A feasibility study for urban tunnelling in soft Tertiary sedimentary rocks of Mizoram, India

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Abstract: The 2.3 km long proposed Aizawl Traffic Tunnel in the northeast of India can be considered to be the first major venture of this kind in a densely populated urban hilly area in the country.

The proposed tunnel would be excavated through an interbedded soft sandstone/siltstone sequence of the Tertiary Surma Group. Based on a geotechnical assessment the paper concludes that the NATM approach with the use of roadheaders could be employed for tunnel construction with recommendation for pre-excavation umbrella support using spile-bolting. Determination of rate of penetration in drilling, specific rock energy index, abrasion value and compressive strength are among other parameters that need to be determined during investigation for making decisions regarding design and selection of equipment.

Dissemination of sound technical information to a highly literate population is considered to be of prime importance for avoiding controversial social issues.

Résumé: Le futur tunnel routier long de 2.3 kilomètres à Aizawl au nord-est de l'Inde, peut être considéré comme le premier projet d'envergure de cette sorte dans un secteur urbain densément peuplé du pays.

Le tunnel proposé serait excavé dans des couches de grès mou et de micro grès intercalées du groupe Surma tertiaire. Basé sur des évaluations géotechniques, l'article conclut que l'approche de « NATM » utilisant des excavatrices à attaque ponctuelle pourrait être retenue pour la construction du tunnel avec pour recommandation de mise à l'abri de la calotte du tunnel, une voûte parapluie renforcée par tire-fonds. La détermination du taux de pénétration dans le forage, de l'index spécifique d'énergie de roche, de la valeur d'abrasion, de la résistance à la pression, etc.. sont entre autres des paramètres qui doivent être déterminés pendant les études d'investigation afin de prendre des décisions cruciales concernant la conception et le choix de l'équipement.

Vu le taux élevé d'instruction de la population, la diffusion d'information technique saine en réponse aux questions fréquemment posées est considérée comme d'importance primordiale pour éviter les issues sociales controversées.

Keywords: Tunnel, drilling, excavations, sedimentary rocks, soft rock, engineering geology maps, Aizawal, India

INTRODUCTION

The idea of a traffic tunnel along the congested Aizawl city ridge (Figure 1) was raised by the Government of Mizoram in the year 2000 and a preliminary plan of sub-surface exploration by drilling was outlined at that time.

Figure 1. Urban congestion on the Aizawl Main Ridge.

In general, the Aizawl Traffic Tunnel (Figure 2) would be excavated in comparatively soft Tertiary strata comprising sandstone, siltstone and shale with their lithological variants. An important consideration for construction is the scarcity of good quality coarse aggregate for concrete in Mizoram. The strongest rocks known so far in the State are shelly limestone and calcareous sandstone – siltstone which have not been found to be suitable as concrete aggregate (Rawat and Parihar, 2001). The arenaceous rocks show vary poor soundness, low compressive strength, abrasion and crushing values. Coarse aggregate borrow areas in river terraces for the Dhaleswari Project in Aizawl District have been reported to be located as far away as 130-190 km (Anand, 1990).

In view of an overall high literacy rate, that is as much as 88.49% in Mizoram and 99.64% in Aizawl, it would be prudent to disseminate technically sound information on the Aizawl Traffic Tunnel Project to the population to maintain a good relationship with the project. A well informed and technically sound 'think tank' would be an essential part of the Project team to answer questions that might arise on subjects such as subsurface drainage, risk of subsidence and building damage, and traffic accidents or power cuts in the tunnel.

