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# Geomechanical Studies for a Himalayan Tunnel in Jointed Dolomites: A Case History

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SYNOPSIS :Reported case history of Himalayan tunnel reveals that Barton's and Bieniawski's classification systems provide better assessment of the rock mass behaviour. The design and shear strength parameters derived from these classifications provided a preliminary design of the tunnel, which has been critically evaluated with the design, adopted at site. Based on the structural feature and ground water conditions, a number of tunnelling conditions have been predicted. The studies indicated the loosening rock pressures would be occuring at site with an estimated range of 0.25 $kg/cm^2$ to 3.58 $kg/cm^2$. Problems of roof collapse, flowing ground condition and cavity formation may occur during the excavation. Multiple drift excavation method is suggested for extremely poor conditions.

## INTRODUCTION

Tunnelling is an essential part of any hydro electric project, located in the Himalaya for the transfer of water from one basin to other. Due to the rugged and inhospitable nature of the terrain, it is usually not possible to conduct thorough investigations along the tunnel alignments. Thus, many hydro electric tunnels lack sufficient design data. The use of rock mass classification systems for the tunnels under such condition serve better purpose for their preliminary design.

The present case history is of a typical Himalayan tunnel, where the application of rock mass classification systems formed a major part of the geomechanical studies conducted for the evaluation of tunnelling conditions, assessment of rock mass behaviour and the support requirements.

The tunnel in question is a horse shoe shaped tail race tunnel at Salal Hydro Electric Project, Stage-II, located in the northern most state of India. This 11.0m dia tunnel is under construction for a length of about 2.60Km in the single litho unit of dolomitic rocks. A layout plan of the project reveals the location of tail race tunnel-II (TRT-II), which is aligned parallel to and at a distance of 100.0m from TRT-I of earliar stage (Fig. 1).

## GEOLOGY AT PROJECT SITE

Tail race tunnel-II is located in dolomites, which have been highly tectonised due to their close proximity to Main Boundary Fault. The fault separates the younger Tertiaries from older rocks. The dolomites at Salal are basically crystalline, grey to greyish white or buff in colour and are massive as well as blocky to highly jointed with joint spacing, varying 5cm. to 100cm. The geology expected to be encountered along the alignment had been projected from those encountered in tail race tunnel-I (Fig.2.0).

Three prominent joint sets are identified in the project area. The bedding joints are predominant and dip 50° to 60° towards North to North-West direction, whereas, the cross joints with similar strike dip 20° to 30° in the opposite direction. Third prominant set is steeply dipping transverse joints with East or West direction. Shear zones of various thicknesses, mostly along the prominant joints are containing highly crushed rock and gougy material.

Based on the physical and structural properties of the dolomites, the following four types have been identified.

Cherty Dolomites are characterised by their greyish white colour, massive appearance and widely spaced bedding joints (0.3 to 1.5m). Presence of quartz/chert bands along the bedding is common.

Blocky dolomites are greyish and massive with widely spaced bedding joints. Few irregular discontinuous cross and transverse joints are also exposed in rock.

Highly Jointed Dolomites are dark grey in colour and are traversed by closely spaced dominant joints. Presence of shear zones and shear seams of varying thicknesses are very common especially, along bedding plane.

Crumbly and Sheared Dolomites are infact, thick shear zones, extending few metres within highly jointed dolomites. This has been identified as the most troublèsome tunnelling media of all the four types.

For the purpose of contracts and support design of the tunnel, the first two categories are combined to make three main types of dolomites at site:

Category I :Cherty, massive and blocky dolomite
Category II :Highly jointed dolomite
Category III:Crumbly and sheared dolomite

## TUNNELLING CONDITIONS

The tunnelling in the soft rocks of Himalaya with adverse geohydrological condition poses a number of problems such as squeezing condition, flowing ground condition, cavity or chimney formation and roof collapse etc. In absence of subsurface investigations, the extent of such problems can not be assessed even if the problems are known to occur prior to excavation.

