Challenges and Strategies for Tunnelling in the Himalayan Region

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ABSTRACT

Tunnels are important elements of Infrastructure projects, Hydro Power, Transportation, water supply & sewerage system etc. Its construction involves many complexities in terms of different shapes, soil/rock conditions, alignments etc. Himalaya is young mountain with complex geology and the tunnelling activity in various projects in Himalayas are suffered by diverse geological problems such as difficult terrain conditions, thrust zones, shear zones, folded rock sequence, in-situ stresses, rock cover, ingress of water, geothermal gradient, ingress of gases, high level of seismicity etc. All these challenges may result in increased cost and extended completion period. Compared with the great advances made in methodology for tunnelling all around the globe, it is obvious that we in India have still a long way to go to catch up with modern tunnel construction technologies. Proper strategies counteracting the challenges need to be formulated and if implemented timely in tunnelling of Himalayas, we can reduce time and cost overrun and enhance safety and stability of the structures.

1. INTRODUCTION

Modern tunnel construction in India has its origin mainly in the Nineteenth century when a number of railway tunnels were constructed for extension of rail network in the various parts of the country for crossing of hill ranges - in Western Ghats, Vindhayas and in the foothills of Himalayas for connecting few hill resorts like Shimla and Darjeeling. Barring few tunnels in the soft rock formations of Himalayan foothills in the North, most of the tunnels were bored in hard rock strata in Peninsular India. Also generally the dimensions of the tunnels were limited to the requirement of accommodating single broad gauge railway track. There were a few instances of tunnels being constructed for roads and other purposes. Early in the present century, a major tunnel was built in Shiwalik ranges in connection with first major hydro power project in Punjab.

Construction of tunnels received a big boost after Indian Independence in 1947 when large programmes for exploitation of water resources were taken up which involved construction of tunnels for water conveyance and other underground works. Apart from tunnels for hydroelectric works, a few tunnel projects were executed for roads and water supply schemes, the notable projects being the Banihal Road Tunnel (J&K) and Tunnels for Bombay Water Supply. Another very important railway and Metro (Urban tunnel) projects executed by the Indian engineers, and presently in operation are Konkan Railway, Calcutta Metro Railway and Delhi Metro Railway.

2. TUNNELLING TECHNOLOGY

Following are the methods of tunnelling.

(i) Conventional Method
   • Drilling and Blasting Method
   • New Austrian Tunneling Methodology (NATM)
   • Drainage, Reinforcement, Excavation, Support Solution (DRESS)

(ii) Mechanized Method
   • Road Headers
   • Tunnel Boring Machines (TBM)

A review of tunneling methods shows that the conventional drill-&-blast method remains practically the dominant practice for excavation of tunnels in India. The tunneling rates achieved using the conventional method of excavation vary from 7.5 m to 81.0 m on monthly average basis depending upon the size of tunnel, geology encountered etc which is comparably much lower than the rates achieved otherwise using mechanized tunnelling elsewhere. Attempts have been made in the past on some projects to use Tunnel Boring Machines (TBMs) with success in some and failure in others.

3. DEVELOPMENT OF TUNNELLING IN INDIA

The development of Tunnelling in India is as follows.
4. CHALLENGES IN TUNNELLING

Inadequate Investigations
Almost every aspect of a tunneling project, from its conception to commissioning, is influenced by the geology of the area. Reliability of the predicted geology, therefore, plays an important role in the success of the project. Inadequate geological/geotechnical investigations and poor anticipation of the nature and the magnitude of problems may result delays and cost overruns. In the past following problems have been experienced due to inadequate investigations:

(i) Buckling of steel ribs requiring rectification under squeezing ground conditions in lower Himalaya.
(ii) Roof falls and chimney formations.
(iii) Water inrush (Chhibro-Khodri tunnel)
(iv) Methane explosion (Giri-Bata and Loktak tunnel)
(v) Running ground conditions

Deficiencies in Contracting Practices
Practically, all the tunneling projects in the country are executed through contractors only and it has been experienced that there are invariably time and/or cost overruns on almost every such project due, among other things, to deficiencies in the contracting practices which is generally found to be indifferent to the project needs.

