Rock cut slope excavated for Settling basins of Seti Khola Hydropower Project

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ABSTRACT: Stability of a cut-slope at the headworks area of the hydropower projects is very important for smooth operation of hydropower plant. Underestimation during construction period may bring a catastrophic consequence. This manuscript presents overall assessment results of the rock cut slope excavated to accommodate two settling basins of Seti Khola Hydropower Project (22 MW) located at Lekhnath, Kaski, Nepal. The height of the cut slope is about 50 m and is among the most challenging part of the construction work. The cut slope is excavated in a highly schistose and deformed phyllite with interbedding of metasandstone layers. The evaluations are made on the overall rock mass and discontinuity characteristics. The results of detailed stability assessment using software program SLIDE in consideration with both normal and seismic loading conditions are presented. Final rock support measures are proposed to ascertain long-term stability of the cut-slope.

Keywords: Settling basin, diversion dam, groundwater, earthquake, stability assessment.

1 INTRODUCTION

Stability of rock slope is dependent on the slope topography, the orientation of discontinuity planes, the shear strength of discontinuities, groundwater and stress conditions, and the seismic acceleration magnitude. The factors that influence the shear strength of the discontinuities are the frictional properties associated to roughness, and infilling condition of the main failure plane and the presence of groundwater (Panthi, 2021). In addition, the geometry of the cut slope and seismic acceleration caused by earthquakes (Wyllie and Mah, 2004) or vibration caused by blasting also influence in the overall stability of a cut-slope (Panthi and Nilsen, 2006). According to Nilsen and Palmstørm (2000) the rock slope stability assessment typically involves a three-step procedure consisting of 1) Definition of potential problem, 2) Quantification of input parameters and, 3) Calculation of stability.

In the Himalaya, slope cutting in highly deformable and fractured rock mass is one of the challenging tasks in the infrastructure development activities such as road cuts, cut slopes for hydropower projects, portals to the tunnels and so forth (Panthi, 2006). The failure criterion in such slopes is hard to define as the failure is governed by the joints, fractures, frequent shear bands, and highly schistose and deformed rock mass which may act as soil like material. Similar complexity is experienced at the settling basin cut slope in Seti Khola Hydropower Project in Nepal. Cracks at the slopes are developed with the progressive excavation going from top to the bottom of slope. This manuscript evaluates the cut slope in terms of geological conditions, slope geometry, rock mass and discontinuity properties and evaluates the overall stability condition of the cut slope.

2 SETIKHOLA HYDROPOWER PROJECT

2.1 Project and Geology

A run-of-river Seti Khola Hydropower Project (SKHP) with an installed capacity of 22 MW is under construction near the city of Pokhara, Kaski district of Nepal. The project will utilize about 40 m^3/s design discharge and 68 m gross static head. The headworks is located at an elevation of 585 masl and the powerhouse on the right bank of Seti Khola at an elevation of 518 masl. The headworks consists of diversion weir, intake structures, two parallel settling basins, forebay and the waterway system consisting of both 3.1 km long headrace tunnel, about 300 m headrace pipe, about 850 m long surface penstock and about 450 m long tailrace pipe. Geologically, the Pokhara valley is in the Midlands of Lesser Himalaya and is surrounded by hills made up of low-grade metamorphic rocks of Kuncha Formation (Figure 1) which is among the oldest formation in the Lesser Himalaya (Stöckling and Bhattarai, 1977). The main rock types in this group are various quality phyllites, meta-sandstone and quartzite that are characterized by low-grade metamorphic rocks of varying qualities. The Main Central Thrust (MCT) is about 19 km north at Hemja and Karkineta and the Main Boundary Thrust (MBT) is at about 45 km south of the project. The rock mass at the project area is highly schistose, deformed and folded forming Nappe and Killipe features.

