Underground Space Technology-Contemporary Scenerio

Rajesh Agarwal

Abstract

The requirement of underground space is increasing with the development of metro rail corridors and spread of rail and road network in hill states. The paper brings out the scenario on the subject especially in rail transport sector. The experience of constructing railway tunnels is shared with focus on important issues like survey, design, and construction. The areas needing attention of Industry regarding capability and expertise enhancement are brought out.

An overview

Metros

The demographic needs of Indian metro cities during the last decade have resulted initiation of many rail based Mass Rapid Transport projects in cities like Delhi, Chennai, Bangalore, Kolkotta, Mumbai,etc. Though Kolkatta metro (1972) was a first step in this direction, but after a gap of almost two and a half decades, Delhi metro has pioneered the latest technology and gone in a big way for underground metro tubes.

The works of DMRC have generated good experience for underground transportation. In phase I about 13 km of route is underground out of 65 km. This experience has brought with it the design and construction experience. In Chennai also 24 km is planned as underground route in the two initial corridors of total length of 45 km. The Bangalore metro has planned 8.8 km out of 42.30 km as underground route. The underground metro in Kolkatta was constructed with cut and cover and those of us who have seen that phase of construction would have vouched not to have any more underground metros. The mining and boring technology used by Delhi metro has generated lot of enthusiasm which will get emulated in other Metros.

The Mass Rapid Transport of the mega cities has to be provided preferably through underground constructions. The surface transport in cities needs to be reduced to only local areas. An ideal vision of transport needs of future cities is pollution less underground rail based mass transport. The local area movements on the surface may be through walkways, cycle ways or electric vehicles on roads. Such arrangement will be environment friendly. It will also be aesthetically pleasant in built environment. Yokohama in Japan has very good underground MRT and supplemented by lean surface transport.

Photo 1. A view of underground metro station

IRSE, General Manager (Projects), Konkan Railway Corporation Limited

Photo 2. An ideal view of clean environment in Yokohama

Photo 3. An underground ring road in Tokyo

The new road network in global metro cities is also gradually being placed underground. A 42 km underground ring road is under construction in Tokyo.

Cross-country transport

In India traffic tunnels have been far and few in both road and main line railway sector. Jawahar tunnel in J&K, railway tunnels between Kalka and Shimla (H.P.) and Lonavala and Karjat (Maharashtra) are few well known examples. The 107 tunnels in Kalka-Shimla mountain railway built more than a century back are a testimonial to the tunnelling skills of the engineers of nineteenth century. Almost over a period of a century the tunnelling technology has transformed itself. Construction of Konkan Railway (1991-1998), through Western Ghats, saw construction of 91 tunnels aggregating to 84.5 km of tunneling. The longest Rail tunnel in operation is 6.5 km. The majority of tunnels are in hard rock -74.9 km, tunnels in soft rock are 8.4 km and through cut and cover are 1.2 km.

In both the cases of rail and road, the provision of transport tunnels reduces the route distances and contributes towards savings of the rapidly diminishing fossil fuels. The travel is also faster due to reduction of U-bends and easing of curves leading to increased speeds. Provision of tunnels saves surface excavations leading to reduction of deforestation and surface erosion. The safety from landslides and rock falls is also enhanced.

Photo 4. A Tunnel on Konkan Railway

The need to provide rail connectivity to remote area in Northern and North Eastern States in Himalayas has also led to approvals of new rail line projects. Related to these projects is the need for tracks through tunnels. In rail sector surveys have been done earlier for 2700 km for new lines in difficult terrain (Himalayan region). Some of these projects in challenging geology are under execution like Udhampur-Srinagar-Baramula rail link (USBRL) project, Sevak-Rangpo rail project in Sikkim and other projects in North Eastern States. The USBRL project calls for more than 130 km of tunnels which is about 85% of the route length. The longest tunnel of 11 km is shortly expected to have breakthrough.

The thrust on improvements of NH is leading to easing of slopes and grades of roads. There is a plan to construct 9 km long Patnitop base tunnel in J&K, on NH1-A. Some of you must have traveled on Mumbai-Pune express Highway. How is the experience different as compared to old route involving open cuts in Ghats. The tunnels of Mumbai Pune expressway were also constructed by Konkan Railway. There are 6 tunnels aggregating to 5.7 km. The area of cross-section for these tunnels is 148-157 m2. These tunnels have cut the time of travel between Panvel on Mumbai side to Dehu Road on Pune side, a distance of 100 km to 1 hr!.

