distance and depth of bore well, should be about 22m below ground level. So the water level gets lowered and excavation becomes easy. Fig.(1) shows schematic diagram for remedial measure applied while such situations.

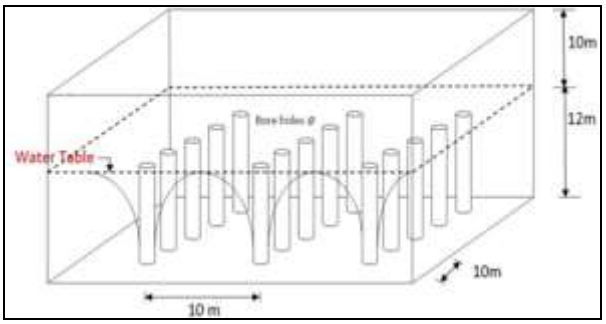

Figure 1

3.2. Supply of Electricity

While operating a construction project like Metro Tunneling, there is requirement of appropriate voltage and uninterrupted supply of electricity. Machineries like TBM, fans, lighting arrangement, cutters, grinders, and welding machines are operating on the electric supply.

So for fulfillment of this requirement diesel generators are used on site. For running the TBM, 11 KVA electric supplies are required. The numbers of diesel generators used are generally 4 to 6. These generators generally consume 25 liters of diesel per hour. Fig. (2) Shows diesel generators of 11 KVA making capacity. Due to this high consumption of electricity every day about 4000 liters of diesel is required. Consumption of diesel per day changes with change of site and change in electric load on diesel generator. Hence use of diesel generators is one of the remedial measures.

Figure 2

3.3. TBM Operation

The Construction of tunnel is done in two stages. First stage is the 'initial drive' and second stage is 'Main drive'. Before initial drive TBM parts has to be lowered in launching shaft. All parts of the machine have to be assembled [fig.(6)] and then by aligning TBM machine and other machineries excavation get started. When the boring gets started by TBM, some reactive force is required for advancement of TBM in forward direction. Normally without giving support, TBM cannot be advanced. So there is always requirement of any support to give reactive force to TBM. In initial drive the Shield

TBM starts excavation followed by reactive force created by reaction frame.

Figure 3 *250 ton self-wt. crane*

Reaction frame is a steel structure which is fabricated using of steel members used to get the reactive force. After horizontal boring of 1.8m, first temporary segmental ring is fixed in between the reaction frame and TBM. After installation of first temporary ring, excavation is continued and 1.4m of boring is done. Second ring is attached to the first one and whole procedure is continued.

The distance between reaction frame and tunnel face is generally depends upon the space available in launching shaft and width of segments. When segment reaches up to the face of the tunnel, excavation has to be continued and first permanent ring should be installed [Fig.(4)]. The gap between the cutting surface and the permanent ring has to be shot created from face of the tunnel and excavation should be continued. Along with the cutter head, skin of the TBM advances. After every single ring installation, grouting has to be done and gap between the segment and cutting face filled by grout.

About 5.5 m^3 of grout material has to be used to fill the gap behind a segmental ring [Fig.(5)]. Quantity of grout changes with change in cutting head diameter and outer diameter of segmental lining. Completion of initial drive can be told after installation of 30 rings. After completion of this initial drive temporary rings are taken out. Rings used in Delhi have external diameter of 6.35m. Also the demolition of reaction frame should be done and taken out from launching shaft.

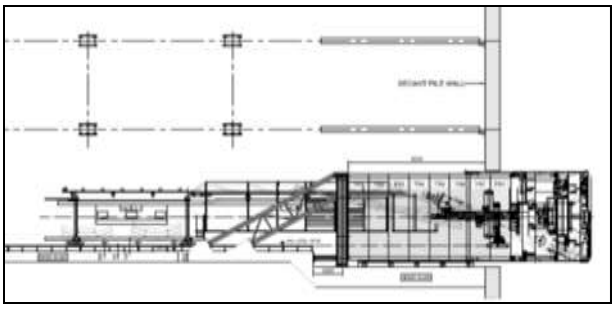

Figure 4

Grouting should be preferred to have bonding between the segmental lining and the face of tunnel. Details of the grouting material and their proportion that should be used are as follows.