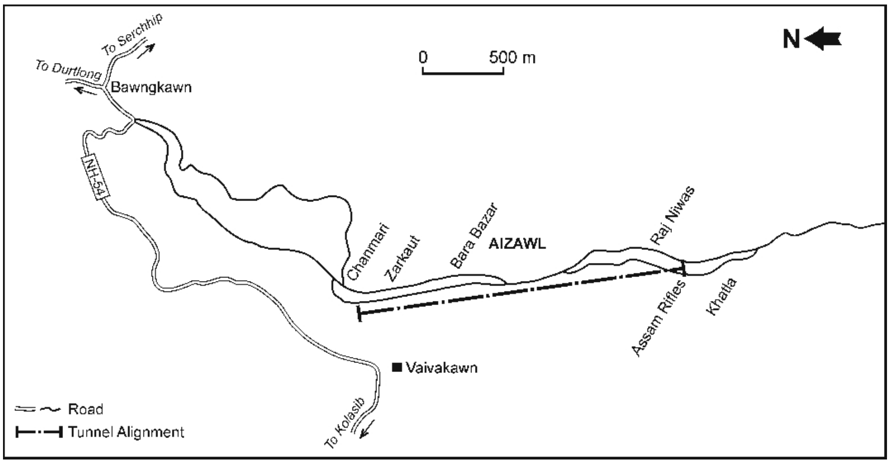


Figure 2. Layout of Aizawl City illustrating proposed traffic tunnel alignment.

An analogy can be drawn with the case of the mighty Tehri Dam across the sacred Bhagirathi River in Uttaranchal, which caused public fury throughout its construction due to apprehension about its safety against high Himalayan seismicity. A well planned public campaign prior to construction could have eased the situation and saved a considerable amount of time.

In the context of the proposed Aizawl Traffic Tunnel, it is worth recording that the Indian experience in urban tunnelling includes two newly commissioned major underground metro systems in Kolkata and New Delhi and smaller water supply and sewage tunnels in Mumbai. These three cases involve entirely different geological settings, viz. soft flood plain deposits of the River Hooghly at Kolkata (Sengupta, 1990), Archean Aravalli quartzites at New Delhi and the Cretaceous Deccan Traps in Mumbai. The local experience of investigation and construction of urban tunnels is therefore limited but quite varied.

SOFT ROCK TUNNELS IN INDIA

The case studies of projects executed in Tertiary formations in the Himalayan terrain, provide excellent information about the general features of tunnelling in soft rocks, that could be indicative of the ground conditions for the tunnelling project at Aizawl. The Siwalik and Murree Group of rocks in NW Himalaya, confined between the Indo-Gangetic alluvium towards south and the MBF (Main Boundary Fault) in the north, include several important hydroelectric projects. In the northeast, hydroelectric projects have been executed in the rocks of Surma Group and Disang Formation.

- Two parallel, circular tunnels (each 1.3 km long, 6.2 m dia), were driven through Upper Siwalik conglomerate and sandrock with subordinate siltstone, claystone and grit at the Khara Hydel Project (Rawat et al, 2001). The rocks have been folded into open antiforms and strike sub-parallel to the tunnel alignment with generally low dips. The tunnel excavation was by means of heading and benching using drilling and blasting (DBM). Steel supports at 50 to 75 cm spacing were provided. The main problems encountered included flowing ground conditions, over-break, cavities, squeezing conditions and low stand-up time requiring small pull and immediate support. The problems called for measures including close spaced forepoling, retention of faces by bulk-heads, quick-setting cement grouting, reduction of pull and cycle period, drainage to release pore pressure, back-filling of cavities with concrete, multiple drifting, reinforcement of supports by runners and bottom struts.
- Seven free-flowing tunnels (61-1896 m length, 2.13-2.43 m section) along the power channel of the Chenani Hydel Project have been driven in the Murree Group of rocks comprising alternate bands of claystone, sandstone and siltstone (Malbarna, 1986). Owing to the small size of the tunnels excavation work progressed without any major problems except for some heavy over-breaks in jointed strata.
- The Early Tertiary (Eocene) Subathu beds, lying between Nahan and Krol Thrusts, were difficult to handle at the Yamuna Hydel Project, Stage-II. The crumpled red shales and siltstone with subordinate quartzite and black plastic clay had very poor stand-up time and hence the excavation of the 9m diameter tunnel was formed either by heading and benching or by multiple drifts (Shome et al, 1979). Problems during tunnel execution included heavy over-breaks, squeezing problems leading to deformation of steel rib supports and flowing

ground conditions. However, the adverse tectonic setting is more to blame for the problems encountered than the soft Subathu strata.

