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Tunnelling through weak and fragile rocks of Himalayas

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ABSTRACT

A considerable amount of tunnelling has been going on in India for various projects such as hydroelectric power, irrigation, roads and railways. Most of these projects are located in Himalayas, far away from the urban areas. Tunnelling through weak and jointed rock masses such as the one in the Himalayas is a challenging task for the planners, designers, engineers and geologists because of high overburden, thickly vegetated surface, weak, poor and fragile rocks and highly varying geology with the presence of numerous small and big shear zones, faults, etc. Due to these reasons, various tunnelling problems have been faced in the past and are still being encountered. Failures and the problems may be regarded as challenges and opportunities for generating new knowledge base and thereby increasing self-reliance in tunnelling. The experiences of Himalayan tunnelling through weak and fragile rocks covering varying and mixed geology, understanding on tunnelling in squeezing ground conditions and applicability of TBM in Himalayas are presented. It has also been highlighted that the probe holes planning, drilling and monitoring shall be followed seriously to reduce the geological surprises.

1. Introduction

Numbers of project involving the construction of tunnels are coming up in India for hydroelectric power, irrigation, roads and railway projects. Main emphasis now is to complete the project either before or as per schedule. With time new methodologies and techniques of tunnelling have been developed. These techniques helped in achieving the desired rate of progress in fastest possible time without much accident and tunnelling problems. Indian designers, scientists and engineers have successfully completed many tunnelling projects in the past, working on new projects currently and planned several such projects to meet out the future demand.

In good and hard rocks, the art of tunnelling has evolved into a science of tunnelling. In weak and poor rocks, on the other hand, tunnelling is in the phase of a mix of art and science.

Tunnelling through weak and jointed rock masses such as in the Himalayas is a challenging task for the planners, designers, engineers and the geologists because of high overburden, thickly vegetated surface, poor rocks and highly varying geology with the presence of numerous small and big shear zones, thrusts, faults, etc. Due to these reasons, the geology ahead of the tunnel face sometimes is not known correctly and tunnelling problems such as squeezing ground condition, chimney formation, face collapse, water in rush, etc. have been faced in the past and are still being encountered.

Himalayan region, therefore, may be regarded as best field laboratory to learn rock mechanics and tunnelling technology for poor and weak rock masses under high stresses. Some of the experiences are briefly highlighted in this paper.

2. Variation in geology-weak rocks affected by fault and shear

2.1. Alternative tunnel alignment

In earlier hydroelectric projects through the Himalayan rocks, in absence of the geological investigations up to the tunnel grade, the straight tunnel alignment between the inlet and the outlet location was chosen. The straight alignment, quite often, had to be changed while constructing the tunnel because of various problems. For example, in the head race tunnel of Maneri–Uttarkashi Stage-I project, India the tunnel had to be diverted because of the water-in-rush and chimney formation. Three alternative tunnel alignments were considered as shown in Table 1. But finally alternative at No.5 in Table 1, i.e., 'New Alignment' was followed to complete the tunnel. This problem had led to time and cost over-runs. Almost same problem was faced in the Chhibro–Khodri tunnel.

Thus, selection of a trouble free tunnel alignment is very much important to complete the project in stipulated time and budget. It has been experienced that a delay of about 20% in time results into cost escalation by 35%–40%. Therefore, detailed geological and

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Table 1
Alternate tunnel alignment between Heena and Tiloth, Maneri–Uttarkashi Stage I Project, India (m) [1].

S. No.	Proposed layout	Total length between Heena and Tiloth	Tunnel length through water charged quartzites	Increase in tunnel length
1	Original	5065	1200	
2	Alternative I	5940	920	875
3	Alternative II	7170		2105
4	Alternative III	5535	920	470
5	New alignment	5207	1600	142

geo-physical investigations of the area are must and shall be carried out in the area where the geology is varying.

2.2. Variation in predicted and actual geology

In the Himalayas, drilling up to the tunnel grade sometimes is not possible because of high rock cover (or high tunnel depth), thick vegetation on surface, difficult and inaccessible terrain. The rocks are severely folded and faulted due to tectonic activity. Due to these reasons, the geological investigations are limited to portal areas. Hence, in number of projects it has been observed that the geology encountered during the tunnelling vary from that predicted or anticipated geology. This results in variation of excavation planning and methodology, supports type and density, etc. For example, the Chhibro–Khodri tunnel (Fig. 1a and b) and the Giri–Bata tunnel (Table 2).

In Chhibro–Khodri tunnel of Yamuna hydroelectric project, recurrence of Krol and Nahan thrusts have resulted in changing geology along the tunnel alignment (Fig. 1a and b). This resulted into the problems of water-in-rush and squeezing ground conditions during tunnelling through the intra-thrust zone, which delayed the project.

