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Prediction of tunnel deformation in squeezing grounds

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ABSTRACT

In this paper, dimensionally correct empirical correlations have been developed with correlation factor of 0.94 to predict tunnel deformation for squeezing grounds. Data of 63 sections from various case histories of 14 adits/tunnels/mine roadway were included for the study. Joint factor (as a measure of rock mass quality)/ Barton's rock mass quality, vertical in situ stress, support stiffness and radius of the tunnel are the governing parameters which have been considered for developing the correlations.

1. Introduction

Himalayan region is full of surprises with regard to the underground constructional activities due to frequently changing geology (Singh and Goel, 2006). The region is highly tectonically active and squeezing of underground structures has been a major problem faced by geologists and engineers (Panthi and Nilson, 2007). Due to the aforesaid problems, the region has been study centre for many researchers. Authors have also chosen the underground openings housed in the Himalayan region for study.

Squeezing may be defined as following (Barla, 1995): *Squeezing of rock is the time dependent large deformation, which occurs around a tunnel and other underground openings, and is essentially associated with creep caused by (stress) exceeding shear strength (limiting shear stress). Deformation may terminate during construction or continue over a long time period.*

The aforementioned definition of squeezing is qualitative. However, some researchers have tried to quantify the limiting value of tunnel deformation for squeezing grounds. According to Jethwa (1981), Goel (1994) and Sakurai (1997) when deformation of an unsupported underground opening exceeds 1% of the size of opening, the ground is categorised as squeezing ground which is likely to result in constructional problems. Singh et al. (2007) have suggested that threshold value of circumferential strain, above which problems are likely to be encountered, will not necessarily be 1% and it will depend on properties of the rock mass. If the supports are inadequate, tunnel deformation in squeezing ground condition may continue for over a period of time (Jethwa, 1981). The undesirable deformation of tunnel can be arrested by providing adequate support system in appropriate time. Stiffer supports arrest larger tunnel deformations and vice-versa. In case, some deformation is allowed, less stiff supports will be required as the rock pressure to be handled by the supports decreases. Squeezing behaviour is a function of rock mass quality, size of the opening and in situ stress state (Goel, 1994). The best way to deal with severe squeezing is to build a strategy well in advance (during planning and design) regarding stability measures for minimising stability problems and optimising the supports (Panthi and Nilsen, 2007). In this view, an estimated value of tunnel deformation becomes highly useful while designing the tunnel supports. The proposed correlations have been established considering numerous data especially from Himalayan region where many surprises had been faced with regard to prediction of geology.

Nowadays New Austrian Tunnelling Method (NATM) is being commonly adopted for tunnelling in which deformation monitoring data plays a key role in assessment of the quantity and quality of the required support for a particular round of excavation. Predicted values of tunnel deformation using the developed correlations would help in support design and making preparatory support arrangements during tunnelling in squeezing ground conditions. Data of adits/tunnels from hydroelectric projects in Himalayan region i.e. Giri–Bata (1 tunnel), Chhibro–Khodri (2 adit/tunnel), Maneri stage-I (2 adit/tunnel), Maneri stage II (2 adit/tunnel), Tala (1 tunnel), Kaligandaki (1 tunnel), Khimti-1 (4 adits); and a mine roadway of Noonidih-Jitpur Colliery have been analysed for the study.

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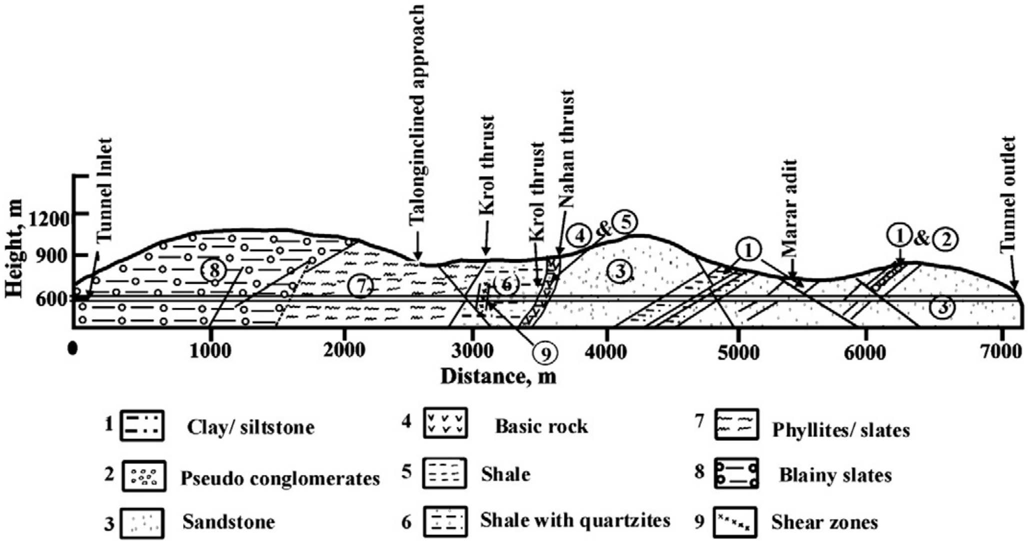

Fig. 1. Geological cross-section along Giri–Bata tunnel.
(After Dube, 1979).