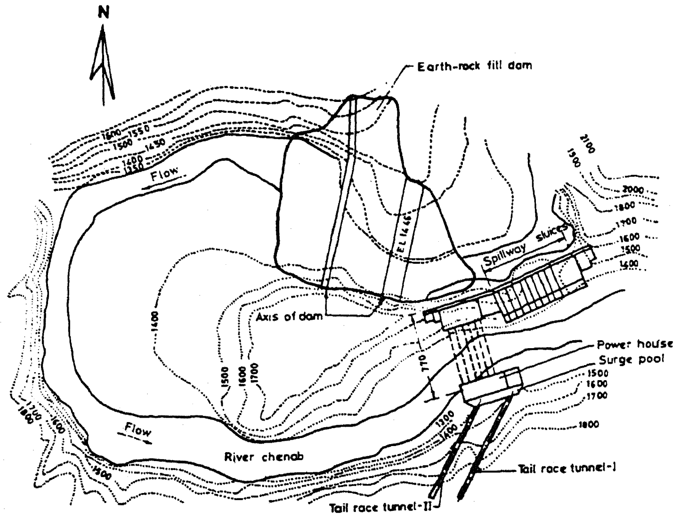
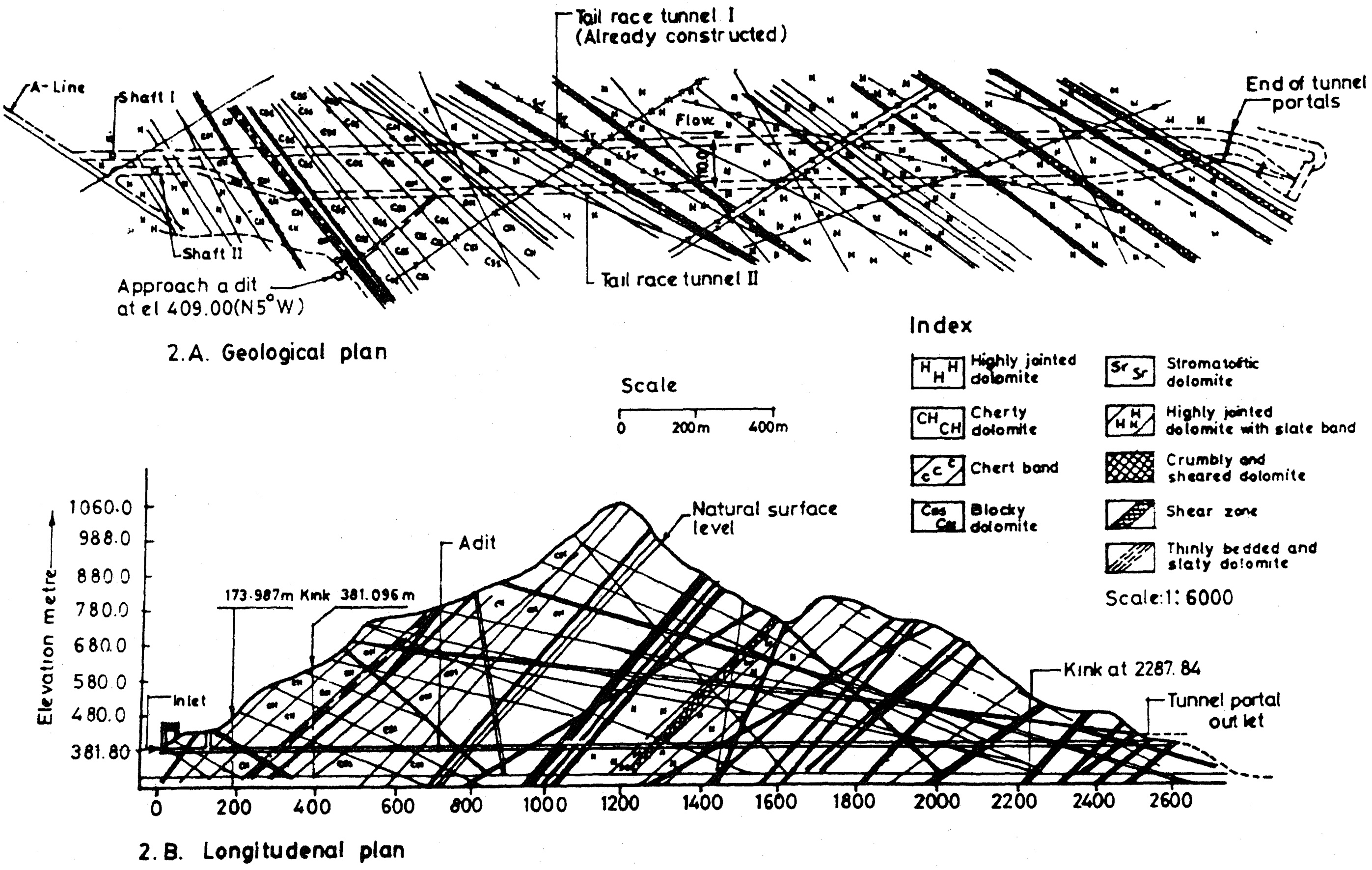


