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Numerical Calibration of Deformation on the Crown of the Powerhouse Cavern: A Case study of Upper Trishuli-1 Hydroelectric Project

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Abstract

This study validates the deformation observed on the crown of the Powerhouse Cavern within the Upper Trishuli-1 Hydroelectric Project. This validation was carried out by comparing the extensometer measurements (MBPX) with the results obtained from a 2-D finite element model, Phase2. The properties of rock mass and the weak band used in the numerical model are derived through back analysis (calibration), to match the observed behavior in the field.

Keywords

Powerhouse Cavern, Numerical Calibration, Extensometer

1. Introduction

1.1 Background

Underground caverns serve various purposes in civil engineering, including housing turbines, generators, and transformers for hydroelectric projects, storing liquid or gaseous fuels, providing subterranean warehousing, and even serving as underground sports facilities. One common application of subsurface is in hydropower projects [1].

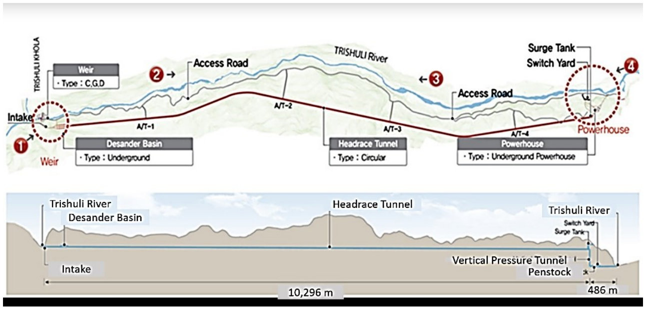

Figure 1: General layout of UT-1 Hydroelectric Project (Upper Trishuli-1 Hydroelectric project report)

One of the most crucial issues in the tunnel engineering is the evaluation of surrounding rock stability, especially in design and construction phase. A number of research studies have been performed to explore the stability of tunnel surrounding rock mass in rock and soil stratum [2].They have demonstrated that the strength of the rock is influenced by factors such as the rock mass strength, its shape, dimensions, and geological features in the region, such as faults and joints [3]. Therefore, this research aims to investigate deformation on the crown of Powerhouse Cavern due to excavation of rock. This investigation will be conducted through numerical analysis using the finite element method, utilizing actual project data from the Upper Trishuli-1 Hydroelectric Project.

1.2 Location of the Project

Upper Trishuli-1 Hydroelectric Project is a run of river project proposed along the Trishuli river in Rasuwa District, of Bagmati Province. The project has 216 MW installed capacity with total annual gross energy production of 1533.06 Gwh. The project consists of 29.5m high Dam, Underground Desander, 9.8 km long Headrace Tunnel (HRT), Surge Tank and Underground Power House as the main structures Figure1 and Figure 2.

1.3 Geological Overview of the Project Area

The Upper Trishuli-1 Hydroelectric Project area belongs to Lesser Himalayan Crystalline in Central Nepal. In the project site, the Lesser Himalayan Crystalline rocks are represented by schist unit, gneiss unit and colluvial deposits (talus). Among the rock types present in the project site, schist unit is the predominant rock type near the Powerhouse Cavern.

Figure 2: Geographical location of the UT-1 Hydroelectric Project site (Upper Trishuli-1 Hydroelectric project report)

2. Experimental Study Adopted for Numerical Calibration

The Powerhouse Cavern of Upper Trishuli-1 Hydroelectric Project is taken for the experimental study. The specific data of the tunnel, viz. dimensions, length, cross section shape, rock mass parameters, overburden, longitudinal profile, layout plan, geological parameters, disturbance factor, earth pressure coefficients, etc. are obtained from project report of the Upper Trishuli-1 Hydroelectric Project.

Table 1: Mechanical rock properties adopted in the numerical model

Rock Properties	Value	Unit
-Q	4 10	
Q, average geological Mapping	8.6	
GSI	54 58	
Intact rock UCS	60	MPa
Ei,Youngs modulus of intact rock	30	GPa
Poisson's Ratio	0.28	
mi	10	

2.1 Mechanical properties of rock mass of Powerhouse Cavern

The tunneling quality index (Q-System) updated by NGI 2015 is used for the rock mass classification.