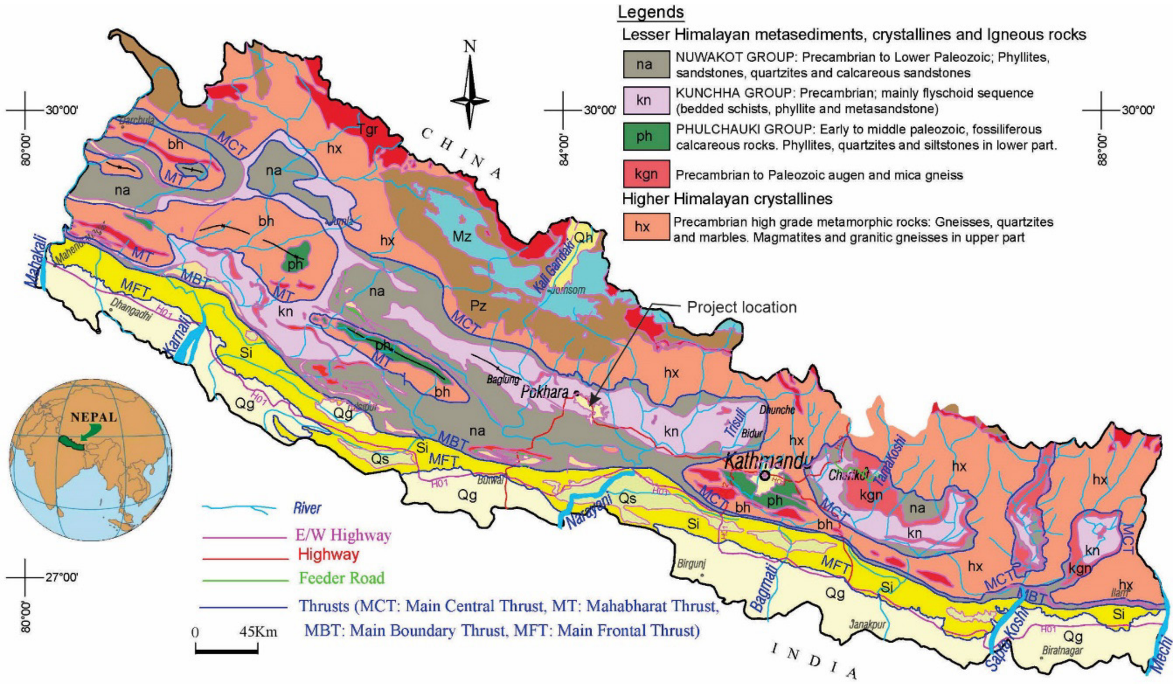

Figure 1. Project location and geology in the project area.

The intake and settling basins are located on the upper and lower terraces of Seti River where terrace of Pokhara formation is seen to the left bank and exposed rock outcrop of the Kuncha formation to the right bank. The rock mass at about 50 m high cut-slope belongs to low grade meta-sediments consisting highly schistose and deformed phyllite interlayered with small bands (up to 25 cm thick) of meta-sandstone. The phyllite can be scratched and broken by the hands indicating very low strength and of very poor to fair quality. The phyllite is thinly laminated, light to dark gray, very soft and weathered which has mainly three joint sets. The orientation of the foliation joints (Jf) varies

215-225/05-12 whereas cross- joints (J1) and (J2) have an orientation of 030-035/75-80 and 090-110/45-50, respectively. These joints in the phyllite are relatively tight, undulated and filled with mica and talk. The join persistence varies from 50 cm to up to 3 m. The groundwater condition at the slope is dry to moist during winter period and wet during monsoon.

2.2 Cut Slope Design

The designed maximum height of the cut slope is about 50 m of which upper 3 to 8 m depth consisted of high to moderately consolidated river deposit consisting angular to rounded pebbles, cobbles and boulders and medium to coarse grained sandy soil. Under the overburden material, a highly schistose and deformed bed rock is found. The planned excavation depth of the cut slope will reach to elevation of 575 masl. Presence of highly schistose and weak phyllite along the cut slope have been challenging regarding stability control during excavation. This demanded careful measures consisting proper drainage, unloading, application of support consisting of rock anchors and reinforced shotcrete. Figure 2a shows slope condition before excavation and Figure 2b shows original design configuration of the cut-slope with original slope topography. Initially, a 10 m height three bench walls with slope angle of around 65 degrees were designed which gave an overall slope angle of 55 degrees.

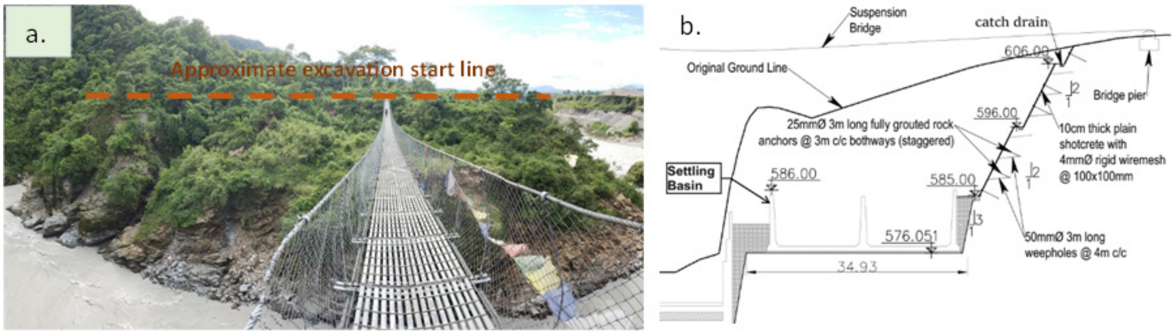

Figure 2. a. Photo showing the slope to be excavated for settling basins, b. originally designed of cut-slope.