Cement--- Retarder---Bentonite--- Water

390kg-------2kg---------16kg----------795kg

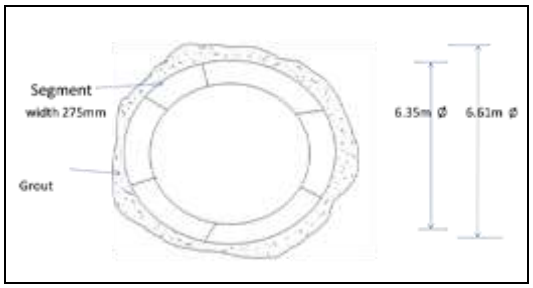

Figure 5

3.4. Breakdown of TBM

Breakdown of the hydraulically driven TBM depends upon the hydraulic pressure. IF hydraulic fluid fails to give required pressure then TBM operation gets stop. The hydraulic pressure in TBM depends upon the performance of push ram cylinders. Push ram cylinder gets jam by mixing of water in the hydraulic oil or by already used oil. By mixing of water bursting of hydraulic pipe takes place. Fig. (7) Shows the motors running on hydraulic oil and pipes and working on connections of hydraulic pipes to motors.

Figure 6 *Images shows launching and assembling of TBM and its parts*

3.5. Seepage in Tunnel

The seepage in tunnel can be controlled by the special provision like 'Gasket'. Gaskets are used at the joints of the segmental rings. These don't allow the entry of water inside the tunnel. Fig.(8) shows the segment and gasket attached to it.

3.6. Settlement of Overlying Tunnels

The whole city metro construction cannot be possible at the same time. Therefore it has to be done in number of phases. After completion of 2 or 3 phases, there may be a condition that two different tunnels of different phases may cross each other with certain overburden in between. If this overburden is low then there may be settlement of the overlying tunnel. This case is happened while constructing Shenzen Metro construction. Here distance between new tunnel and existing tunnel was 2.2m only. Engineers have used automatic monitoring system [fig (9)], for calculation of settlement of overlying tunnel. On the basis of the results they have used following remedial measures.

Here they have decided to give strength to the portion between the two tunnels by grouting that portion in two phases. Portion between the two tunnels has to be grouted with minimum pressure so that deformation will be minimum. High precision and watch is required on this type of problem.

Figure 7

Figure 8 *Gasket*

Same situation has been occurred at a station in Delhi. Two tunnels from phase-3 metro tunnel construction are crossing at 90^0 to existing phase-2 tunnels. There is overburden of 5m. They are monitoring the settlement of existing tunnel by same automatic monitoring system and keeping eye on it. In this system total stations are mounted at certain intervals on the side walls of the tunnels. Grouting has been used to give strength to the portion in between the tunnels. Special teams are taking watch on these tunnels. Every day they take the reading and analyses the settlement.

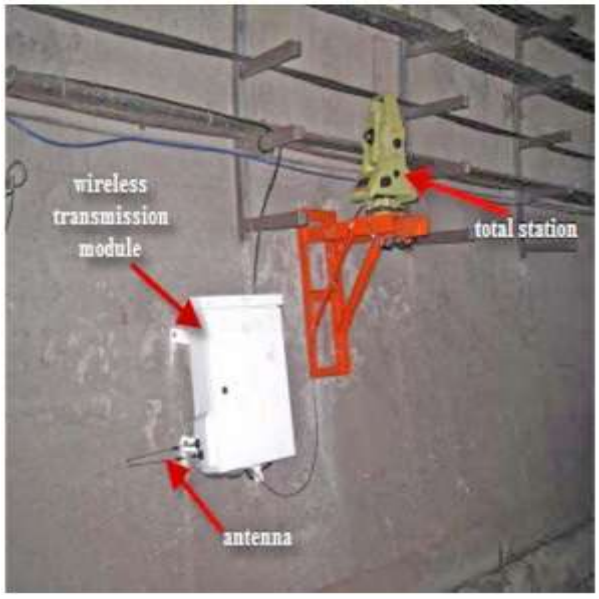

Fig.9. *Automatic monitoring system at tunnel sidewall*

4. Operational Problems

Operational problems like station construction, land use management have been discussed here.

4.1. Station Construction

Method of construction of station depends upon various factors such as ground strata, plan of execution, excavation time etc. If the ground strata is sandy silt with clay as in Delhi then the 'Diaphragm' wall construction should be preferred.

In the area like Delhi, ground is sandy silt with clay. So if you try to excavate the station area then there may be possibility of collapse of side walls of station. So diaphragm wall construction should be proffered around the station area. It acts as a retaining wall and you can construct all structural elements inside the station. First of all station or launching shaft should be excavated. Then TBM should be lowered and then internal station work should be done. The width of diaphragm wall may be wide from 0.8m to 1 meter. Fig. (10) Shows station construction and diaphragm wall.

Figure 10 *D-wall*

4.2. Land Use Management

In the cities like Delhi, Mumbai, Chennai etc. availability of land to execute the project is very short because of high population density. Managing various things like equipments, machineries, offices in limited area is a challenging task. It also includes offices of engineers, mess/canteen, store room etc. Due to less availability of space these offices should be managed on as minimum land as possible. In dense populated area like Delhi we can see, offices may made by the use of containers and they have placed over one another as shown in Fig.(11).

