Stability of Mountain Slopes Affected by the 2015 Gorkha Earthquake: A Case Study of Bhotekoshi Hydropower, Sindhupalchowk, Nepal

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Abstract: This study assesses post-earthquake slope stability at the Bhotekoshi Hydropower site, Sindhupalchowk, severely affected by the 2015 Mw 7.8 Gorkha Earthquake. Using SMR and Stereographic Projection, key discontinuities (235°/67°) controlling instability were identified. RMR = 27 and SMR = 37.8 classify the slope as Class IV (Bad), with 57% planar and 28% wedge failure-prone areas, highlighting the need for stabilization and monitoring.

Keywords: ***Mountain slopes, Post-earthquake, Slope stability analysis, Slope stabilization.***

Introduction

Sindhupalchowk is tectonically active with landslide-prone slopes, particularly along the Araniko Highway (DMG, 2018). Slope stability at Bhotekoshi Hydropower was assessed using RMR, SMR, and stereographic projection to identify planar and wedge failures (Bieniawski, 1989; Romana, 1991; Dahal, 2006).

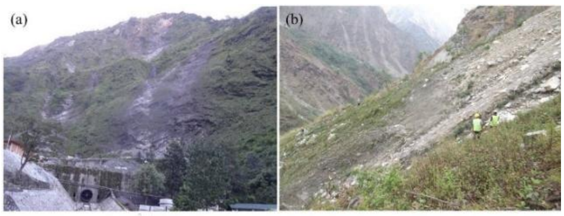

Figure 1, Bhotekoshi Hydropower area showing (a) rockfall and (b) debris flow.

Study Area

The study site, Upper Bhotekoshi Valley, Sindhupalchowk (~110 km NE of Kathmandu), is a run-of-the-river hydropower project on the Bhote Koshi River, with headwork ~500 m downstream of the Bhote Koshi–Jung Khola confluence and powerhouse ~3.7 km downstream at Jhirpu, accessible via the Araniko Highway to the Sino-Nepal border.

Method and Materials

Desk studies were complemented by field surveys using Schmidt hammer, GPS, and Brunton compass, with analyses for RMR, SMR, stereographic projection, and landslide mapping.

RMR and SMR

Rock Mass Rating (RMR) considers UCS, RQD, discontinuity spacing and condition, groundwater, and orientation (Bieniawski, 1989):

$$RMR = \sum R \quad (1)$$

Rock Quality Designation (RQD) was estimated using joint data.

$$RQD = 115 - 3.3J_v \quad (2)$$

Where, J_v is the sum of the number of joints (total joints seen) per unit volume and known as volumetric joint count (Palmstrom, 1982).

SMR accounts for slope-specific geometry. SMR was calculated by the relationship defined by Romana (1991) as follows:

$$SMR = RMR + (F_1 \times F_2 \times F_3) + F_4 \quad (3)$$

Where, RMR is the Rock Mass Rating. F1, ranging from 1.00 to 0.15, accounts for the parallelism between joints and slope face strikes, given empirically by:

$$F_1 = (1 - \sin A)^2 \quad (4)$$

Where A is the angle between the slope faces and discontinuity strikes. F2 (1.00–0.15) represents joint dip in planar failure, F3 accounts for slope–joint dip relationship, and F4 adjusts for the excavation method.

Stereographic Projection

Joint dips and directions were analyzed using stereonet to identify planar, toppling, and wedge failures.

Results and Discussions

Geological vs Geomorphological Setting

The The Upper Bhotekoshi Valley (≤4,000 m) has a steep, monsoon-affected terrain (2,500–3,000 mm/yr), with phyllite, schist, gneiss, limestone, and quartzite; weak phyllites and road cuttings increase landslide and rockfall risk (Krahenbuhl and Wagner, 1983).

Rock Mass Rating (RMR)

RMR was calculated using Schmidt hammer tests, joint spacing, condition, and groundwater (Bieniawski, 1989). RMR values at four sites ranged 22–33 (overall 27), indicating poor rock quality and high slope instability.

Slope Mass Rating (SMR)

The major discontinuities of slopes in four different parts of the study area are given below:

Table 1, Major discontinuities of slope.

No.	Dip Direction (Azimuth)	Dip Amount
1	304°	71°
2	235°	67°
3	231°	80°
4	230°	76°

The main discontinuity among them is 235°/67° and these joint sets could play main role in plane as well as wedge failures around the area.

RMR from the calculation as per standard chart = 27.

F1 = 0.7 (20°-10°), F2 = 1 (dipping more than 45°), F3 = -6 (difference is 0°-10°), and F4 = 15 (Natural Slope). Then, SMR = 27 + (0.7 x 1 x (-6)) + 15 = 37.8. The calculated value lies on IV class (Bad), unstable having planner or big wedges failure of SMR and needs to be corrective measures in the slope.

Stereographic projection

Using Stereonet 8, slope stability analysis (Figures 2–3) shows limited planar and wedge failures, consistent with the defined failure conditions.

Discussion

Slopes at the Bhotekoshi Hydropower site are Class IV (SMR = 27), indicating instability with potential planar (57%) and wedge (28%) failures. Weathered phyllite-gneiss slopes with concave topography, similar to the Opi landslide (SMR = 34; Kafle, 2010), are highly susceptible to planar and wedge failures, as confirmed by stereographic projection.

Conclusion and Recommendation

Rainfall-triggered landslides and RMR/SMR data (RMR = 27; SMR = 27) highlight high slope instability. To mitigate risk, detailed hazard mapping, proper site surveys, and slope stabilization measures—retaining walls, gabions, rockfall barriers—should be implemented. Reforestation, public awareness, and permanent rehabilitation are essential to reduce landslide impacts and protect infrastructure.

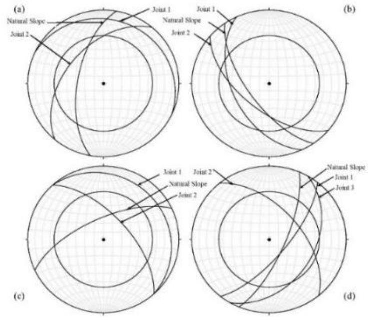

Figure 2, Stereographic projections of slope at Highway near Bhotekoshi Hydropower site: (a), (b), (c) and (d).

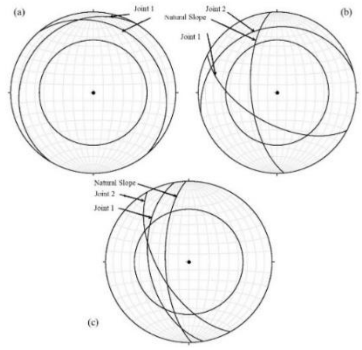

Figure 3, Stereographic projections of slope at Highway near Bhotekoshi Hydropower site: (a), (b) and (c).

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