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# Engineering geological and geotechnical investigations along the head race tunnel in Teesta Stage-III hydroelectric project, India

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ABSTRACT

An investigation of the engineering geological properties and geotechnical parameters of rock masses along a horseshoe-shaped head race tunnel (HRT) in the Teesta Stage-III hydroelectric project, Sikkim, India, was carried out to analyze the rock mass properties for optimum support system. The empirical methods, field tests and numerical modeling were employed to determine rock mass properties. Several empirical equations and statistical analysis were performed to obtain the rational and reasonable results. The tunnel passes through different geological formations and critical zones. The field investigations indicate the presence of five joint sets, which contribute towards the development of unforeseen wedges along the tunnel alignment. The attitudes of joints were measured by Brunton compass and analyzed with Dips v.5.1 software. The potential wedge block analysis and factor of safety (FS) were determined using Unwedge v.3.0 software. The rock mass classification, assessment of tunnel stability and necessary support types were carried out with Q, RMR and RMi systems as empirical tunnel support design methods. The numerical method (Phase$^2$ v.6.0) was used to quantify plastic zone and squeezing potential of the tunnel. The installed support systems as per empirical methods were cross-checked by means of numerical modeling, field observations and engineering judgments. According to the results from different methods, 3.0–4.4 m rock bolts, shotcrete 0.1–0.15 m, wire mesh and final concrete lining were proposed. It was observed that the plastic and deformed zones surrounding the excavation area got appreciably reduced after the recommended support installation.


## 1. Introduction

The Teesta hydroelectric project of 1200 MW capacity is located on the banks of River Teesta in the North-Sikkim district of India (Figure 1). A number of hydroelectric projects were initiated along River Teesta in the Himalayas. These projects were identified from higher to lower topographic levels as Stage-I, Stage-II, Stage-III, and Stage-IV. The adits, head race tunnel (HRT), inclined pressure shaft tunnel, diversion tunnel and tail race tunnel of more than 25 km length were undertaken by drilling and blasting methods in the Teesta Stage-III project. The young mountain range around the project site provides innumerable challenges for geotechnical investigations to complete the project. The engineering geological investigation is more important (Rahimi et al., 2014) and has significant role on design and execution level of civil engineering projects. The present study provides details of such engineering geological aspects for a ~13 km long head race tunnel.

Three critical zones ($CZ_1$, $CZ_2$ & $CZ_3$) were identified in course of excavation period of the HRT (Figure 2). The $CZ_1$ and $CZ_2$ are the contact zones of different rock masses which need special attention (cf. Feng et al., 2012). The desilting chamber (DC) was constructed through $CZ_1$. This zone consists mostly of schistose rocks at the upper part and phyllitic rocks at the lower part of DC. The phyllitic rock present in the core of a syncline in the gneissic rocks in $CZ_2$ is highly crushed and sheared in nature. The high overburden makes this zone geotechnically very weak. There was severe water ingress problem in $CZ_3$ in phyllitic rock mass (cf. Liu et al., 2010 for similar problem), caused by one of the tributaries of the Teesta River flowing above. The above critical zones were given more attention regarding support system and sealing of water ingress problem.

## 2. Engineering geological assessment

### 2.1. General geology of the project area

The state of Sikkim dominantly comprises of Precambrian metamorphic rocks represented by phyllites, schists and gneisses. These Precambrian rocks were affected by the deformation processes of the Himalayan orogeny during Tertiary period, which developed major faults striking ~E–W and dipping northward (Mohanty, 2012). The tectonic units between two bounding faults define a thrust belt. The investigated site is located between the Main Boundary Thrust (MBT) in the south and the Main Central Thrust (MCT) in the north. Quaternary alluvial sediments occur as distinct terrace and fan deposits in the

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**Fig. 1.** Location map of the study area.

middle Teesta valley (Bhattacharyya and Mitra, 2009). The project area is located within the Higher Himalayas in the Central Crystalline Zone, comprising Chungthang Formation (calc-granulite and quartzite), Kanchenjunga Gneiss (high grade gneisses), Darjeeling Gneiss (kyanite and sillimanite bearing garnetiferous biotite gneiss) and Bangli Schists (garnetiferous biotite schist and chlorite-sericite schist). The rock units exposed in the HRT (Figure 2) belong to the Chungthang Formation and Kanchenjunga Gneiss (Mukul, 2010). The entire project area is located in the seismic zone IV (high) and has records of seismicity in adjacent areas (De and Kayal, 2004).

### 2.2. Discontinuity study

The rock masses have mechanically weak planes and inherent geometrical structural irregularities. Therefore, the physical and mechanical properties of rock masses show substantial changes during the excavation period. The parameters which have significant influence on the rock mass properties include the number of fracture sets and their orientations, persistence, aperture, roughness, filling material, water inflow and weathering. Due to the presence of folds and faults in the young mountain belt the same rock mass units (RMUs) are encountered repeatedly, and have variable physical and mechanical properties. Thus, the present study analyzes physico-mechanical properties for individual rock mass units (RMUs) according to Q and RMR ratings of joint parameters (Table 1).

### 2.3. Stereographic projection

Joints or weak planes are the fundamental input parameters for rock mass strength criteria which have strong influence on engineering construction designs. Therefore, the discontinuity surfaces in the project area were analyzed by stereographic projection to distinguish different sets and their attitudes (Figures 3, 4). Five dominant joint sets were observed in the field with intermittent local joints. The joint orientation readings were taken by using a Brunton compass. The field data of different joints were plotted on a stereographic projection net by using Dips v.5.1 software (Rocscience, 2002a). The details of the software steps are given in Appendix I(a). The lower hemisphere projections of pole concentrations (Figure 3) show five different sets and the rosette diagram (Figure 4) indicates the dominant strike of NW–SE.

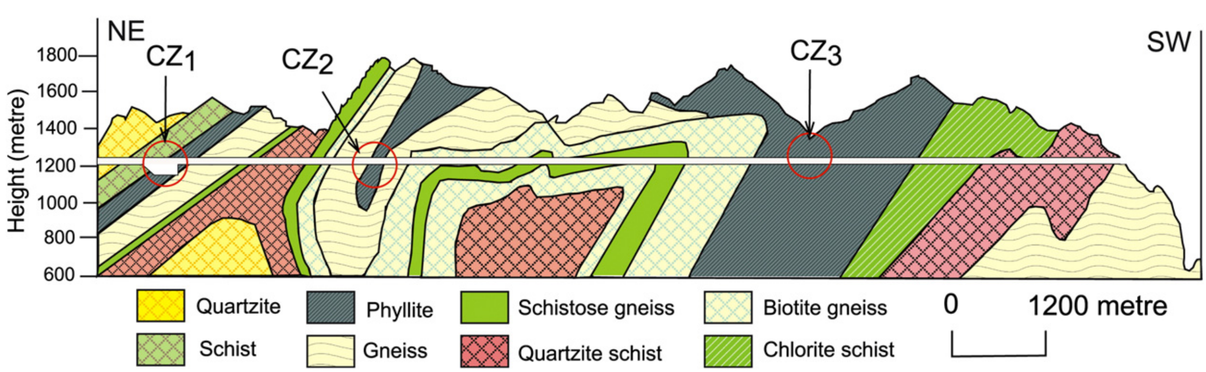


**Fig. 2.** Geological cross-section along the head race tunnel (HRT).