- Poor rock cover, ingress of rain water, and minor swelling characteristics of clay shale led to a series of tunnel collapses at Ranjit Sagar Dam Project located in Lower Siwalik Formations (Pande and Andotra, 1990).
- For the 9m diameter proposed tunnels in Tertiary sedimentary strata (sandstone, siltstone, shale, claystone) at Tuirial Hydroelectric Project in Mizoram, the use “Q” and “RMR”classification systems were used and support comprising systematic bolting and shotcreting was recommended (Rawat and Parihar, 2001).
- At Doyang Hydroelectric Project in Nagaland, poor “Q” values of 0.007-0.305 and poor to fair “RMR” values of 10-52 were derived for the 12m diameter tunnel located in sandstone, siltstone, mudstone and shale of the Surma Group of rocks, along with squeezing ground conditions over a 100m length (Mazumdar, 1990).
- The 6.778 km long and 3.81 m diameter water conductor tunnel of Loktak Hydroelectric Project in Manipur, located in lake sediments, terrace deposits and sandstone, shale and siltstone of Disang Formation (Eocene), experienced problems of flowing ground, floor heave and squeezing ground (Choudhury and Chattopadhyaya, 1982) in addition to a methane gas explosion.

GEOLOGY OF AIZAWL

Aizawl and its surroundings have a rugged and immature topography. In general, the north-south aligned Aizawl Main Ridge from Bawngkawn in the north to Tuikhuhtlang in the south is a dissected cuesta type feature. The Ridge elevations vary around 1000m above MSL (Civil Hospital BM : El 1092.2 m). The Ridge has three main saddles, Bawngkawn in the north, Chanmari in the middle and Khatla in the south and three main lower transverse ridges. Two of these intersect at Tuikhuhtlang on either side. The western one, on which the Assam Rifles establishment is located, is being developed for the new Secretariat Complex and the Governor’s House. The third transverse ridge intersects at Chanmari area through Vaivakawn and Luangmual area.

The Aizawl Main Ridge comprises compact siltstone/fine sandstone, underlain by soft siltstone/shale (Rawat and Deva, 2001; Figure 3). The strata strike NNE-SSW in general and have low-moderate easterly dip (15°-40°). The strike ridge with its gentle dip slopes on the eastern side and the steep obsequent slopes in siltstone/sandstone on the western side, give rise to the cuesta landform. The gentle slopes in the soft siltstone/shale interbeds, with a marked break in slope with the overlying steep slopes in siltstone/sandstone, are conspicuous on the western side of the Ridge. Siltstone/sandstone beds occur conspicuously in the upper parts of the Aizawl Main Ridge and in the dip slopes on the eastern side while the soft siltstone/shale is exposed at lower elevations, such as in the Assam Rifles and Vaivakawn areas. Dip reversal, with somewhat steeper angle, is reported towards west, defining an antiformal structure with the area to the west of the Aizawl Main Ridge being an anticlinal valley. However, the major structural feature is an open fold and the rocks in the Aizawl Main Ridge have near uniform easterly dips. Highly disturbed bedding, seen locally in the weathered sandstone, is interpreted to be the result of rock creep or flexure folding, rather than tectonic folding (Figure 4). The Geology & Mining Wing of the Industries Department has interpreted a few faults running both along and across the Ridge.

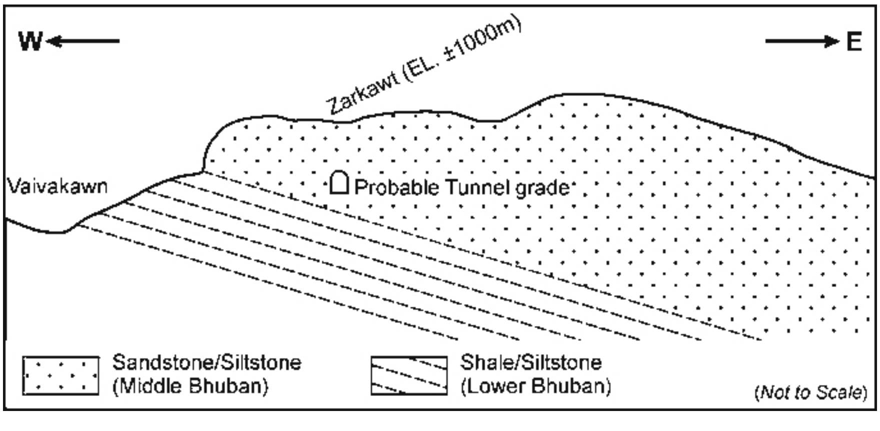


Figure 3. Interpreted geological section across Aizawl Main Ridge.