Delayed Financing
It is often seen that finances for the tunnelling projects if not provided in time are leading to delays in construction of tunnels resulting in increase in completion cost.

Delayed Decisions
Large delays in decision making often result in delaying the completion of the projects. The case of Kadabagatti tunnel in Karnataka may be cited here. After a collapse in the tunnel, the work was held up for 7 years for want of a decision while several alternatives for rectification of the collapsed zone were being examined and discussed. However, once the decision was taken, the rectification was completed within a couple of months.

5. GEOLOGICAL PROBLEMS

Geological Complexities
The difficulties during tunnelling posed by the geological features like thrust zones, shear zones, folded rock sequence, in-situ stresses, rock cover, ingress of water, geothermal gradient, ingress of gases, high level of seismicity etc. have been experienced on different project sites in Himalayan region.

Thrust Zones
These are the major tectonic features, having a strike length of more than 100 km and affected zone of more than 100m, characterized by highly deformed, water charged, crushed, brecciated, pulverised rock mass sandwiched between two undeformed litho tectonic blocks. The rock mass conditions within the thrust zones usually pose multiple problems while driving tunnels through these sections.

Shear Zones
Shear zones are characterized by highly deformed, sheared, water charged, poor rock mass conditions. These are minor tectonic features and usually have affected zone of less than 10m thickness. Serious tunnelling problems have been experienced when the rock mass is affected by multiple shear zones. The problems are mostly related to loose fall, chimney formation, squeezing/heaving and collapses due to less standup time of rock mass of class VI and beyond Class VI (Q=0.01, RMR <20). In these adverse tectonised zones the tunnels have been driven with utmost care by fore poling, multiple drifting, and controlled blasting followed by instant rock bolting, at times, by self driving anchors (SDA), reinforced shotcreting (using steel fiber) and provision of drainage holes. Sometimes, steel rib supports at very close interval have also been provided as additional measures.

Folded Rock Sequence
In Himalayas, rock sequences are folded and refolded, regionally and locally, due to polyphase deformations. The rocks are tightly folded due to high compression in the close vicinity of major tectonic features like thrusts. The rock mass, present at the closures of synclinal and anticlinal structure behave differently when tunnels are driven through them. In antilines the rock mass is highly fragmented/jointed at the closure and structurally controlled failures are anticipated at the crown of the tunnels, whereas in the synclinal troughs the rock mass is mostly water charged and at times act as huge water aquifers. The fold axes are usually traversed by numerous shear zones and present difficult ground conditions for tunnelling due to extremely poor rock mass. These problems severely affect the tunneling schedule.

In-situ Stresses
In-situ stress in Himalayan region varies from place to place. A major uncertainty lies in forecasting the magnitude of the stresses in different sections of tunnel alignment. In view of the high rock cover and closer valley side associated with poly phase deformations in Himalayan region, it becomes sometimes necessary to measure in-situ stresses by means of hydraulic fracturing or flat jack test. The thrust zones, other tectonised zones, high cover reaches are the areas of high in-situ stresses and here the rock masses are heavily stressed. The phenomenon of squeezing and swelling, which cause an inward movement of the tunnel periphery due to dilatation or distressing needs to be accounted to ensure safety of tunnel support. In several hydroelectric tunnels in Himalayas, squeezing phenomenon has been recorded when tunnelling through difficult ground conditions specially where the in-situ state of stress is high and the tendency to heave and large displacements along periphery of tunnels have been found in Maneri Bhali stage I and II, Giri-Hydal tunnel etc.

Rock Cover
The problems associated with the vertical and lateral rock cover are indeed very serious during tunnelling. The vertical rock cover above the tunnel periphery has direct influence on in situ stress (vertical) which in turn has significant bearing on the behaviour of rock mass around the opening.

