

Excavation and Support Challenges in an Exceptionally Weak Shear Zone in the Lesser Himalaya: A Case Study on Tunneling at UKHPP (28.1 Mw), Taplejung Nepal

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Abstract: This paper presents a case study on the challenging excavation of an exceptionally weak, 25.5 m thick shear zone encountered during the construction of the Headrace Tunnel (HRT) at the Upper Kabele Hydropower Project (UKHPP). The weak section, located between chainages 4+075.75 and 4+032.25, is composed primarily of light greenish gray silty clay (90-95%) with highly weathered phyllite fragments, resulting in an exceptionally low Q-value (<0.01) rock mass classification (Class VI) and it has oblique relation with the tunnel direction and the bedrock foliation. To safely manage the adverse geological conditions, sequential Heading and Benching method was adopted, complemented by the immediate installation of robust support measures.

Significant tunnel squeezing (up to 30-40 cm over a 5 m stretch) was observed, which was effectively controlled by the installation of the invert strut and its bracing. The weak section was excavated slowly over 50 days without major overbreak. Furthermore, non-core recovery probe drilling was strategically employed ahead of the face to investigate and pre-judge the onward rock mass condition. This case study underscores the importance of adaptive excavation techniques and comprehensive support systems for safely mitigating high-risk, weak geological structures common in the Nepal Himalaya.

Keywords: Excavation, Tunnel, Heading and benching, Shear zone, Tunnel squeezing.

Introduction

The 4896 m long Headrace Tunnel (HRT) of the Upper Kabele Hydropower Project (UKHPP), a 28.1 MW, is situated in the Lesser Himalaya zone, Taplejung Nepal. The major rock types of the project areas are Metasandstone, Phyllite, and Schist.

An exceptionally weak rock mass condition was encountered at the HRT outlet section, spanning approximately 25.5 m in between chainages 4+057.75 and 4+032.25 m. This weak section, identified as a shear zone, is characterized by light to medium dark gray, silty clay with interspersed rock fragments. The occurrence of sheared bands, shear zones, weak zones, and groundwater inflow are common geological challenges during underground excavations in the Nepal Himalayan

region (Sunuwar, 2016). These weak zones develop due to faulting, folding, rock mass shearing, chemical alteration, stress anisotropy, and other factors. The orientation of foliation changes across the shear zone: the generally East-oriented foliation (70-100 dip direction) shifts towards NNE to NE (10-50) with an almost consistent dip amount.

Geological condition of the weak shear zone (4+057.75 to 4+032.25)

The excavated rock mass within this shear zone primarily consists of light greenish gray, silty clay (90-95%) with a minor component of light gray to dark greenish gray, highly weathered, thinly foliated, very low-strength, lustrous phyllite (5-10%). Fragments of deformed quartz veins were also noted within the phyllites.

The rock mass downstream of the weak section is highly fractured, exhibiting three plus random joint sets (3+R). Joint sets are indistinct, possessing smooth planar to undulating surfaces. Joint apertures range from tight to open (up to ~4mm) and are infilled with silt and clay. Joint persistence is low to medium (1-10 m), with spacing ranging from 0.05 to 0.5 m.

Groundwater conditions during excavation and face mapping were dry to damp, and the Q-value of the rock mass was exceptionally low (<0.01) (Rock Mass support Class VI). The attitude of the shear zone is 2200-2400/400-500 (DD/DA), which maintains an oblique relationship with both the tunnel direction (008) and the foliation (700-1000/200-300, DD/DA). After excavation advanced up to chainage 4+044.85, the shear zone gradually narrowed and shifted towards the crown portion.

Excavation and support installation

To prevent the cavity formation/overbreak and strengthen tunnel stability, sequential heading-benching and immediate support installation method are adopted for the safe excavation of the weak zone.

The installed rock support system at this very weak zone included a robust combination of support elements: Steel Rib Sets (ISMB/ISHB 150*75,150*150), Invert Struts, Anchor Bars, Rock Bolts, Shotcrete (Plain and Steel Fiber), Spilling/Fore poling Rods etc.