Surperficial deposits comprising residual soil and slopewash seems to be thin but the effects of weathering may extend to some depth.

The rocks of the Aizawl Main Ridge belong to the Bhuban Sub-group (Lower and Middle Bhuban Formations) of the Tertiary Surma Group (Figure 5) forming a part of the Aizawl-Sialsuk Anticline. The Fold Mountain Belt involving Surma Group of rocks constitutes the eastern part of Tripura-Mizoram depositional basin (Nandy and Sarkar, 1973). From a regional point of view, the structure and lithology of the Surma Group of rocks forms a homogeneous domain that is broken by local structural geometry at places such as the Serchhip-Thenzawl area (Bannerjee et al, 1977).

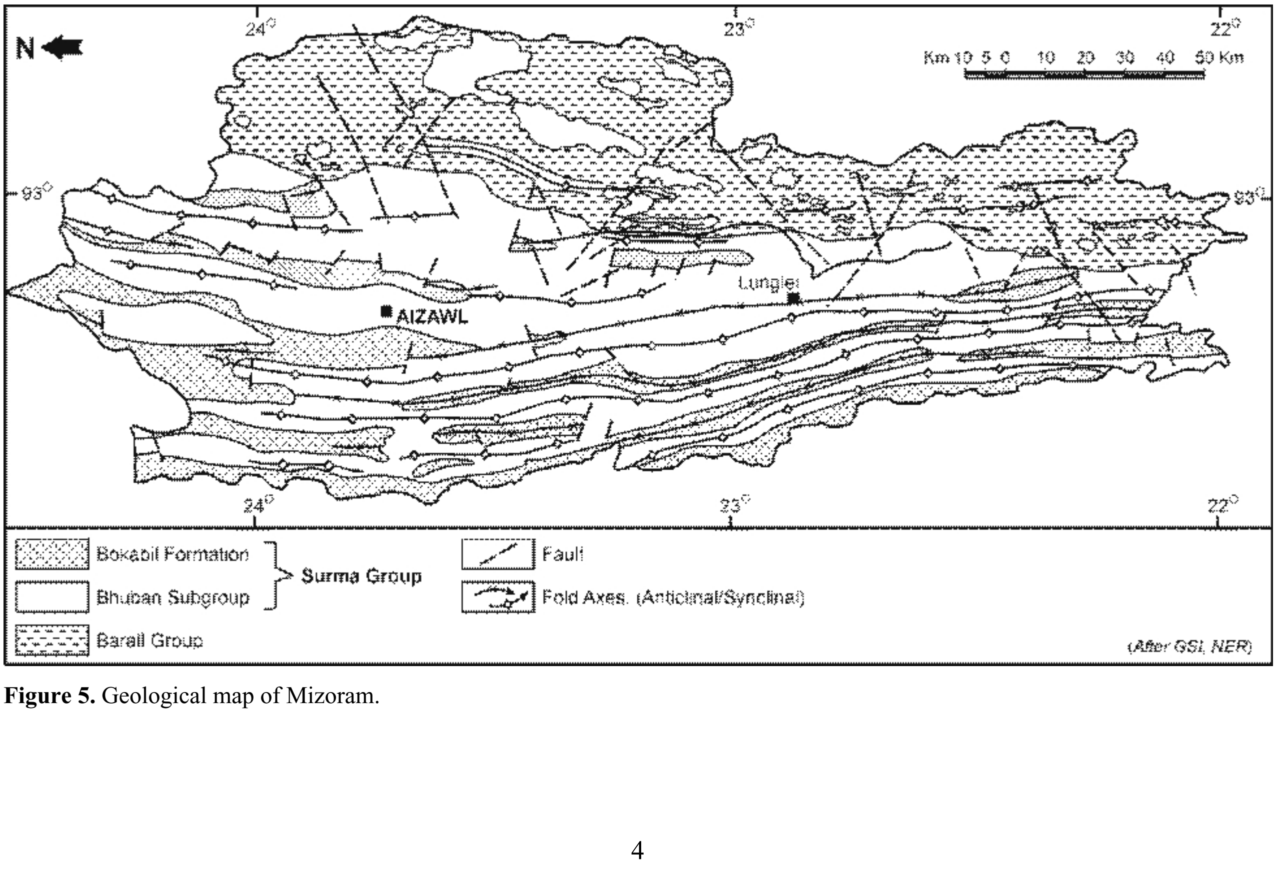
While the Middle Bhuban Formation is predominantly arenaceous comprising medium to fine grained, compact, well-bedded sandstone and siltstone with interbedded silt/shale interlaminated units, the Lower Bhuban Formation is predominantly argillaceous and includes moderately compact medium to fine grained sandstone with shale and silt/shale intercalations.