**Fig. 1: Layout Plan of the Project.**

This causes delay in early completion of tunnel and adversely affect the cost of the project. It is thus, essential to conduct a thorough investigations to get exact information on subsurface geology so that proper excavation strategy and design of the underground structure can be planned. However, most often, the detail geological exploration and investigation plan are not materialised because mostly these structures in the river valley projects of Himalayan region are located in deep gorge with steep slopes and have no accessibility for any kind of detail investigation. Thus, underground openings are aligned mainly based on the surfacial mapping and scanty borehole data.

The excavation of tail race tunnel-II is undertaken at a time when stage-I has already been completed and commissioned. The additional geological and geotechnical informations made available from the underground excavations of Stage-I were useful for the design and the plan of excavation strategy of TRT-II. The troublesome reaches in the tunnel were marked by projecting their locations from TRT-I. At few locations, some of these features were either not encountered or met at shifted locations due to the uncertainity and complexity in the rock mass. Under these condition, the use of geophysical techniques plays a major role in delineating the shape, size and extent of the features. However, this technique could not be used in the present case due to unfavourable site condtions.



2.A. Geological plan

2.B. Longitudenal plan

**Fig. 2: Geological Plan and Section of tail race tunne1-II**

### Rock Pressure Condition

The rock mass at site with high degree of fracturing may cause loosening rock pressure on the support of the tunnel. Such a rock mass may present flowing ground condition, if charged with excess water.

Based on the interpreted geology of TRT-I, the percentage of each category of rock mass to be encountered was calculated. Fig.3 indicates that 65% of the tunnelling would be in fair media as compared to crumbly and sheared dolomites, which is a poor tunnelling media and would be about 12% along alignment. 23% of the rock would be good and may have low rock pressure.

Tunnelling through highly fractured rock mass with considerable water head may cause squeezing pressure on the support at some reaches, under the high rock cover i.e. exceeding 300m. Swelling pressure may occur locally in the shear zones with expansive clay minerals. Assuming loosening rock pressure snall be acting on the tunnel support, the rock pressures by various empirical methods have been calculated.

### Ground Water Condition

Ground water in the jointed dolomites is basically fed by Chinab river and through precipitation. The water seepage through TRT-I is also seems to be contributing to the rock mass. The moderate to highly jointed dolomites are known for ground water reservoir.

One of the primary effects of the underground excavation in rock is flow of water into the tunnel through joints, causing hindrence to smooth working of construction. In addition, the water flow induces rock instability by eroding soft infilling material thus, reducing the effective stress of joints.

The water seepage in TRT-II may vary from light seepage to profuse water flowing. The highly jointed dolomites may encounter medium to heavy water seepage. Heavy water flow under moderate pressure may be expected in some reaches of crumbly and sheared dolomites. The low or no permeability value of infilling materials, mostly clays, in shear zones may act as barrier for the underground water, which may enter into tunnel under pressure on excavation.

