

Tunnel Stabilization: A Case Study of Effective Grouting and Support Measures in Upper Sanigad Hydroelectric Project, Bajhang, Nepal

Anil Kumar Chaudhary^{1*}, Ranjan Kumar Dahal¹ and Kanchan Chaulagari¹

¹Department of Geology, Tribhuvan University, Nepal

(*Corresponding E-mail: ac787578@gmail.com)

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Abstract: This case study presents a comprehensive overview of the small size tunnel stabilization and excavation efforts undertaken in the Upper Sanigad Hydroelectric Project (USHEP), located in the Kalanga Basin, Bajhang, Nepal. The project site is situated in the Lesser Himalaya geological unit, Galyang Formation of Midland group, by complex geology comprising meta-sedimentary and carbonate rocks. The tunnel excavation faced significant ground stability challenges due to the weak and fractured nature of the rock masses, high tectonic stress, and significant water pressure.

The project team employed a combination of grouting, debris removal, and support measures, including forepoling, rib installation, and sprayed concrete. The treatment process, which spanned approximately three and a half months, successfully stabilized the tunnel and allowed for safe excavation. A total of 1031 bags of cement were used in the two stages of grouting, and 2078 cubic meters of debris were removed from the tunnel.

The project's success demonstrates the effectiveness of a well-planned and executed stabilization and excavation strategy in overcoming complex geotechnical challenges in the Himalayan region. The case study highlights the importance of careful planning, precise execution, and adaptability in navigating uncertain geological conditions. The findings and lessons learned from this project can be applied to similar tunnel stabilization and excavation projects in the Himalayas, providing valuable insights for geologists, engineers, contractors, and project managers.

Keywords: Tunnel stabilization, Upper Sanigad Hydroelectric Project, Kalanga Basin, Lesser Himalaya, Meta sedimentary rock, Carbonate rock.

Introduction

The Sanigad River is one of the major tributaries of the Kalanga River, which ultimately joins the Seti river in western, Nepal. The project site is located in Bungal Municipality, Bajhang district (Figure 1).

The Upper Sanigad Hydroelectric Project (USHEP) is a run-of-river type hydropower facility with an installed capacity of 10.7 MW. It is situated within the Kalanga River basin, alongside two other hydropower projects developed by the same private entity: the Upper Kalanga Hydroelectric Project (UKHEP) with a capacity of 38.46 MW, and the Kalanga Hydroelectric Project (KHEP) with

a capacity of 15.33 MW. These developers are pioneers in initiating medium-capacity hydropower investments in Nepal's Far Western region from the private sector.

The Head Race Tunnel (HRT) of the USHEP spans 2,802 meters and was constructed without any adit tunnels. During excavation, four major cavities were encountered from both tunnel faces. Notably, the second cavity was discovered on the outlet face between chainage 1+886.6 and 1+856.6 (approximately 30 meters) on August 29, 2020. This geological feature is the focus of the present case study.

Initially, the rock mass was classified as fair to poor, characterized by thin to medium-bedded fractured dolomite, multiple shear bands filled with 2–4 cm thick clay, and three + random joint sets with moderate water inflow. Based on the assessed Q-value, rib supports were installed at 1 to 1.5-meter intervals in accordance with the approved design. A sudden cavity outburst occurred after the installation of the third rib set, during drilling for forepoling. Although there were no human casualties, the muck loader, Shotcrete machine, and jackhammer were buried under the debris.

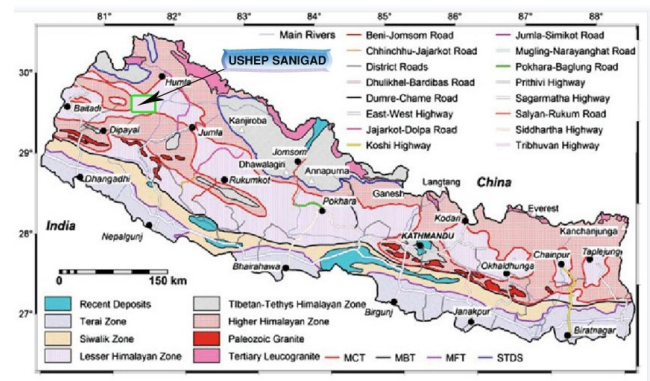


Figure 1, Location of the Project (USHEP, 2020) and Geological Map of Nepal, modified after Dahal and Hasegawa 2008.

Cavity treatment was carried out in a systematic sequence including debris removal, extraction of buried equipment, face sealing, drilling of drainage holes, grouting, heading and benching excavation and implementation of support measures (Figure 2 and 3).

The grouting concept aimed to allow heavier grout particles to settle within the water-saturated debris, gradually raising the water level inside the semi-enclosed cavity chamber. This process enabled controlled water inflow through already drilled holes at higher elevations. Once initiated, the operation proceeded smoothly, and the approach proved effective. The loose zone was successfully stabilized after the second stage of grouting.



Figure 2, Debris Flow after over bursting Cavity.

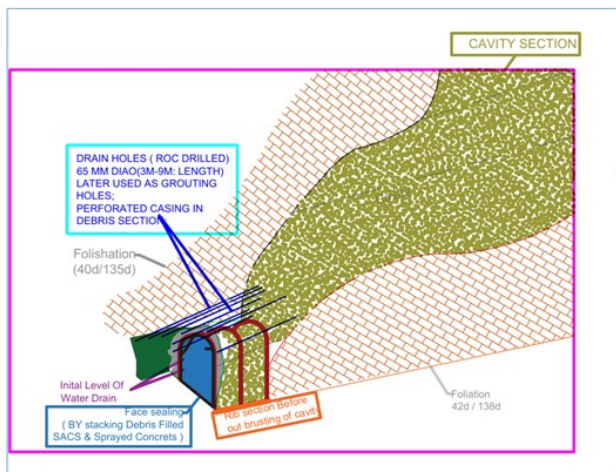


Figure 3, Schematic diagram of cavity and Treatment approach.