The area around Aizawl has been affected by faults of varying magnitude. These are longitudinal, transverse and oblique (Jaggi, 1986). Besides the predominant bedding joints, vertical to steeply dipping joints dissect the strata. In the Bawngkawn-Chanmari area, sets of joints include N 070°/steep, N 340°/vertical to steep and, in the Arm Veng area, the joint sets include N 010°/vertical and N 305°/steep.

The area receives very high rainfall of about 250cm per annum. Numerous springs have been recorded at different altitudes in the area (Jaggi, 1986). The discharge of water varies from spring to spring – mere seepage to about 3 lpm – and, in general, the discharge rate decreases from December to April. The river Tlawng, supplying water to Aizawl city through pumped lifting, has considerable discharge throughout the year (3-5 cumec). The sandstone beds, in general, may be expected to be holding large volumes of ground water, specially along contacts with argillaceous beds.

Figure 4. Flexure folding in sandstone, Assam Rifles area.

From the seismotectonic viewpoint, the northeast of India and its surroundings are tectonically complex and are considered among the most seismically active intra-continental regions of the world (Rawat and Parihar, 2001). Some of the largest known earthquakes, up to 8.7 magnitude, have occurred here. Seismicity is related to plate subduction in the east of Mizoram while northwards it is intra-continental and caused by adjustments along steep faults oriented oblique to the Himalayan trend. The east - west compressive stress field of Indo-Burma origin and directed from the east is believed to have deformed the rocks by folding, strike faulting and adjustments along conjugate shear fractures.



(After GSI, NER)

Figure 5. Geological map of Mizoram.

TUNNEL LAYOUT

The available background geological information is a reasonably good criterion for selecting the preliminary layout of the proposed 7m x 5m Aizawl Traffic Tunnel. In all likelihood, the tunnel would pass through the arenaceous interbedded sandstone/siltstone rocks of Middle Bhuban Formation. The fixed portal locations would leave little scope for adjustments of tunnel layouts on geological grounds. The site conditions are expected to permit the following options and constraints for the selection of the tunnel layout.

- Location of the north and south portals of the tunnel in the saddle areas in Chanmari and Khatla areas, respectively allows the tunnel to bypass the main present day traffic bottlenecks. The tunnel length would be around 2.3 km. However, in view of the expected future expansion and development of the city, the option of placing the north portal in the saddle area at Bawngkawn and increasing the length of the tunnel by about 1.5 km may be considered by the town planners on the basis of traffic density and flow. A straight tunnel alignment would be slightly skew (10°-15°) to the strike of the strata and, therefore prone to tunnelling problems associated with longitudinal weak rock zones such as shears and major joints that would persist for longer distances due to their sub-parallelism with the bedding of the rock. On average, the tunnel would be located about 30-40m below the ground level.
- Outward gradients of the tunnel from both the portals would allow drainage of the tunnel under gravity both during construction and operation. The importance of this aspect was demonstrated by an incident at the Dul Hasti Hydroelectric Project in Jammu & Kashmir where the unconventional upstream (outward) gradient at the inlet end of the TBM driven Head Race Tunnel was a major saving factor during an artesian blowout (Deva, 1994).
- An emergency exit tunnel could also serve as a construction adit on either side of the tunnel, somewhere in the middle of the alignment to the south of Bara Bazar. This adit, besides providing two additional working faces during excavation, would allow easy access to the tunnel for pedestrians and the maintenance crew. Like the main tunnel, the adit should also have an outward gradient. For the same reason, the working faces of the tunnel from the adit, should have gradients towards the adit junction.
- Physiographically, the Ridge slopes would permit location of adit portals on either side and adits may be provided on both sides of the Ridge for the convenience of pedestrians. The length of the adits is estimated to be about 300m.