### Tunnelling Condition

The tunnelling through highly jointed dolomites may give rise to a problem of overbreaks and rockfall due to intersection of closely spaced transverse and cross joints with bedding joints. Flowing ground condition and chimney formation may also occur within this category of rock due to increase in joint intensity. Three dimensional geological records of earliar tunnel has been useful in identifying the locations of cavity formation and flowing ground condition for TRT-II, thus saving time and money by having information beforehand. On the contrary, cherty, massive and blocky dolomites may provide good tunnelling media due to its quality. Nevertheless, minor rock failure may take place wherever the cross joints are well developed and intersect bedding joints at the crown. In addition to tunnelling problems like overbreak, cavity formation, flowing ground etc, squeezing condition is also likely to be met in crumbly and sheared dolomites under high rock cover.

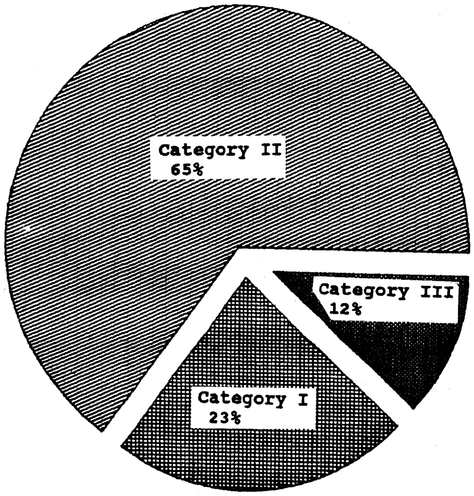


**Fig. 3: Percentage of different dolomites along alignment of the tunnel.**

### ASSESSMENT OF ROCK MASS BEHAVIOUR

The qualitative description of rock mass does not help in generating data for the design of tunnel support and lining. Definite quantities of rock load and modulus of deformation are required for their preliminary design. The use of rock mass classifications had been in use since Terzaghi (1946) proposed his classification of rock tunnel engineering. Terzaghi's classification was based on qualitative description of rock masses hence, it had a greater scope for personal bias. Later, many workers coined their semi quantitative to quantitative ideas for classifying the rock mass. Of these, the classifications proposed by Bieniawski (1973) and Barton et al (1974) are accepted and being used throughout the world. At many projects, they form the only practical basis for the design of the underground excavations.

They proposed independent classifications wherein a particular rock mass parameter had been assigned a numerical rating. This had quantified the concept of rock mass behaviour and helped in numerically assessing the rock pressure, modulus of deformation and shear strength parameters.

Bieniawski's and Barton's approaches had been used in estimating the rock pressure for various categories of dolomites (Table-I). In addition, Bieniawski's method was also utilised for obtaining modulii of deformation as well as for the cohesion and angle of internal friction of dolomites (Table-II).

The rock pressure had also been calculated by Block Theory (Goodman and Shi, 1985). As it is a well known fact that rock joints and discontinuities in a rock mass play an important role in the design and stability analysis of underground opening. Goodman and Shi (1985) developed the key block theory based upon joint information for determining the structural stability and support design. Two key blocks were identified by means of all permutations and combinations of joint sets for an excavation of 12m span. Internal friction angle of 45°, zero cohesion and average unit weight of rock 2.84 gm/cc yielded a rock pressure value of 0.25 kg/cm$^2$ for the rock mass with zero water pressure. Similarly, the dolomites, under moderate water pressure i.e. 2 kg/cm$^2$ would have rock pressure of about 2.25 kg/cm$^2$.

The maximum value of rock pressure for extremely poor rock mass, although not common, were considered as high as 4.00 kg/cm$^2$. The analysis for the walls indicated the blocks formed on the walls are stable and have no lateral pressure.