Photo 5: Breakthrough of Railway Tunnel- 44 in J&K.(Dec'10 -KRCL work)

Photo 6: Bhatan Tunnel of Mumbai Pune Express Way (By KRCL)

Hydro-electric sector

The necessity of head race and tail race tunnels for hydro electricity generation has been the main activity for underground construction in power sector. For the HE and Irrigation projects hundreds of km of tunnels have been constructed and more are under construction.

Other Underground works

There are works of Strategic nature like, underground Petroleum/Oil storage, defense works etc which call for creation of large underground spaces.

The Challenges in Underground Space Construction-Experience of construction of New Rail line project in J&K

Geological Survey

Railways are generally the harbinger of development. Hence, the construction of tunnels for rail transport in hilly areas is normally in remote unexplored areas. Not much detailed information regarding geology is available for such virgin areas. It requires experienced engineering geologists to undertake geological survey in these remote

Photo 7: Owk Irrigation Tunnel in Andhra Pradesh (By KRCL)

Photo 8: A TBM tunnel for HE project in Uttaranchal

areas. There is scarcity of good surveyors and more often a good pre-survey is lacking even for important sites. Under such situations geological surprises are met and the time and cost overruns are common.

The geological mapping has been found to be a very useful tool for early geological survey of a vast area. The confirmatory boring at tunnel portal locations and other accessible locations along the alignment can further refine the mapping predictions. If possible it is also important to map the hydrogeology. It will help to identify the likely water pockets. The geophysical methods may be of help in this survey work.

The survey in mountainous area is difficult on account of poor accessibility. Railways initiated the alignment selection process in State of J&K, using the NRSA data and Digital Elevation Model of the terrain. Based on the railway's ruling gradient criteria and topography, the likely alignments were marked and tentative longitudinal sections and plans were developed. These proposals were then geologically mapped to suitable scale and refined by confirmatory borings. The drillings upto 600m deep have been done for the above railway projects. The overburden at few places is as high as 1300m and at such places geological mapping has to be relied upon.

Photo 9: Folds at exposed outcrop near a Tunnel alignment in J&K (KRCL)

The Great Boundary Fault and its offshoots run through Himalayas from west to east. The variations in geology on this account are very rapid. During tunnel excavation work the ground is continuously required to be fore probed and tunneling methodology is to be adapted to suit the geology. In Deccan plateau the geology is comparatively better as hard rock is encountered at most of the area.

Photo 10: Crushed Dolomite with water flow in tunnel in J&K (KRCL)

It is also to be noted that even with the best and most detailed surveys, the geological surprises cannot be totally eliminated. There are many such cases even in the best surveyed projects, for example, heavy water ingress in TBM tunnel at Joshimath in State of Uttaranchal, unknown shear zone again in TBM tunnel at Gotthard Base tunnel in Switzerland.

Design

It is no doubt that construction of underground works call for very different concepts for design and construction. In open construction like bridge we construct the support structure and thereafter apply load gradually. In case of creation of underground space, the loads are always present. The geo supports are to be replaced by structural supports. The assessment of loads in such cases is the primary requirement. This assessment needs an accurate survey of the strata, its structural discontinuities, their joint properties and so on. For tunnels at great depths the continuum theory of rock mass may work but near to surface tunnels need an understanding of the discontinuities and study of joints and Joint properties. In deep tunnels with hard rocks –rock burst may be an issue, but in near to suface the influence of squeezing may have to be seen. In clay stone strata swelling pressures may lead to deformations.

The geological strata to be encountered are classified according to the adopted design concept. The RMR classification system is generally adopted for better class of rock and ranges from 1-100 and 'Q' system is adopted for wider range of rock as it spreads from 0.001 to 1000. Another concept of Geological Strength Index is also being formulated by Bureau of India Standards. It will be useful for weak rocks.

The design concepts for the support systems being used in tunneling are mainly empirical. The most common being, New Austrian Tunnelling Method (NATM), Norwegian Method of Tunnelling (NMT) and Conventional system. In India, Bureau of Indian Standards has published "Tunnelling methods In Rock Masses- Guidelines", which is a good reference. The philosophy of Empirical design calls for a very high level of experience for optimization of the support systems. The tunnel engineer has to keep in mind that empirical design concepts were developed for a particular geological area and while adopting these classifications to the area of work, the differences in the geology have to be understood. For that matter the tunnel engineer has to understand the geology very well and the geological skills are to assist the engineering and not a substitute.

In the empirical design approach the behavior of initial support is watched with the instrumentation especially in squeezing ground conditions till the movements have stabilized. According to the necessity, the supports at certain locations are increased to keep the deformations within the permissible limits. Occasionally extra allowances in dimensions are made to accommodate squeezing of supports.