The cut-slope excavation was continued up to elevation 590 masl, the second bench in Figure 2b. The combination of 25 mm diameter and 3 m long rock bolts and 10 cm thick reinforced shotcrete was applied as support measures. After reaching elevation 590 masl, a tension crack appeared at the top of the slope and the slope started creeping forming cracks in the cut slope (Figure 3a) indicating that the rock mass is incapable to hold a bench inclination of about 65 degrees. Hence, a decision was made to unload the upper part of the slope as such that the upper part of the cut slope has an approximate angle of 42 degrees (Figure 3b). In addition, longer rock bolts were proposed to be installed below elevation 591 masl.

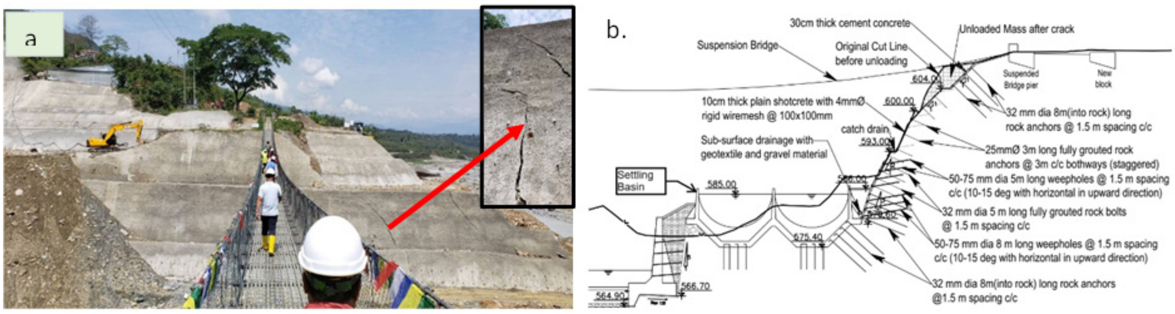

Figure 3. a. Excavated cut slope showing developed cracks, b. revised design of cut-slope with unloading.

Even after this unloading, cracks were continued to develop while cutting the slope further down which led to carry out through stability assessment and redesign of the cut slope. Stability analysis of cut slope at selected sections with modified support patterns is presented in this manuscript below.

3 STABILITY ASSESSMENT OF CUT-SLOPE

After analyzing the tension crack, cracks that were appeared in the cut slope at different elevations, it was concluded that the slope is forming a complex failure mode with multiple shear planes. The program SLIDE was used for the detailed stability assessment considering circular slip surface. The ratio of resisting moment to sliding moment at equilibrium was considered as the factor of safety (FoS) for the slip surface considering both normal and seismic movement conditions. For the seismic analysis, the peak ground acceleration (PGA) value of 0.38g corresponding to 475-year return period event was used. Both horizontal and vertical seismic coefficients were calculated using Eurocode 8 (prEN 1998-1:2003 E and prEN 1998-5:2003 E). The selected coefficient was used as pseudo-static during the analysis considering shear strength reduction with relatively small displacements. The input variables used for the analysis of cut slope are shown in Table 1. The material properties are estimated based on the geophysical investigation, surface mapping of actual cut slope and published data from different literatures etc.

Table 1. Input parameters used for the stability assessment of cut-slope.

Descriptions	Consolidated overburden material	Highly deformed phyllite	Meta-sandstone layer
Horizontal seismic coefficient (αh)	0.26	0.26	0.26
Vertical seismic coefficient (αv)	0.13	0.13	0.13
Cohesion (kPa)	80	150	2500
Internal friction angle (degree)	25	30	35
Specific weight (KN/m3)	20	27	27

The typical section after unloading of the upper part of the cut slope as presented in Figure 3b was analyzed considering both normal and seismic loading conditions and no support and with different support measures applied in the cut slope.