**TABLE-I:Rock Pressures in kg/cm$^2$ for Salal Dolomites by Various Methods**

| Rock Types | Terzaghi's Method | Bieniawski's Method | Barton's Method | Block Theory |
|---|---|---|---|---|
| Category-I:<br>Cherty & Blocky Dolomites | 1.70 - 2.3 | 0.44 - 1.13 | 0.31 - 1.14 | 0.25-2.25 |
| Category-II:<br>Highly jointed Dolomites | 2.30 - 7.40 | 1.46 - 2.35 | 1.30 - 2.21 | 0.25-2.25 |
| Category-III:<br>Crumbly and Sheared Dolomites | 7.40 | 2.35 - 3.03 | 2.01 - 3.58 | 0.25-2.25 |

**TABLE-II:Design Parameters for Salal Dolomites, Based on Bieniawski's Approach (1973)**

| Rock Types | RMR | Tunnelling Media | Cohesion (kg/cm$^2$) | Internal Friction Angle (°) | Deformation Modulus (x10$^6$ kg/cm$^2$) |
|---|---|---|---|---|---|
| Category-I:<br>Cherty & Blocky Dolomites | 67-87 | Good | 3 - 4 | 35 - 45 | 0.34 -0.74 |
| Category-II:<br>Highly jointed Dolomites | 31-57 | Poor to Fair | 1 - 3 | 15 - 35 | 0.034-0.14 |
| Category-III:<br>Crumbly and Sheared Dolomites | 11-31 | Poor to Very Poor | ≤1 - 2 | ≤15 - 25 | 0.011-0.34 |

## SCUSSION OF RESULTS

ious design parameters estimated by irical approach can be used for the liminary design of TRT-II. Table-I reveals a ge of rock pressures obtained by various hniques. The rock presure values, based on zaghi (1946) are on conservative side and .ms to be very high for the rocks at site ıs, they are not considered for the tunnel.

The rock pressure values obtained by Bieniawski's and Bartons methods are more realistic because the most of the parameters responsible for assessing the rock mass quality are taken into account by the them, thus the values are more reasonable for the tunnel design. The range calculated by Bieniawski is 0.44 to 3.03 kg/cm$^2$ whereas, the values based on the Bartons range from 0.31 to 3.58 kg/cm$^2$. Based on Goodman's Block theory the jointed dolomites with zero values of cohesion and water pressure would exert support pressure of 0.25 kg/cm$^2$ for an excavation of 12m diameter whereas, dolomites with cohesion of 0.5 kg/cm$^2$ and water pressure of about 2 kg/cm$^2$ would give a support pressure of about 2.25 kg/cm$^2$. The internal friction angle in both cases is assumed to be 45°. Thus a range of 0.25 to 2.25 kg/cm$^2$ is obtained by the Block Theory.

Table-II indicates dolomites to be met along the alignment vary from good to very poor rock. Highly jointed dolomites may vary from fair to poor rock, whereas the most weakest category among all does varies from poor to very poor tunnelling media.

The standup time for cherty and blocky dolomites may be one year for 10m span whereas, highly jointed rock mass may have 10 hours for 2.5m span. However, under most favourable circumstances it may be slightly better i.e. upto one week for 5.0m span. The crumbly and sheared dolomites may have a standup time of about 30 minutes for one metre span, which may be for the worse rock mass within category-III. 77% of rock mass belonging to category-II & III would be met in the tunnel for which average stand up time varies 30 minutes to 10 hours. Rest 23% of tunnelling would be in category-I which is self supporting and has stand up time of about a year for 10m span. Thus the excavation in this category may not require support except a layer of shotcrete and occasional rock bolts in the crown to avoid any wedge formation.

The values of shear strength parameters and modulus deformation as revealed in Table-II are recommended for the final support design including lining.

## SUPPORT REQUIREMENTS

The location of TRT-II is about 100m inside the rock from the TRT-I, where the extent of weathering is expected to be less as compared to TRT-I or even it may be absent. Thus, it can be understood that the overall tunnelling media would be better than that of TRT-I. Keeping in view the experience of TRT-I, the following supporting system was designed by the project authorities for the TRT-II.

The support design for category-I involves systematic rock bolting followed by 50-100 thick shotcrete with wire mesh. The rock bolts are 3500mm long, 25 ɸ @ 2000mm C/C staggered both ways.

Category-II envisages steel rib support ISHB 200x200 @ 1000mm C/C and packing with initial concrete behind the precast slabs.