The tape extensometer readings can raise the initial alarms. A critical review of the geology and the supports is required to be done where the squeezing is more than 1% of the lateral tunnel dimension. The tape extensometer data is supplemented by the profile meter readings with respect to centerline of the alignment and read along with the 3-D geological log to understand the cause of deformation. It is advisable to concurrently plot the support system, hydrological data, instrumentation data and 3-D geology on the same scale to understand the tunnel behavior.

It's a common experience in the tunneling that deformations do take place. The structural supports provided get damaged and may need replacement with stronger supports at few locations. With experience, such situations can be minimized but cannot be eliminated altogether. For the new rail line project in J&K, the geology encountered has been difficult. The most intriguing part is that the geological surprises are met within the short distances. The alignment had to be locally adjusted at few places. In railway geometry detours at sharp angles cannot be provided. It will have severe constraint on speed potential. For speed potential of 100 kmph the curves need to be about 1000 m radius. Hence, lengths involved for detour of alignment through reverse curves may be much more than the lengths of adverse geology to be bye passed.

Shape

The transport tunnel have to have the flat track bed. Ideally the D-shape is preferred as this provides least area of excavation. But this shape should not be provided in adverse geology i.e., strata with squeezing and swelling properties. Such problems are more when the strata are with clay bands or clay stones. The issue is of top and side pressure. In case of only top pressure, Elliptical shape is about 30% stronger than D-shape. In case of both top and side pressure, elliptical shape is about 300% stronger than D-shape. Under latter type of loading there is large increase of maximum bending moment and shear force on the vertical supports. The large scale deformations of the vertical supports have been experienced.

Size

The increased activities of underground works are also associated with the increased size of spaces to be created. For the railway tunnels there is a serious debate about provision of single tube with two tracks or two tunnels with single tracks. The combined tunnels call for large diameter tunnels.

For single railway line the payline area of cross section in short tunnels (less than or equal to 3km length) is 56.36 m2 and the finished area is 39.23m2. Within this cross section 1.2m walkway has been provided on either side of the track as escape walkway. For single line sections with long tunnels (more than 3 km) a 3.0 m wide motorable pathway on one side and 0.75m walkway on other side for rescue and maintenance is required to be provided. Here the payline area is 70.38m2 and finished area is 50.75m2. Here also it is debated whether to provide this pathway through the same tube along with the track or to provided a separate tube for rescue. In case of underground stations, the size of openings are very large which have to cater for railway tracks, platforms and operational structures.

Support Systems

The support systems are active and passive. The bolts and anchors are active support provided to act as reinforcement to rock strata. The normal steel bolts are provided where the drill hole does not collapse and mmediate strength is not required. In such case the bolt can be placed in drilled hole and grouted. The self drilling bolt is required where the hole if drilled in advance collapses. In this case the bolt tip is provided with drilling bit and is buried along with the bolt. Further this bolt is provided where strength is essentially required after the setting time of the grout. Such bolts can be of longer length, normally in multiples of 3 m. The swelling bolts are provided in cases where the drilled hole does not collapse immediately but immediate strength is required i.e, time required for grout to gain strength is not available. Such bolts are blown with pressure and hold their strength with friction.

In the conventional system of supports, steel ribs and backfill concrete act as passive support. The steel ribs supporting the crown and resting at haunch have been found to be more successful. With this support the provision of wall beam between the crown support and the sides support is not required. The wall beam is otherwise a construction necessity to support the crown during heading excavation.

The conventional support system takes more time to erect the supports. The unsupported time lag leads to crack propagation and thereby mobilization of more load on the support system. However, this is the system which works if the alignment has to be taken through a running and flowing strata as in shear zones. In such locations umbrella fore poling and multi-drifting method is essential and thereafter the steel ribs and lagging are provided and backfilling is done. Once the squeezing is stabilized, lining is provided.

The two stage support system of NATM is found to be suitable in strata which can take shotcrete and rockbolts. The immediate flexible support of shotcrete checks the crack propagations and the rock bolts provide the active compressive support. The instrumentation guides the needs of further measures to be taken. Once the redistribution of the loads has stabilized the secondary support system of lining is provided.

Excavation Methods

Based on the method of excavation tunnels are classified as “mined tunnels” or “bored tunnels”. There can be “cut and cover tunnel” also, but those are not discussed, as the methodology is more related to foundations and structural engineering rather to Underground excavation.

The mining of the tunnels may be executed with tunnel excavators if the formation is soft. Else, drill and blast method is used. The use of mining method is more popular in varying geological strata met at close intervals along the tunnel alignment. It is also useful in grounds with fault and shear zones and with heavy ingress of water. Another reason for adopting mining method is availability of limited geological information at the time of commencement of excavation.