From the above, it emerges that the tunnel could be driven at an upward gradient from the terminal portals at Chanmari and Khatla, and also from the adit junction towards the working faces on both the sides. The finished tunnel, therefore, would have a siphon-like gradient – rising from the end portals and then going down towards the adit junction (Figure 6-a).

Alternatively since the tunnel length is only about 2km, it could be excavated with only two working faces at the terminal portals. The outward gradients would result in a simple inverted-V type tunnel profile (Figure 6-b).

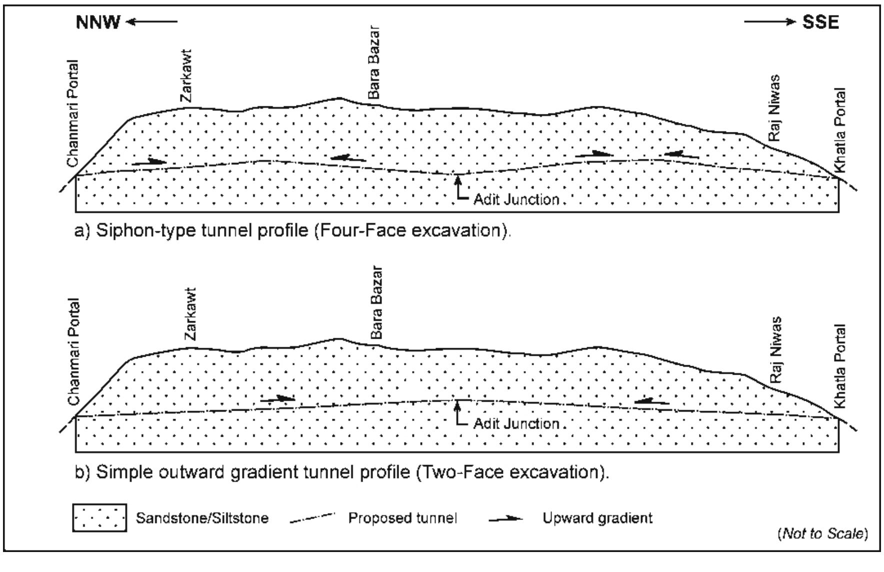


Figure 6. Geological section illustrating alternative profiles of the proposed traffic tunnel.

The tunnel gradients may be kept as gentle as possible for facilitating traffic movement as well as allowing drainage under gravity. A gradient of 1:300 to 1:500 may be considered.

INVESTIGATION

The targets for the geotechnical investigations of the tunnel may include:

- Detailed engineering geological mapping of the Aizawl Main Ridge on 1:5000 scale for overall geological perspective and discontinuity data information. Identification of shears and faults will require utmost attention. Remote sensing techniques (aerial photographs and satellite imageries) may be used for identifying structural lineaments and continuity of major lithological units.
- Interpretation of the geological section along the tunnel alignment with particular reference to the thickness of different lithological units close to the tunnel grade. This would require sub-surface exploration through core drilling that would include cyclic water percolation tests and Standard Penetration Tests (SPT). Selection of drill hole sites along the tunnel alignment may face limitations due to traffic and buildings and may therefore not be located exactly on the alignment.
- Rate of drilling penetration, or determination of specific rock energy (Izquierdo and Chiang, 2004), could serve as an important criterion for selection of plant for excavation.
- In view of the limitations in drilling, exploration through drifts may be an attractive proposition. The X-drifts from the Ridge side, following the emergency adit alignments, may provide excellent data regarding both the geotechnical features and the working conditions during execution. Two other drifts could be driven from the end portals of the main tunnel in the Chanmari and Khatla areas.
- Geophysical surveys could provide vital information regarding sub-surface conditions. Resistivity surveys would be helpful in deciphering highly water bearing zone and seismic refraction surveys would indicate the strength of the rock in terms of seismic velocities. However, in view of the interbedded soft and hard rock units, the underlying softer units may get suppressed by the overlying harder units during seismic surveys. Considering the requirement of at least 3-X spread for the geophysical surveys, these may have to be carried out along the road at night. Further, for seismic surveys, a weight-drop technique may have to be used in place of explosives in view of the sensitive social fabric of the area.
- Physio-mechanical properties of the rock such as compressive strength, tensile strength, Young's Modulus, abrasion value need to be determined as design parameters.
- Based on the data collected, the tunnelling media would be divided into rockmass classes for deciding corresponding support systems – both primary as well as permanent. The regional geological setting favours rockmass classification using RMR (Bieniawski, 1974) rather than the more universal Rockmass Quality “Q” (Barton et al, 1974).