Category-III envisages steel rib support ISHB 200x200 @ 500mm C/C and packing with initial concrete behind the precast slabs.

The above supporting system is a combination of steel arch section and rock bolt with shotcrete for tunnelling condition varying from good to fair to poor rocks. The design and strength parameters derived from the studies, have been used to evaluate the supporting system being adopted at site.

Keeping in view the above design and availability of the supporting material, a support system has also been worked out based on the Bieniawski's approach. The method used is more practical and suitable for the tunnels under Indian conditions because they are mostly supported either by steel section only or in combination rock bolt and shotcrete. On the contrary, the Barton's approach provide only combination of rock bolts and shotcrete as a supporting system and have yet to win the confidence among indian designers and engineers.

Table-III reveals the supporting system and method of excavation, recommended for the tunnel. It should be noted that the support system suggested by Bieniawski is for a maximum 10m width of tunnel. The excavated diameter of the stage-II tunnel is approximately 12.0m. Thus a little modification to the supporting system in Table-III is to be made as per the site condition. The support system as well as the excavation method being adopted at site is more or less the same as suggested by Bieniawski's approach. Although for category-II, steel set alternative is not considered by him.

Regarding the loosening of surrounding rock mass due to the opening of joints and fractures near the excavated profile, it was recommended to spray a thin layer of the shotcrete immediately after the excavation so as to limit the extension of rock mass loosening around opening.

### Excavation And Support System For Critical Reaches

For the critical reaches, it was recommended to consolidate failed rock mass by adopting umbrela grouting at the tunnel face as soon as any sympton is seen on the face. Forepoling should follow after grouting. Then after excavation by multiple drift system should be employed for the heading portion of the tunnel. The rib errection should be carried out simultaneously. During the excavation of TRT-I, some critical reaches were excavated through by adopting a number of techniques such as pre-grouting, pre-drainage, shorter pulls with controled blasting, close ribbing and shotcreting etc. These techniques can be employed with more efficiency in the TRT-II.

## CONCLUSIONS

The geomechanics studies conducted for the tunnel indicate that the rock pressures to be borne by the supports are of loosening type. The highly fractured and sheared rock mass charged with water, under the high rock cover may give rise to squeezing condition. Minor Seepage to profuse water flowing condition may occur. Roof collapse, cavity formation, and flowing ground may be met during the excavation in the poor rock.

Bieniawski and Bartons methods provide better assessment of the rock mass behaviour for the Himalayan tunnels under adverse conditions. The rock pressure range obtained can be used for the preliminary design as well as for the modification of the supports. However, these are short term rock pressure.

Modulii of deformation and shear strength parameters obtained for various categories of dolomites are reasonable for the rock massess at site and may be used for the designing the final lining.

Heading and bench method of excavation is most suitable for the tunnel. Multiple drift method can be employed for the extremely poor condition of dolomites. Providing of Drainage holes and use of forepoling at the tunnel face, can be useful for improving the tunnel progress in the poor rock condition.

**TABLE-III:Support System for Tail Race Tunnel-II, Based on Bieniawski(1973)**

| Rock Types | Support | | | Excavation Method |
|---|---|---|---|---|
| | Rock Bolts (dia 25 ϕ) | Shotcrete | Steel set | |
| Category-I | Locally Bolts in crown, 3m long, spaced 2.5m with occasional mesh | 50mm in crown where required | None | Full face 1.0-1.5m advance complete support 20m from face |
| Category-II | Systamatic bolts, 4m long spaced at 1.5-2.0m in crown and walls with mesh in crown | 50-100 mm in crown, 30mm in sidewalls | None | Top heading & bench 1.0-1.5m advance in heading. Install support concurrently with excavation 10m from face. |
| Category-III | Systamatic bolt, 5-6m long spaced 1-1.5m in crown and walls with wire mesh. bolt invert | 150-200mm in crown, 150mm on sides and 50mm on face | Medium to heavy ribs spaced 0.75m with steel lagging and forepoling, if required. close invert | Multiple drift. 0.5-1.5m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting. |

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