Tunnel squeezing

Tunnel squeezing is a prevalent challenge in the Nepal Himalaya, particularly when tunneling through shear zones, dominant in clayey material (Sunuwar 2006). Under medium to high stress conditions, weak rock masses containing shear zones are prone to deformation, which occurs both during and after the installation of support. At this specific tunnel section, the vertical overburden measured between 300 and 315 m.

During the excavation of the weak section using the Heading and Benching method, the upper half of the tunnel was excavated first, followed by the immediate placement of the crown portion of the steel rib sets. However, while fixing the vertical legs of the ribs, the crown plates/flanges experienced squeezing of 10-15 cm from each side. Over a 5 m stretch, the weak section exhibited a maximum convergence, or squeezing, of 30-40 cm.

Installation of an invert strut and its bracing with vertical anchors proved crucial in controlling and minimizing the tunnel squeezing condition. Continuous measurement and monitoring of deformation are ongoing at the weak section to assess the rate of squeezing and evaluate the ground response to the applied support system.

Probe drilling

Probe hole drilling (rotary drilling) was executed to determine the condition of the onward rock mass. This critical investigative technique involves advancing a borehole ahead of the current excavation face to gather essential data regarding the rock mass condition, the presence of groundwater, and other relevant geological features. A total of six probe holes, each 14.2 m long, were drilled at various positions on the tunnel face at chainage 4+047.75 (Figure 1).

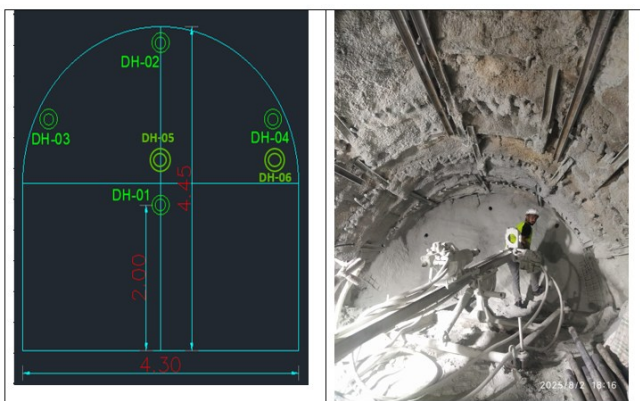


Figure 1, Probe hole location drilling at ch:4+047.75.

Conclusion

An adverse geological condition was encountered at the Headrace Tunnel (HRT) Outlet section of the Upper Kabeli Hydropower Project (UKHPP), specifically within the chainages 4+057.75 and 4+032.75. This 25.5 m thick shear zone was excavated slowly and safely, without any major overbreak, over a period of 50 days.

The excavation of this critical section was successfully executed using the Heading and Benching method complemented by immediate support installation. All rock support measures were implemented in accordance with expert suggestions and site engineer instructions. The comprehensive support system employed included steel rib sets (e.g., ISMB 150*75, 150*150), an invert strut, anchor bars, steel fiber shotcrete, plain shotcrete, spilling rods, and rock bolts.

Recommendation

The following recommendations are derived from the experience gained during the excavation and support installation within the very weak geological condition:

- **Pre-Excavation Analysis:** Analyzing the condition of the excavated rock mass and conducting a pre-judgment of the upcoming rock mass condition ahead of the tunnel face are critical practices in underground excavation. This detailed analysis is essential for selecting the appropriate excavation procedures, support systems, and installation methods, thereby enhancing the safety and efficiency of the excavation process.
- **Continuous Monitoring:** Continuous observation and monitoring of the weak section, including the ground response to the applied support system, are crucial. This proactive approach allows for the timely identification of any potential failures and the prompt implementation of further necessary support measures.

References

- Sunuwar, S. C. (2006). Engineering geological problems of shear and fault zones in Nepal Himalaya. *Journal of Nepal Geological Society*, 34, 47–52. <https://doi.org/10.3126/jngs.v34i0.31878>
- Sunuwar, S. C. (2016). Geological mapping in the Nepal Himalaya: Importance and challenges for underground structures. *Journal of Nepal Geological Society*, 51, 47–52. <https://doi.org/10.3126/jngs.v51i0.24096>