4 ASSESSMENT RESULTS AND DISCUSSIONS

A comprehensive analysis using SLIDE indicated that the original slope was critically equilibrium at the banks of the Seti River. Figure 4 shows the stability condition at the cut slope after excavations for both normal and seismic loading conditions. As can be seen in the figure the cut slope is at critical stage with FoS below one at normal loading condition and at failed state at seismic loading condition.

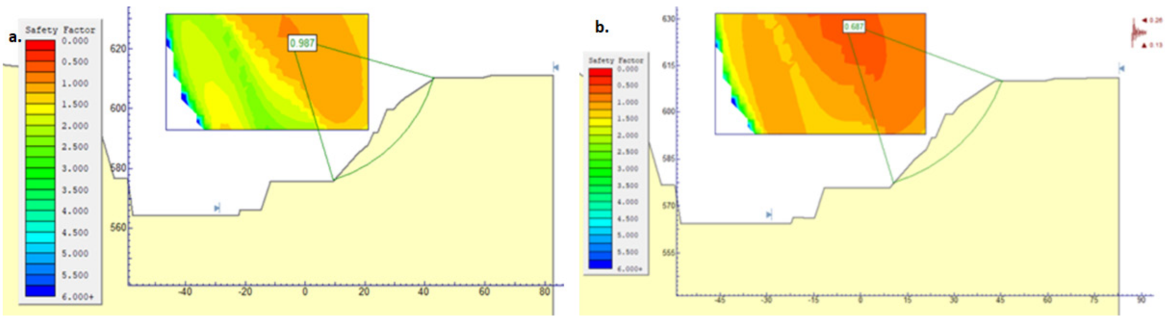

Figure 4. Achieved factor of safeties before support measure. a. At normal, b. At seismic loading conditions.

Therefore, it was necessary to carry out further stability assessment implementing the supports measures that will bring cut slope at a stable condition for the long-term perspective since at the toe of the slope there will be constructed two settling basins of the hydropower plant. These two settling basins are critical structures for the successful operation of the project. The result of analysis considering support measures are presented in the Figure 5. Figure indicates a substantial enhancement of the Factor of Safety (FoS) for both normal and seismic loading conditions. As one can see, the achieved FoS for normal loading condition is above 1.5 and for seismic loading condition around 1.1 which is considered to be safe enough for this project.

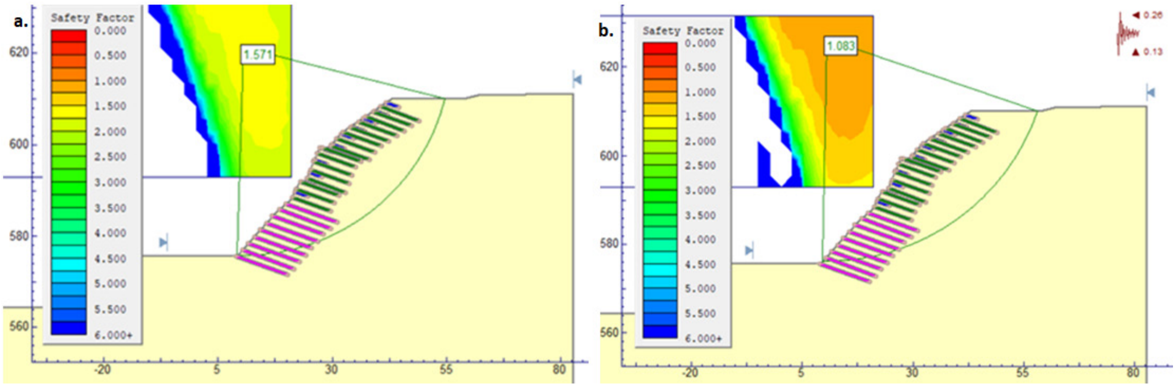

Figure 5. Achieved factor of safeties after support measure. a. At normal, b. At seismic loading conditions.

As one can see in Figure 5, the much longer rock bolts were required to stabilize the cut slope. Especially this is the case for the failed lower part of the cut slope (Figure 3a) which lies below elevation 592 masl. Based on the assessment results a final design decision was made with a support measure shown in Figure 6 considering long-term safety of the cut slope.

