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Experiences and lessons from the use of TBM in the Himalaya – A review ☆

R.K. Goel

Central Institute of Mining and Fuel Research Regional Centre, Roorkee, India

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ABSTRACT

Tunnel boring machine (TBM), with its many advanced features, is being regularly planned now for the excavation of long tunnels in the difficult geology of the Himalayan region. The experience, so far, with the TBMs in three tunnels of Himalayas in India has not been encouraging. However, efforts are being made to overcome the problems and make the TBM a successful venture in the difficult grounds of Himalaya in India. The recent successful completion of 14.75 km long TBM portion of head race tunnel in Kishanganga hydroelectric project in J&K state has shown that the TBM can be used in the Himalayan tunnels as well.

In the paper the experiences of TBM in four Himalayan tunnels are briefly highlighted. In case of Tapovan-Vishnugad head race tunnel, the variation of ground in terms of difficulty in managing the TBM thrust and penetration rate has also been highlighted. At the end, some issues have been presented which seems to be important for the success of TBM in the difficult grounds.

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E-mail address: rkgoel15@hotmail.com

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1. Introduction

Tunnel boring machines (TBM) are used as an alternative to drilling and blasting (D&B) method of tunnel excavation. In comparison to the D&B, type of TBM to be used for excavation varies with the rock mass quality or ground. The big investment in a sophisticated tunnel boring machine (TBM) with the expectation of high advance rate is sometimes spoiled by the unexpected delays caused by unexpected ground. Only a few percent of the total tunnel length may be problematic, but these few percent could increase the construction time considerably.

Tunnelling in adverse ground is significantly less forgiving of the limitations of the tunnelling approach than tunnelling in good ground. Generally, the more difficult the ground, the more flexibility is also needed. Tunnelling in the Himalayas, the Andes and until recently the Alps has shied away from TBM use due to perceived inflexibility and the likelihood of the machines getting trapped by adverse ground conditions, either as a result of squeezing or spalling/bursting conditions or because of ground collapses associated with rock falls or with running or flowing ground within faults. Any of these situations can lead to problematic tunnelling at best and collapses and abandonment at worst. This is what has been experienced in the three tunnels in Himalayas where TBM was deployed.

Experience of TBM tunnelling in the Himalayas, so far, is not encouraging. This is due to high tunnel depth, high in situ stresses, mix geology and presence of folds, faults, shear zones, water charged formations, etc. Therefore, the designers were hesitant to use TBM for tunnel excavations in the Himalayas.

Although the geology along the deep tunnels are difficult to predict, regular probe drilling during the cutter change and maintenance shifts could largely help in minimising and/or removing the unexpected ground conditions.

The content of paper is mainly taken from the author's another publication, Goel (2014).

2. Experience of TBM in the Himalayas

Four cases of TBM tunnels are briefly presented here to highlight the experiences of using TBM in the Himalayas.

2.1. Parbati hydroelectric project Stage II, H.P

The Parbati hydroelectric project Stage II near Kullu in Himachal Pradesh, India has planned to use TBM for the excavation of 9.05 km head race tunnel (HRT) out of the total length of 31.5 km.

The HRT passes through the upper section of the lesser Himalaya mostly comprises of granites/gneissose granites followed by quartzites. Bands of biotite schist, talc chlorite schist or metabasics were expected along the entire length of the TBM drive. The gneissose granites are hard and massive exhibiting a well developed foliations in some areas (Madan and Kumar, 2004). Being very close to main central thrust (MCT), the rocks along HRT have undergone intense compression and thus are folded, faulted, foliated and jointed which is the typical characteristics of the Himalayan rocks. The overburden above tunnel along the TBM section varies from 100 m to 1300 m.

Looking into the geology, the TBM selected by the project authorities was refurbished Atlas Copco Robbins MK-27 open face hard rock TBM of 6.8 m diameter. The maximum machine thrust is 18,550 kN and considered suitable for hard rocks. The machine is open type high performance with six 525 kW main drive motors. There are 49 cutters of 432 mm (17″) diameter; maximum recommended operating load per cutter is 267 kN. Nominal cutter spacing is 65 mm, the installed cutter head capacity is 3159 kW and stroke length is 2.05 m. Cutter-head drive includes six variable speed drive motors (VFD). Maximum cutter-head rotating speed is 5.77 rpm. Maximum total gripping force is 55,600 kN carried over 4 gripper pads with 3.6 m height and 1.4 m width resulting in maximum rock pressure of 3.22 MPa.

The machine is equipped with ring-mounted probe drilling equipment, which can cover 360° of tunnel. The machine also has two number probe drills. Maximum probe length is about 120 m. TBM has arrangement of rock bolting, wet and dry shotcreting and ring beam erector for erection of heavy steel arches. In the event of unexpected geological conditions, drilling into rock ahead of face through cutterhead would be possible in upper arc. The high performance injection grouting plant is also equipped with the machine.

2.1.1. Problems during TBM tunnelling

The initial reach of the tunnel boring comprised of gneiss with schist bands and minor quartz lenses. The rock formation then changed to schistose gneiss with bands of chlorite schist, which were weak and highly jointed. Due to the presence of four primary joint sets and random joints a large block of 6.0 m × 2.5 m separated from the crown at chainage (ch.) 748 m and formed a cavity in the roof. The rock bolter could not access the cavity and pre-grouting was not possible because of tight joints. To tackle this problem, the ring beam had to be installed and the rock was supported with channels and girders. The cavity was backfilled with concrete. The treatment work took about three weeks. With this experience, modifications had been made in TBM to provide extension drilling system to access the cavities and arrangement of manual shotcreting just behind the cutterhead. The next 250 m faced the problems of rock/wedge failure forming cavities up to 5 m above the crown and required a lot of concrete backfilling. The excavation rate dropped significantly. Subsequently, the ground condition has improved and a weekly rate of about 90 m could be achieved (Sengupta et al., 2008).

The failure on several gripper cylinders caused approximately 8 weeks of downtime and necessitated the project authorities to call the Robbins Company for support. The Robbins Company took over the operation of the remaining TBM drive of head race tunnel. The excavation rate of 250 m/month and 24 m/day could be achieved. The unfavorable rock conditions like rock bursts and large over break were encountered in gneisses and quartzites. This has resulted into immediate requirement of rock support using steel ribs, fore poling, steel channel lagging and back filling with shotcrete. As the work progressed the rock conditions got even worse, as several mica schist bands were crossed. These resulted in numerous over breaks requiring closely spaced (0.4 m c/c) steel ribs, lagging, fore poling and shotcrete immediate behind the cutter head. Significant convergence of tunnel walls was observed as well, requiring additional rock support behind the grippers. These measures further decreased the TBM progress (Sengupta et al., 2008).

In May 2007 routine probe drilling ahead of TBM tunnel in sheared and faulted quartzite having 900 m overburden punctured a water bearing horizon which resulted in inflows of water of over 120 l/s containing about 40% sand and silt debris. The inflow was sudden and occurred at a high pressure which could not be contained. Eventually over 7500 m^3 of sand and silt debris buried the TBM. The project supposed to be commissioned in 2007 could not be completed till now.

While drilling the probe holes, it is important to have a close watch on drilling penetration rate, bore hole washings and quantity of water coming out of the bore hole. Puncture of saturated water bearing zone by probe holes may lead to the problem as experienced in this project.