Ingress of Water
Tunnelling through rock mass which is highly charged with ground water faces major problems such as:
(i) Heavy ingress of water in tunnel hampers the construction activities inside.
(ii) The saturated rock mass looses its strength as the shear strength (cohesion and friction) gets reduced due to lubrication, and failure of rock mass occurs from the crown and above spring level. Virtually it is flowing ground condition.

(iii) The high pore water pressure behind the tunnel periphery adversely affects the support system resulting to distress.

Geothermal Gradient
The occurrence of hot water springs and high geothermal gradient is mostly associated with the Higher Himalaya which is marked by young granitic intrusions and deep seated faults. When deeper geothermal sources/aquifers are connected with the avenues like faults, shears and joints, the hot water oozes out in the form of hot springs. Tunnelling through hot water or high geothermal zones is very difficult due to deteriorations in working condition because of high temperature and humidity. The chemicals present in hot water have corrosive effect on concrete lining.

Ingress of Gases
In some of the hydro projects in Himalaya like Ranganadi Hydel Project (405 MW) in Arunachal Pradesh and Loktak Hydel project (105 MW) in Manipur high inflammable methane gas was encountered during tunnelling for head race tunnels. In Loktak project the loss of human lives was reported due to the inflammable gases.

High Level of Seismicity
From the tectonic model of Himalayan region, it is clear that Himalaya is in a state of persistent compression due to continuing northward movement of Indian plate towards the Asian plate and there are contemporary crustal adjustments which is evident from recurrent seismicity. Hence, the rate of convergence between the Indian plate and Eurasian plate has a direct bearing on the seismicity in Himalayan region. The seismically sensitive Himalayan belt has been witnessing earthquakes of different magnitudes and intensities.

Difficult Terrain Conditions
The rugged terrains of Himalayan region which are characterized by high mountains, deep gorges, undulating slopes, steep slopes, overburden slopes, bad land and mass wasting activities pose various problems while accommodating the project features as per the designed layout. In case of run of the river schemes the main problem results excessive deformations at the crown level.

Construction Methodology
In view of huge tunnelling activity involved while executing many proposed hydroelectric projects in Himalayan region where challenges are more, attempts are being made to induct modern techniques of engineering geological investigations in order to unravel geological complexities and adversities well in advance, so that geological surprises are minimized during construction. Besides, numerical modelling for design considerations and fast tunnelling technology using Tunnel Boring Machine (TBM) are being considered to reduce time and cost overrun and ensure safety and stability of the structures. With new tunnelling techniques, extensive developments have taken place in the field of special excavation equipment - hydraulic jumbos, Tunnel Borers, Road Headers, explosives, methods of ground stabilization, methods for rock support, special equipment for concrete lining, which enable realization of tunnel construction at much faster rate.

Deficiencies in Selection of Equipments
There is validity in the point made in the past that use of latest technology in tunnelling entails high initial costs, which the job owner should be prepared to bear. The use of such equipment has been possible where high rates have been allowed for the tunnelling work compared to what are normally allowed for such jobs, using conventional methods. In case of use of TBM for tunnel for water supply, this method was adopted due to requirement of contractor indemnifying owner against any possible damage to buildings at surface due to tunnel construction. Further use of TBM was facilitated due to owner giving substantial funds for purchase of TBM. The ultimate justification for incurring high cost on equipments is the early realization of benefits from the scheme.

7. STRATEGIES FOR HANDLING THE CHALLENGES OF FAST TRACK TUNNELLING

Adequate Geological & Geotechnical Investigations
It is important to have a very good assessment of geological/ geotechnical conditions before hand to optimize the construction activities. A detailed topographic survey would be required to finalize the alignment of the tunnel and location of adits, if any. Locations of intermediate significant features such as streams or nallas, visible fault zones etc. need to be identified. For tunnels of long lengths or going through a large spread of land, faster methods of survey than the traditional Total Station-based surveys would be resorted to. The modern tools of surveys such as Aerial surveys, photo-grammetry-based surveys, GPS based systems which have very good accuracy are to be used.