Table 2 shows the difference in the predicted and the actual geology along the Giri–Bata tunnel. The difference was mainly in terms of the position of faults and thrusts, which were struck as surprise and resulted into the delay in completion of tunnel.

Table 2
Predicted and actual geology, Giri–Bata tunnel (m) [4].

Geological features	Predicted	Actual	Difference
1. Krol thrust	R.D. 2780	R. D. 3360	580
		R. D. 2980	200
2. Nahan thrust	R.D. 3405	R. D. 3520	115
3. Sile branch fault	R.D. 3350	R. D. 3196	154
		R. D. 3236	14
		R. D. 3266	84
4. Marar fault	R.D. 4959.5	R. D. 3360	169.5
		R. D. 2980	89.5
5. Length of Blaini Formation	1710	1312	398
6. Length of Infra-Krol	1070	1660	590
7. Length of Dadahus	625	384	241
8. Length of Nahans	3710	3593	115

Rohtang highway tunnel project in H.P. state, India is a challenging project through the higher reaches of Himalayas. The tunnel is being excavated at an altitude of more than 3000 m and has the rock cover of up to 1.9 km above the tunnel. Out of total length of 8.8 km of this horse-shoe shape tunnel, about 4 km has been excavated. While tunnelling from south end, the Seri nala fault was encountered about 300 m before the expected location. As per the investigations, it was extrapolated to be encountered between Ch. 2.20 and 2.80 km from south end. But, during the tunnelling, the Seri nala fault was struck at Ch. 1.90 km. At Ch. 1.918 km the fault line was visible on the tunnel face where left half face is weak strata charged with water and the right half of the face is undisturbed strata.

No probe hole was drilled to ascertain the location of Seri nala fault. Generally, it is advised to have number of probe holes in different directions to know the location of such important features. In this tunnel, as the excavation from south end progressed, Seri nala fault adversely affected the tunnel excavation and created difficult conditions for tunnelling as shown in Fig. 2. Finally, the tunnel through the fault zone was excavated using the DRESS method, which is found to be useful to excavate tunnel through soft, weak and water charged strata [5]. The DRESS (Drainage, Reinforcement, Excavation and Systematic Support) method has systematic predrainage ahead of face, reinforcement of ground, use of forepoles

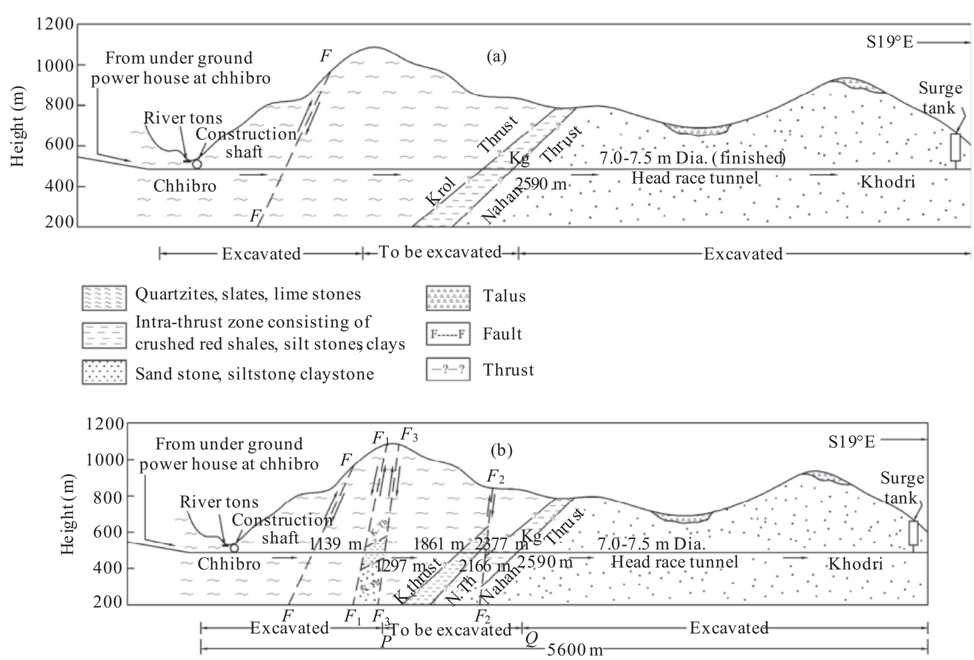

Fig. 1. Geological cross-sections along Chhibro-Khodri tunnel (a) original before starting tunnelling (b) actual encountered during tunnelling [2,3].