The progress of single line tunnel with one face with Drill and blast technology has been about 60-70m per month with normal level of difficulties, i.e., average lead to portal 1000m, and Q=0.1-1.0. Under better circumstances it may be increased by another 30% . This is 10% progress when compared to TBM.

The tunnels can also be bored using road headers. Road headers have been used in small way in railway project in J&K. Their utility was not very effective as the strata was varying rapidly and heavy seepage of water was also encountered. The compatibility of equipment with the strata is essential. A judicious decision is to be taken for deployment of road header as it calls for large investment for equipment and its associated electrical supply arrangements. The benefit is that in areas of low cover zone and built up areas, the ground vibrations due to blasting are eliminated, thereby damage to overlying structures is reduced.

The use of Tunnel Boring Machines (TBMs) are also gaining popularity. TBMs are generally economical for long tunnels say 5 km or more. These machines have been successfully deployed in Irrigation projects in Andhra Pradesh, Metro tubes for DMRC

Photo 11: Drill and Blast tunnel with Heading and benching and Conventional Supports in J&K (KRCL)

etc. In Himalayan areas also TBMs have been used. There are difficulties for deployment due to remote locations of projects with poor road accessibility. The steep topography permits limited space for assembly of TBMs. Generally a space requirement of about 200 m is required. If this space is not there, TBM has to be assembled within the pre-excavated tunnel using drill and blast method.

Before making a choice for deployment of TBM, the geological survey of the alignment needs to be completed in great detail. Based on this survey, the type of TBM to be used is decided and ordered for procurement. The survey of geology in Himalayan region is difficult and it is experienced that wrong geological interpolations and missing details have led to struck up of TBMs in tunnels.

The familiarity with the drill and blast technology and apprehensions about the success of TBMs, involving heavy investments, has not encouraged project authorities to deploy TBMs in large scale. It is hoped that with the development of EPBs and better geological surveys, use of TBMs may gain popularity.

Status of Construction enabling systems

The mechanization of construction

activities has helped in undertaking larger construction jobs with lesser completion periods. The availability of boomers, side loaders, large muck trucks, robotic shotcrete machines have reduced the cycle time. It is essential that capacity of equipments is compatible with the tunnel methodology and cycle time requirements.

Tunnel Instrumentation

Soft ground tunneling near to ground requires measurement of deformations to know the efficacy of supports. It is generally seen that instruments once installed get damaged and damage rate may be as high as 50-60%. Hence, it is essential that sufficient instruments are installed. The simplest way is to know the deformations is tape extensometer. The periodical readings are noted and plotted. The study of plots give better idea of the variations.