Methodology and treatment approach

Debris removal and equipment extraction

The operation began with the gradual removal of debris and the extraction of buried equipment, including a muck loader, shotcrete machine, and other machinery.

Face sealing near the cavity

The next objective was to seal the tunnel face near the cavity section. This sealing was carried out at the first rib, which had been installed prior to the cavity outburst. The process involved:

- Stacking debris-filled sacks
- Fixing crossed rebar of 25 mm dia. and steel channels
- Applying sprayed concrete

Water ingress was allowed to escape from one side of the sealed face to relieve pressure.



Figure 4, After Sealing of Face.

Drilling and grouting

The subsequent step is drilling holes to release water from the cavity and to inject grout into the semi-enclosed chamber. A total of 20 holes were drilled, ranging in length from 3 to 9 meters and with a diameter of 65 mm. These were positioned at various levels and back Chainage from the sealed face. The connection to the cavity chamber was confirmed by encountering loose debris zones and observing water discharge from some of the holes.



Figure 5, Drilling of Drain holes by ROC.

Grouting commenced from the lower levels and progressed upward. Due to the presence of loose debris and water within the cavity, a thick, neat cement grout with a water-cement ratio of 0.35 to 0.45 was injected using a high-efficiency piston-type grout pump. During the first stage of grouting, 780 bags of cement were consumed. To accelerate the setting time, a quick setting agent was mixed with the grout.

Initially the injected grout mixed with the water inside the semi-enclosed chamber(cavity) and drained out

through the water flow. Gradually heavier grout particles settled at the lower levels of the cavity, causing the water level to rise. This was observed through reduced water outflow at the lower level and a slight increase just above it.

An attempt was then made to stop the lower-level water flow, and grouting continued. Eventually, the water flow from the lower level ceased completely, while flow increased at higher levels. Grouting continued progressively from the lower level to the upper levels, redirecting water flow first to the higher levels then to the crown, and finally to the back Chainage. At this point, grout injection was stopped.

Heading and benching excavation with support measures

Following the successful grout injection and adequate curing time, the next phase involved excavation using the heading and benching method. Excavation was carried out with a pneumatic breaker. Initially, two sets of crown ribs were carefully installed at intervals of 0.3 to 0.5 meters. Subsequently, the bench portion was removed, allowing for the installation of the rib legs.

Forepolings were also implemented above the spring level, using 3.5 M long rebar of 25 mm dia, spaced at 150-200 mm intervals.



Figure 6, Heading and Benching -Excavation after Grouting.

Afterward, the second stage of grouting commenced in a similar manner, with a total of 251 bags of cement injected. Excavation continued using the heading and benching method, accompanied by the installation of support structures.

In total, 50 sets of steel ribs were installed- 0.3 to 0.5 M spacing in the major cavity section and 1.0 to 1.2 M in adjacent section the cavity section was successfully stabilized over a period of three and a half months.

Risk and challenges

The measured water inflow from the cavity, recorded three days after the initial outburst, ranged between 50 and 60 liters per second- an exceptionally high rate for a small tunnel. The discharged material from the cavity consisted of a mixture of water, clay, gravel and boulders. The situation became hazardous when large boulders obstructed the cavity's mouth, during debris

removal near the cavity, sudden efflux occurred intermittently, posing significant risks. Therefore, the debris was cleared with extreme caution, ensuring the angle of repose was maintained to further instability.



Figure 7, Rock Mass after Major cavity zone.

Sealing the tunnel face near the cavity was one of the most challenging tasks. As an immediate measure, debris-filled sacks were stacked promptly while maintaining the slope of the face. This temporary wall of sacks acted as a permeable barrier, allowing water to filter through and thereby relieving pressure within the cavity.

Diverting the water flow from a lower level to a higher level through the grout injection presented another significant challenge. Injecting grout precisely at the intended location was difficult, as the continuous water flow prevented the grout particles from settling effectively. To overcome this, multiple drain holes were drilled at various levels, which helped redirect the water inflow and ease the diversion process.

Conclusion

The tunnel stabilization efforts undertaken in the Upper Sanigad Hydroelectric Project exemplify a successful integration of geotechnical engineering principles and adaptive field strategies in a challenging Himalayan setting. Faced with fractured dolomitic rock, high water ingress, and sudden cavity outbursts, the project team implemented a systematic and responsive treatment approach—combining debris removal, face sealing, staged grouting, and robust support installations. Key achievements include:

- Stabilization of a major cavity zone over a span of 30 meters within three and a half months.
- Effective diversion and control of high-volume water inflow through staged grouting and drainage.
- Installation of 50 steel rib sets and extensive forepoling to reinforce the tunnel structure.
- Safe recovery of buried equipment and resumption of excavation using heading and benching methods.

This case study underscores the importance of site-specific solutions, real-time decision-making, and multidisciplinary coordination in tunnel engineering.

The lessons learned from USHEP provide a valuable reference for future hydro power and infrastructure projects in geologically complex regions of the Himalayas. By documenting the challenges and solutions in detail, this work contributes to the growing body of knowledge on Himalayan tunneling practices and reinforces the critical role of adaptive engineering in ensuring project safety and success.

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