2. Geology and tunnelling problems faced in the studied tunnels

2.1. Giri–Bata hydroelectric project

This project with installed capacity of 120 MW was constructed on Giri river, a tributary to Yamuna. It is located near Girinagar in Sirmour district of the state of Himachal Pradesh in India. A 7.1 km long head race tunnel with finished diameter of 3.60 m was driven through a ridge separating the valleys of Giri and Bata rivers (Dube, 1979). The tunnel was excavated by drill & blast method and was supported by steel ribs. Plain cement concrete lining of 300 mm average thickness was applied as final support.

The tunnel traverses through Blaini series rock formations of carboniferous age for a length of about 1500 m and through highly jointed claystones, highly crushed phyllites and siltstones for the rest length. The Blainis are dark grey to black quartzitic slates containing angular to round pebbles and boulders firmly embedded in a clay-silt matrix. The rock formations showed extensive jointing and shearing at places and the strike generally remained parallel to the tunnel alignment (Figure 1). The strata in the vicinity of the faults and thrusts were highly saturated, soft and plastic (Goel, 1994). Most of the tunnelling problems were faced in zones of phyllites and slates. Joints were spaced at 45–50 mm dipping with 60–70°. These formations were highly crushed exhibiting angle of internal friction between 20 and 26°.

2.2. Chibbro–Khodri hydroelectric project

The project was constructed on river Tons, a tributary of Yamuna river located about 45 km North of Dehradun in the state of Uttarakhand, India. A tunnel with finished diameter of 7.5 m was constructed between Chhibro and Khodri to utilise discharge of the Chhibro powerhouse to generate 120 MW of power through a surface powerhouse at Khodri.

The Chhibro–Khodri tunnel, passed through three geological series namely Mandhali series (Paleozoic), Subathu-Dagshai (Lower Miocene) and Nahan series (Upper Tertiary). Mandhali series consists of boulder slates, graphitic & quartzitic slates and Bhadraj quartzite unit with 5–10 m thick crushed quartzite along Krol thrust (Figure 2). Subathu-Dagshai series is comprised of 1–3 m thick plastic black clays along the series thrust and red & purple crushed, brecciated and sheared shales and siltstones, minor grey and green crushed quartzites, 20–22 m thick black clays with thin bands of quartzites and 5–10 m thick soft and plastic black clays along the Nahan thrust (Jain et al., 1975). Nahan series is comprised of greenish grey to grey micaceous (Upper Tertiary) sandstones, purple siltstones, red, purple, grey and occasional mottled blue concretionary clays. General strike of these lithounits is nearly perpendicular to the tunnel axis with the dip ranging from 20° to 60° in NNW to NNE direction (Shome et al., 1973).

There are two main boundary faults running from Punjab to Assam along the foothills of the Himalayas. The faults are known locally as the Nahan and the Krol thrusts. The dips of the Nahan and the Krol thrusts vary from 27° to 30° due N10°E to N10°W and 26° due N26° W respectively. The strike is almost normal to the tunnel alignment.

Major tunnelling problems were faced within the intra-thrust zones due to squeezing ground conditions. In order to minimise the frequent rock falls, multi-drift method was adopted at faces. Heavy steel arches of 300 × 140 mm and 150 × 150 mm sections, with 20–25 mm thick plates welded on both flanges were erected at

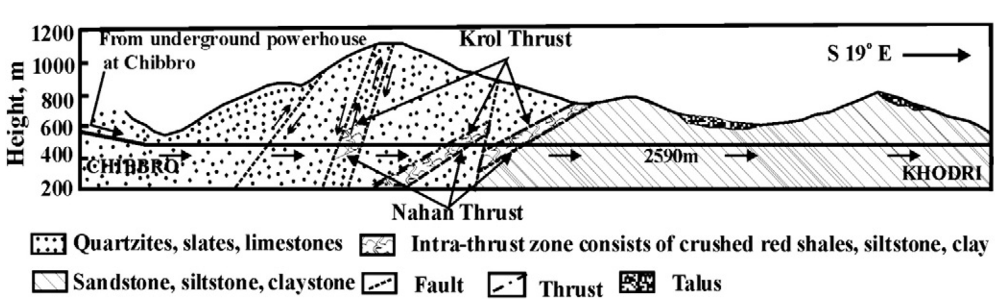

Fig. 2. Geological cross-section along Chhibro–Khodri tunnel.
(After Jain et al., 1975).