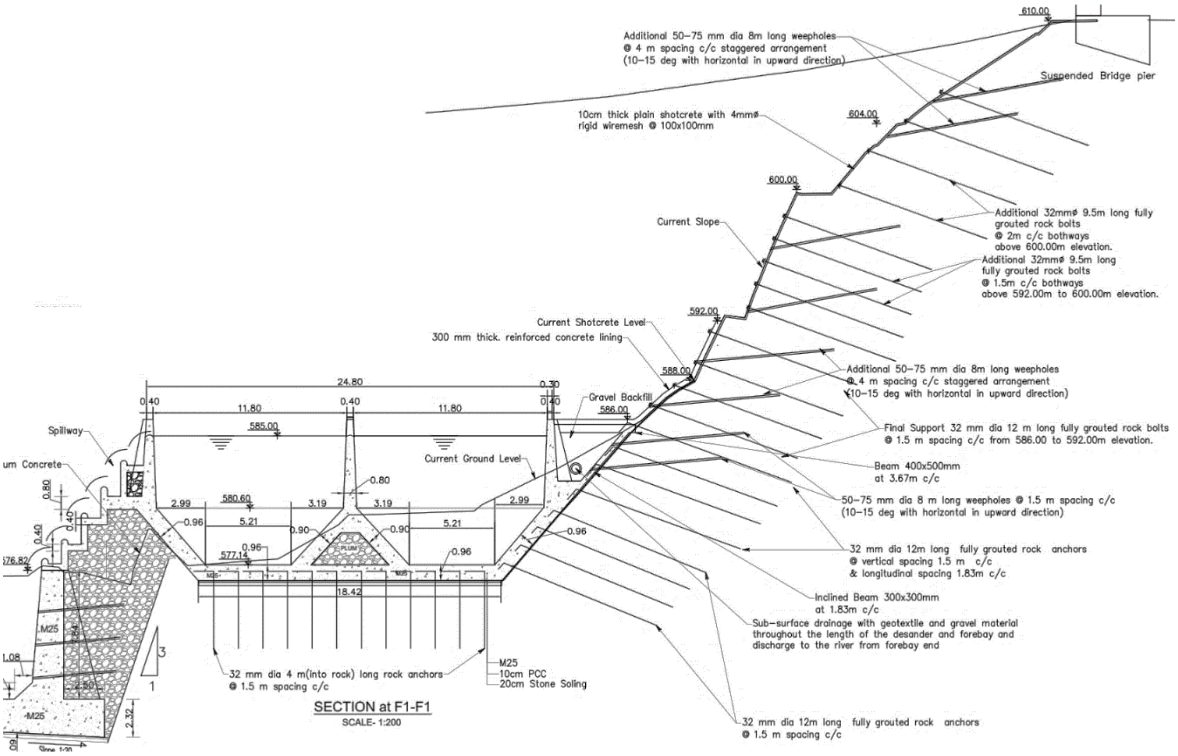

Figure 6. Final design arrangements of the settling basins with fully supported cut slope.

As seen in Figure 6, in addition to 10 cm thick reinforced shotcrete, the cut slope is supported with patterns of bolts having 32 mm diameter with varying length. The primary bolt length is 9.5 m long placed at 2 m spacing above elevation 600 masl, at 1.5 m spacing between elevation 600 and 592 masl and 12 m long bolts spaced at 1.5 m below elevation 592 masl. More importantly, grouted rock bolts have been used where the grouting was done during bolt installation at each hole to strengthen the rock mass of the cut slope. The grout (2:1 to 1:1 water cement ratio with bentonite in water bearing area and plasticizers having non-shrinkage properties were used) consumption was in considerable amount in most of the holes (more than 300 kg cement per hole in average with maximum 750 kg). In addition, drainage weep holes having 50 to 75 mm diameter and 8 m long are being implemented to ascertain that the ground water built up is avoided in future. A subsurface drainage system is also considered at the bottom of the cut slope at the hill side of the right wall of settling basin. The whole cut slope has been excavated using this modified support pattern and no further movement have been noticed.

5 CONCLUSION

Excavation of the cut slope is among the critical part of the construction activities of the Seti Khola Hydropower Project to accommodate space for the two parallel settling basins located at the highly schistose rock mass. The assumption made originally that the overall cut slope angle of 55 degrees will provide sufficient stability seems insufficient. Since the rock mass found during excavation of the cut slope is much weaker than it was anticipated during detailed design, progressive failure in the form of tension crack at the top and cracks in the cut slope wall occurred. This situation led to reconsider the design made prior to the construction. After modified design with comprehensive application of the support measure, the stability of the cut slope is enhanced substantially. However, it is emphasized here that the project crew must continue with the monitoring of the movement and make sure the changes, if any, to be recorded.

ACKNOWLEDGEMENT

The authors appreciate for the support given by the project developer while writing this manuscript. We are thankful for giving permission to submit this manuscript to ISRM 2023 congress and present the findings.

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