TUNNEL EXCAVATION

The depth of tunnel excavation, more than 30m, is of paramount importance in taking a decision regarding the preferred mode of excavation technique and installation of supports – both primary as well as permanent – with factor of safety kept at a high level.

Considering the shallow depth of the tunnel, delicate social fabric and existence of old buildings above the proposed tunnel, it would be advisable to avoid conventional modes of tunnel excavation by drilling and blasting (DBM). The soft lithological assemblage of the Bhuban Sub-group in the Aizawl Main Ridge, could be an ideal sub-surface media for excavation using roadheaders. If the tunnel excavation is planned using four working faces – two from the end portals and two from a central adit – it may necessitate deployment of four roadheaders that could be an expensive proposition for a short tunnel, unless the redeployment of the machines is dovetailed with some other project. As an alternative, a single machine may be deployed at the adit end for handling excavation at both the working faces thereby saving expenditure on one machine. Excavation from two working faces would require only two machines.

SUPPORTS

Simultaneous support erection and lining would be the key to a smooth and incident-free tunneling operation. The need for a high level of safety would permit no compromise on design and implementation of support systems.

In general, the application of NATM (New Austrian Tunnelling Method) could be an economical and practical approach to the execution of the Aizawl Traffic Tunnel. The method involves creation of a load-bearing ring of supported rock around the excavation, where the ground itself becomes an integral part of the support system. In general, steel supports are not used in this method and rockbolting and shotcreting form the main support elements.

To begin with, pre-excavation umbrella coverage for the overt portion of the tunnel may be provided through spile bolting or forepoling in the usual 3m long segments. The spacing of spile bolts would conform to the rock condition. The consecutive spile-bolted or forepoled segments would have appropriate overlap.

For a 3m long segment under umbrella support, excavation may be carried out for an approximate 2-2.5 m length by road-header, followed by erection of primary supports in the form of shotcreting, rock bolting and, if necessary, steel supports. These methods may have to be used in isolation or in combination depending upon the rock condition. For reinforced shotcrete, use of steel fibres may be considered as an alternative to coarse aggregate, for which there are few quarry sources within a reasonable haul distance.

Provision of bulk-heads may have to be maintained to counter flowing ground conditions that could occur in water bearing shear zones or crush zones along faults, particularly in siltstone and shale beds.

As far as possible, the permanent supports, concrete lining and consolidation grouting, wherever necessary, should follow the excavation sequence as closely as possible.

CONCLUSIONS

In general, the proposed Aizawl Traffic Tunnel would be excavated through interbedded Tertiary sandstone/siltstone of the Middle Bhuban Formation of the Surma Group. The strata occupy the upper portion of the Aizawl Main Ridge, a dissected cuesta type landform. The tunnel can be driven from the two terminal portals with an upward gradient facilitating drainage under gravity – both during construction as well as in operation. Excavation by roadheaders may be preferred to drilling and blasting in the urban environment. Tunnel construction through NATM is recommended for which the support systems would be primarily shotcreting and rock bolting. Pre-excavation umbrella support through spile-bolting may be advisable.

Besides detailed engineering geological mapping and sub-surface exploration through drilling and geophysical surveying (resistivity and seismic refraction), excavation of drifts at portal locations may provide crucial geotechnical information. Rate of penetration in drilling, specific rock energy index, SPT, compressive strength and abrasion value are amongst the parameters that are required to be determined for designing the structure and for selection of roadheaders.

In view of the high literacy rate in the project area, dissemination of sound technical information about critical social issues is of paramount importance and needs to be addressed by a professional team right from the beginning.

Finally, it should be kept in mind that "a stitch in time saves nine", or, in the present context, it would be more apt to say that "a minute spent in support erection saves nine in corrective measures".

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