Figure 11 *Office containers kept on each other*

Also there may be use of the things like electrical panel, mechanical equipments and related other materials, muck stock yard, store etc. placed on site. You should think about available land and required land and likewise arrange all the things in a proper site logistic.

5. Quality and Safety related Problems

5.1. Grouting

The concrete or grout has property of segregation i.e. the cement paste may come to the top of the grout and other material remains at the bottom. So the sodium silicate is used to stop this segregation. Within 11 seconds of the mixing of sodium silicate with the grout, it becomes the gel and stops segregating. Sodium silicate used is about 8% to 10 % that of grout. The maximum grout pressure that has to be applied is 3 bar.

Two different names are given to two separate liquids. First one is 'A liquid' and second is 'B liquid'. 'A liquid' is grout and 'B liquid' is sodium silicate.

These two liquids came in contact with each other 1.5m near the grouting place, before that they come separately. Within 11 seconds two liquid material converts in to gel and we have to take care that pipe would not jam.

5.2. Construction of Ramp

Construction of ramp structure is also a challenging work where underground and elevated lines meet each other. While excavating stipulated area, side wall may collapse in to the excavated portion. So strengthening the side wall is an important thing [Fig.(13)]. Strengthening can be achieved by shotcrete and rock bolting of diameter 25mm and length of 3 m.

Figure 12 *Shotcreting and rock Bolting*

6. Miscellaneous Problems

Miscellaneous problems like sewer and utility services, seepage from drainage, availability of material on site, excavation of hard soil have been discussed here.

6.1. Sewer and utility Services

In city areas utility services are located at shallow depth. During excavation of ground these utility services may get damaged. Repairing and diversion of these utilities becomes an important task. Utility services include sewer line, electric supply cables, telephone cables, gas pipelines, water supply mains etc. During excavation work if these utilities came across the work then it has to be diverted from constructional area.

While construction of station area, high weighted cranes up to 250 tons may be used [Fig.(3)]. Due to the operation and movement of these cranes, sewer line may get damaged, which may require one day repairing it. That means delay of work may happen by a full day.

6.2. Seepage from Drainage in to the Ground

Experiencing the many failure cases in the project is a regular thing. Here I have discussed a case of failure. If TBM passes below the drain and there may be the overburden on the TBM then the portion which is in between the drain and TBM may experience seepage from the drain. The soil at that place may be loose. As TBM passes through that region, some part of the soil may get collapsed in to the tunnel. That extra soil has to be removed from the tunnel and collapsed portion has to fill with grout. Fig.(13) shows the schematic diagram of above said problem.

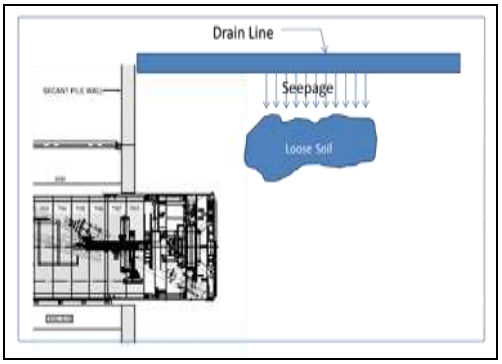

Figure 13

6.3. Availability of Material on Site

The required material should be available on time. Unavailability of the material leads to the interruption in work by some hours to days. It is important to have planning before starting the work so that material will be available on time. For that material should be stacked on site in advance. During scarcity of material or when material can't be reached on time then this material should be available for use.

There may be less space available for stacking the segments, cement sand etc. The segments should be stacked at stockyard which may be far away. Segments should be transported at night due to traffic issues. Also the fabrication work may be undergone at the same place. The material excavated by TBM can be stacked on site for a day only and it should be transported to the dumping yard every night. This leads to the smooth progress of work.

Figure 14.*Material stacked on site*

6.4. Excavation of Compacted/ Hard Soil

The soil which is to be excavated may be hard or require great force by TBM. For loosening the soil in

front of the TBM cutter head a mixture of Foam, water and the air should be sprayed on it. Due the effect of these materials, soil gets loosen and TBM requires less thrust to cut the soil as compared with original state. Below image shows make of foam.

Observations

At every particular Metro Tunnel construction site, Engineers and management have to face various problems. Most of the problems are not common and they vary from site to site. So after studying completed and ongoing projects of Metro Tunneling, we shall know the exact type of problems and their remedial measures that have been adopted by respective Engineers on site.

Due to the occurrence of one problem, the work schedule gets collapsed. Some activities are depending upon its preceding activity. And hence loss of time and cost has to be bear by the contractor. In this paper we have discussed about Water seepage problem. That effects on excavation of station and ultimately on other activities. Other activities may get stopped if this problem cannot be solved. The study may be useful to most of the tunnellers in particular the Metro tunnels.

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