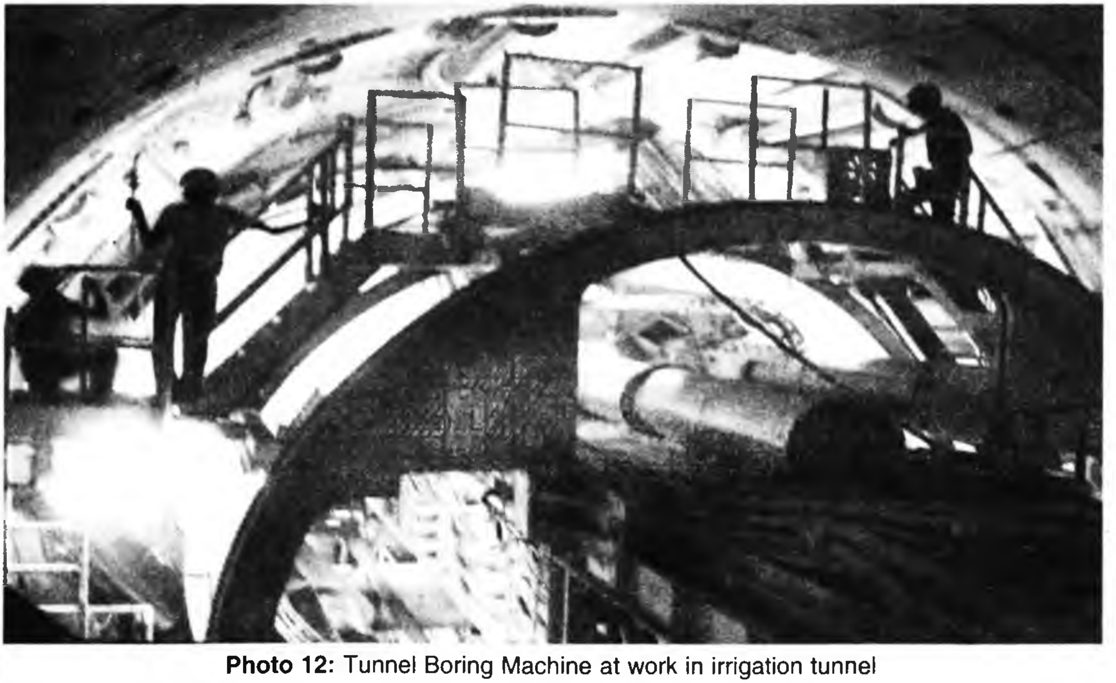

Photo 12: Tunnel Boring Machine at work in irrigation tunnel

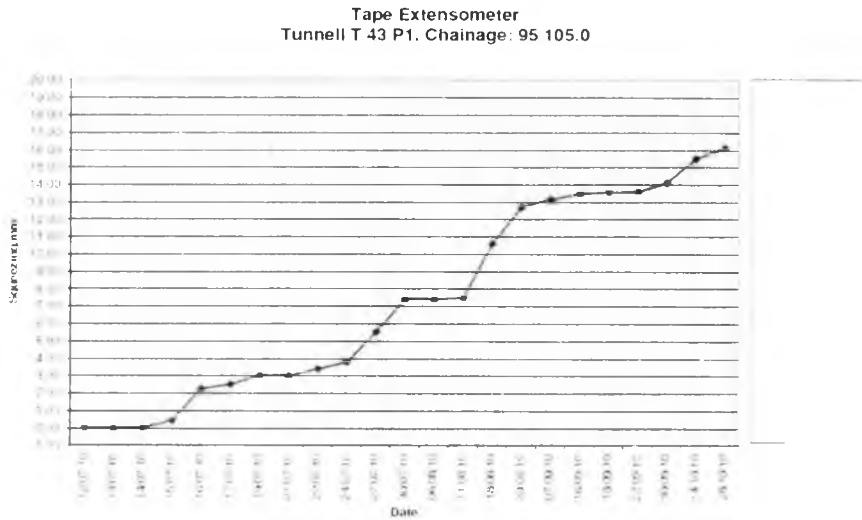

Photo 13: A typical graphical data of tape extensometer of a tunnel J&K (KRCL)

A separate team of engineers to collect the instrumentation data and interpret the readings and document the same is essential for the underground works. As mentioned in the para on design, the tunnel design is empirical and hence, the instrumentation data is required to validate the design. This data is also useful for understanding the long term maintenance problems during the service life of the tunnel.

Safety requirements for railway tunnels

The railway tunnels are preferably to be provided with Ballast less tracks. This is essential as maintenance requirements like screening of ballast inside tunnels is very difficult. For proper upkeep of Ballastless track and electric traction equipment the tunnels need to be waterproof.

Photo 14: A view of ballast less railway track in tunnel

Photo 15: Damage to railway track fittings with water

There are other safety requirements especially for the railway tunnels. The monitoring of gases in the tunnels is required. As per need the ventilation systems are installed and operated. In Himalayas, for new railway lines, access roads, rescue area (500m2) and helipads are being provided at the portal locations of long tunnels.

Availability of resources for underground works

Agencies for survey works

The under ground works need high quality of survey for geology. It is difficult to find agencies with high degree of professionalism especially in difficult and remote terrain. The industry needs to take this challenge.

Experienced and Skilled Manpower

The availability of experienced designers and engineers for the underground works is not commensurate with the present requirements. It was sometime in early nineteen eighties that IIT Delhi had started a Masters program in Rock Mechanics, the first of its kind in India. The engineering institutions need to take the call for initiating and augmenting the programs for providing the qualified engineers for the underground works.

Psychological Issues

The word underground immediately invokes a negative connotation in the mind of a layman. It is associated with socially unacceptable issues. This has historical genesis related to caves which were dark, cold and damp. In underground tunnels there is lack of direction or orientation and there is fear of entrapment. It also leads to a sense of confinement and connection with nature is lost. The users have to be oriented to become adaptive to replacement of natural surroundings by technologically showcased environments. The engineers and workers who are involved in construction of underground spaces need to be specially trained for such psychological issues. Underground construction industry is required to take care of these issues also.

Conclusion

It has become essential to provide Underground space for infrastructure due to increased transportation requirements of cities and also of remote areas in hill states. The difficulty levels in underground construction are more and risks are also many. It requires meticulous planning for construction of such structures. The experience of ongoing works needs to be shared. Technical institutions are required to augment the courses on such specializations in their curriculums. The industry also needs to address the psychological issues related to underground space creation and utilization.

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