Table 2: The principal field stress adopted in the model based on the hydraulic fracture test result

SN	Principal Stress in planes	Magnitude (MPa)	Azimuth Azimuth
1	σx	7.26	In South, 180° 180°
2	σy	4.36	In East, 90° 90°
3	σz	6.01	Vertical, upwards(+)

From the geological mapping of Powerhouse Cavern, the maximum and minimum Q-value for rock at Ch. 0+067 at the location of Powerhouse Cavern are 8.33 and 5.5, respectively. The GSI of the surrounding rock mass is calculated based on Q value using an empirical relation provided by Bieniawski [4]:

GSI = RMR-5, and

RMR = 9*ln(Q)+44

For verification, the GSI value is also estimated by using the relation given by [5]:

GSI = (52 / (1+Jr/Ja) Jr / Ja)+0.5 RQD,

Where, Jr is joint roughness number and Ja is Joint alteration number and RQD is Rock Quality Designation. The GSI value is further verified by site observation based on the chart presented by Hoek [5].

The principal field stresses adopted in this research for numerical modelling is extracted from hydraulic fracture test report from Upper Trishuli-1 Hydroelectric project. The testing results at second location at Ch. 0+230 of ventilation tunnel are selected for the modelling as it close to the Powerhouse Cavern. The major and minor principal stress is oriented to sub horizontal plane, the intermediate principal stress in sub vertical, indicating high tectonic movement impact in the project area. Based on the main access tunnel to powerhouse drawing, the longitudinal axis of the powerhouse cavern is at 272.56°. It can be assumed in E-W direction. In the powerhouse cavern cross section plane, the lateral stress ratio is estimated about 1.2.

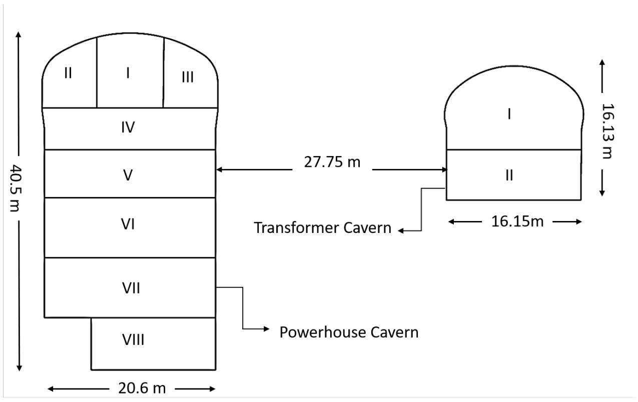

Figure 3: Excavation sequences and dimension of Powerhouse and Transformer Cavern sadopted in the numerical modeling.

The dimensions and excavation sequence adopted in the model are derived from the drawing of Powerhouse and Transformer Caverns from Upper Trishuli-1 Hydroelectric Project report.

3. Finite Element Modeling

Phase2 has been used in this research for two-dimensional numerical modelling. Among the two methods of modeling under Phase2 i.e. Core Replacement Method and Load Factor Method, load factor method is used for analysis so, internal pressure can be applied in the model. Internal pressure is applied normal to the boundary and varies with stage with maximum value equal to in-situ stress and minimum value equals to zero. In this study, field stress is taken as constant as shown in Table 2. Analysis of failure was performed using Generalized Hoek-Brown criterion.

The excavation sequence (heading and benching) of Powerhouse Cavern in finite element analysis is conducted using Phase2 in three sequential stages: consolidation stage in which, the model is subjected to the in-situ stress field before carrying out any excavation. During this phase, the model is allowed to undergo deformation under the influence of the existing stress conditions. The purpose of this stage is to observe how the surrounding soil or rock consolidates and adjusts to the in-situ stress without any excavation. In excavation stage (second stage), the tunnel excavation process is simulated. The heading of the Powerhouse Cavern is excavated. To control the closure or deformation of the tunnel, a uniform internal pressure is applied to the tunnel boundary. This stage assesses the behavior of the tunnel and the surrounding material during and after excavation. The third and final stage involves the removal of the internal pressure that was applied in the previous stage. In this stage shotcrete liner and rock bolts are applied to stabilize the deformation. These three stages together provide a comprehensive analysis