Drifting
It is sometimes very difficult to locate shear zones or fault zones or other significant features which have a large impact on the tunnel construction by the conventional exploratory methods. Though bore hole data, the traditional method of geological exploration provides useful information, it may not be sufficient for overall assessment of the geological features along the tunnel alignment. Exploration by drifting
is a classical method of investigation and gives reliable information for large projects. Exploration by drifting which gives reliable information is to be considered appropriately.

Geophysical Investigation
Nowadays many advance methods of investigation are available. Geophysical methods of investigation are now well developed and are available for predicting underground conditions in advance and are to be used in future in addition to bore hole investigation methodology. Some of the methods involved are electrical resistivity tests, seismic reflection and refraction techniques, geophysical tomography techniques, bore hole logging, cross hole seismic tomography, geo radars, etc. Other modern techniques include assessment of in-situ stresses by hydraulic fracturing techniques, etc. Once the locations of significant features are identified by various macro investigations, more detailed investigations can be conducted around these locations to get more details.

Selection of Tunnelling Equipments
Keeping in view that number of tunnels would be needed for overall development in hydropower, road, railway and metro sectors, it is planned to use mechanized methods and latest tunnelling techniques which would help in speeding up the work with much higher productivities as compared to manual working besides facilitating overall quality and safety. Boltec types of machines which are available for installing long rock bolts with good accuracy and faster speeds, even in locations difficult to access are also to be considered. Shotcreting machines with robot arm which are available for fast spraying of the shotcrete at various heights and in difficult locations, with very minimal ill-effect to the operator also results great benefits.

Adequate Contracting Practices
Keeping in view the delay and cost over runs being caused due to the inadequate contracting practices shall be looked in to seriously at the time of finalizing tender documents. The developers and also the Government should take the lessons from their previous experiences and prepare a Model Contract Document consisting of following to be used as guidelines for adoption in future projects.

(a) Standard Bidding Document Guidelines.
(b) Works Manual Guidelines
(c) Arbitration Manual Guidelines
(d) Schedule of Rates and Construction Cost Indices Guidelines
(e) Guidelines for grading of construction agencies

Site Clearances
In some of the projects, bids are invited before obtaining the statutory clearances. Even the Letter of Award of works is issued incorporating the completion period say 45 - 60 months stating that the period of completion starts from the day of receipt of the letter of award by the contractor. In such situations contractual problems arise resulting in delay and cost over runs. Efforts be made to ensure the statutory clearances are available before awarding of works.

Construction Materials
Various materials involved in the construction of tunnels such as supporting systems, grouting materials, concrete etc. should all be planned/procured well in time, as and when required and with appropriate quality. Adequate provisions should also be made to take care of special contingencies which may occur if geological surprises are encountered so that valuable time is not lost for lack of financial resources.

Financing
For large projects, it is important that financial setup be effected before commencement of the actual construction to ensure that proper cash flows are available at all times during the construction. Moreover, Govt. of India has also set-up special agencies for project finances.

Construction Agencies
Construction Industry in India is growing at a faster pace. Keeping in view the execution of large no. of projects for accelerated development of tunnel projects, sufficient agencies are not available in the country. To enable more construction agencies to enter in the field, Policies and procedures have been simplified by Govt. of India. With the change in policy and procedures, some international reputed companies have already started operation in India in recent past.

Documentation of Experience
On some of the recent projects, there has been collaboration with foreign agencies which introduced modern techniques and State-of-the Art equipment for construction of tunnels. On these projects, underground excavations have been carried out with ASTM technique using various kinds of rock support systems and deploying the most modern equipment which are available for Tunnelling. The experience gained on such tunnelling projects needs to be documented and made available to engineers all over the country so that appropriate guidelines can be evolved for future tunnelling works.

8. CONCLUSION
Tunnels are generally located in difficult environments in rocks of various types' hard or soft media and the alignment may traverse zones of various complexities. It is important that such engineering projects are properly conceptualized and planned systematically to ensure smooth implementation. It is also to be ensured that adequate investigations have been carried out, proper selection of tunnelling equipment has been made, appropriate contracting practices are available, statutory clearances have been taken, competent construction agencies are available, social issues have been taken care of and similar other issues are duly considered.

REFERENCES