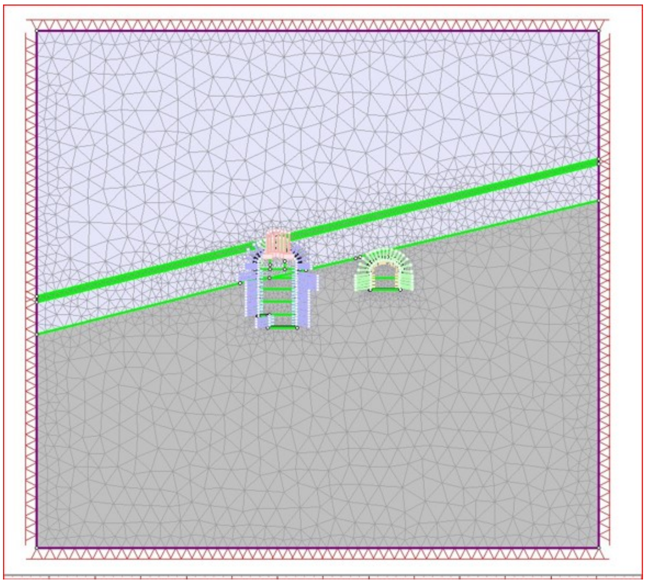

Figure 4: Finite element model and mesh generation in Phase2 software

of the underground excavation, considering factors such as initial stress, excavation-induced deformation, and support strategies.

3.1 Calibration of Numerical Model with the Extensometer Data

The calibration of the numerical model is performed considering the rock properties from the geological investigations. From the geological investigations at the Ch.0+067 m chainage, two layers of the rock; upper rock layer having weak rock properties than lower rock layer, along with a thin layer of weak band having jointed rock mass are found. In the numerical model, the two layers of rock are modeled as upper rock layer (residing the crown of Powerhouse Cavern) and lower rock layer along with weak band of average thickness 3 m as shown in Figure 4.

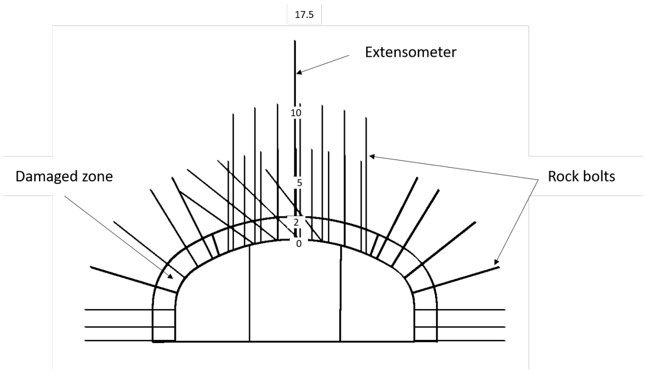

Figure 5: Typical instrumentation installed on the Powerhouse Cavern roof

The extensometer was set up on the crown of the Powerhouse Cavern as shown in Figure 5. The rock properties for lower rock layer are adopted from the geological investigation report of Upper Trishuli-1 Hydroelectric Project as shown Table 2.Whereas, the rock properties of upper rock layer are adopted after calibrating with the extensometer data from the site. The extensometer on the crown was installed and the displacement on the crown was recorded after the heading and stabilization of the crown.

The calibration of the model at Ch.0+067 m is based on the deformation data obtained directly from the site as mentioned, serving as the reference dataset. Therefore, as per the site condition, considering the cumulative vertical deformation on the crown at 0 m, 2 m, 5 m and 10 m, where extensometers were installed, the model of the powerhouse cavern is calibrated accordingly. When the excavation of the Powerhouse Cavern commenced and heading was completed, the deformations in the roof were measured by means of the extensometer. These deformations were compared with those predicted by the numerical modelling.

4. Results and Discussions

The result of the elasto-plastic finite element analysis is compared with the experimental findings. The outcome of the numerical analysis is illustrated, Figure 6, 7, and 8.

From the comparison, it is found that, the discrepancy between the numerical modelling and extensometer reading at 0 m, 2 m, 5 m and 10 m from the crown of the Powerhouse Cavern are -0.08%, 2.65%, -2.61% and 30% respectively. From the calibration of the numerical model, the rock properties of upper rock layer and weak band are verified. The calibrated

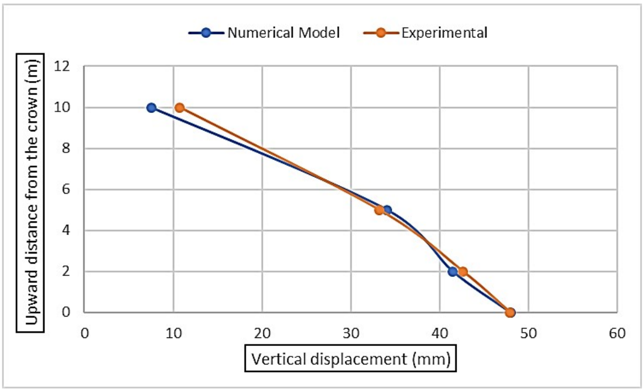

Figure 6: Comparison between the displacement from numerical modeling and extensometer on the crown of powerhouse cavern after heading.

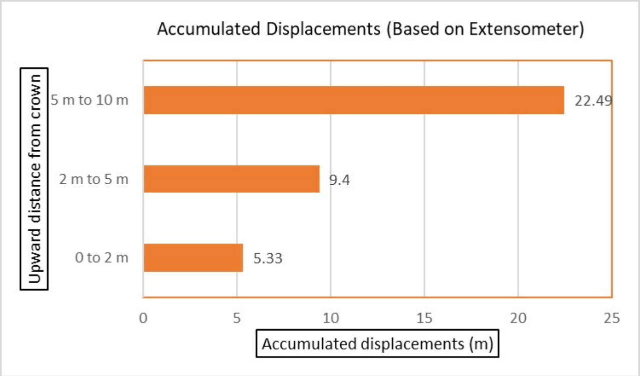

Figure 7: Accumulated displacement on the crown of Powerhouse Cavern after the heading measured by extensometer

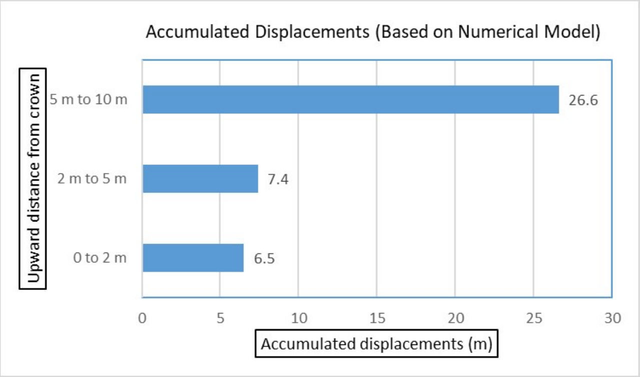

Figure 8: Accumulated displacement on the crown of Powerhouse Cavern after the heading simulated by numerical modelling

properties of upper rock layer and weak are presented in Table 3.The verified result from numerical analysis with the extensometer data can be further utilized in the stability calculation of the powerhouse cavern.

5. Conclusion

This paper presents the 2-D numerical validation of the deformation data measured by extensometer on the crown of Powerhouse Cavern. On the basis of the study, the following conclusion has been drawn. The approach used in numerical modeling appears suitable for parameter identification (back analysis) to find the optimized values of the selected parameters of the rock as shown in Table 3. The calibrated numerical model demonstrated a significant reduction in discrepancies when compared to the extensometer data, particularly in the vicinity of the tunnel crown. This improved agreement between the numerical simulations and the extensometer measurements underscores the effectiveness of the calibration process. It signifies that the model's behavior near the crown nearly represents the real-world conditions, which is a critical achievement for ensuring the model's reliability and predictive capabilities in this specific context.

Table 3: Rock parameters obtained after the calibration of Numerical Modeling

Description	Upper rock layer
GSI	46
Intact rock UCS (MPa)	60
Young's Modulus(GPa)	40
Disturbance Factor (D)	0.3
Poisson's Ratio (υ)	0.25
MI	10

References

[1] Abolfazl Abdollahipour and Hossein Ghannadshirazi. Stability analysis and determination of rock pillar between two adjacent caverns in different regions of asmari formation in iran. *International Journal of Mining Science and Technology*, 24(5):593–596, 2014.

[2] Zhiqiang Zhang, Fangfang Chen, Mingming He, and Hui Wang. An analytical calculation method for displacement criterion on tunnel surrounding rock mass stability. *Advances in Civil Engineering*, 2022:1–9, 2022.

[3] Jian Deng, ZQ Yue, LG Tham, and HH Zhu. Pillar design by combining finite element methods, neural networks and reliability: a case study of the feng huangshan copper mine, china. *International Journal of Rock Mechanics and Mining Sciences*, 40(4):585–599, 2003.

[4] Zdzislaw Tadeusz Bieniawski. Estimating the strength of rock materials. *Journal of the Southern African Institute of Mining and Metallurgy*, 74(8):312–320, 1974.

[5] E Hoek, TG Carter, and MS Diederichs. Quantification of the geological strength index chart. In *ARMA US Rock Mechanics/Geomechanics Symposium*, pages ARMA–2013. ARMA, 2013.