

Engineering Geological Assessment of Slope Stability Issues for Bridge Sites in the Central Nepal Himalaya

Ujjwal Krishna Raghubansha^{1*} and Ranjan Kumar Dahal²

¹ PhD Scholar, Central Department of Geology, Tribhuvan University

² Professor, Central Department of Geology, Tribhuvan University

(Corresponding E-mail: ragubhansiujjwal@gmail.com)

Abstract: The Himalayan region presents major challenges for infrastructure development due to active tectonics, steep terrain, and fractured rock masses. This study investigates slope stability at two adjacent bridge sites in central Nepal within the Kalitar Formation of the Bhimphed Group, comprising mica schists, micaceous quartzites, and chloritic-sericitic schists. Engineering geological mapping, discontinuity surveys, geomechanical analysis, and Electrical Resistivity Tomography (ERT) were conducted. The rock mass is thinly foliated, highly fractured, and variably weathered. Three major discontinuity sets and one random set were identified, with closely spaced joints and occasional argillaceous infill. Kinematic analysis indicated no planar failure potential, moderate wedge failure potential, and high toppling failure potential. Rock mass characterization yielded a Geological Strength Index of 40–45, uniaxial compressive strength of 0.396–4.133 MPa, and deformation modulus of 2311–2362 MPa. Limit equilibrium analysis of an approximately 50 m slope at Pile P4 produced a Factor of Safety of 1.411 under static, dry conditions. ERT surveys identified subsurface moisture zones, weathered horizons, and potential slip surfaces. Recommended measures include extended slope analysis, including areas upslope and downslope of access roads, detailed topographic and subsurface investigations, drainage management, bioengineering, environmentally sensitive construction, and structural assessment of bridge foundations to support safer infrastructure development.

Keywords: Slope stability, Kalitar formation, Nepal himalaya, Geo-mechanical analysis, Toppling failure, Electrical resistivity tomography

This study evaluates the engineering geological conditions and slope stability at two adjacent bridge sites in central Nepal, located within the Kalitar Formation of the Bhimphed Group in the Kathmandu Complex. The geological formations consist mainly of mica schists, micaceous quartzites, and chloritic-sericitic schists, with occasional garnetiferous and carbonate bands. The varying degree of weathering, closely spaced joints, and complex discontinuity orientations significantly influence the stability of the exposed rock slopes. Understanding these characteristics is essential for identifying potential slope failure mechanisms and assessing their implications for bridge foundations and surrounding road infrastructure.

The investigation incorporates detailed engineering geological mapping, discontinuity surveys, rock mass characterization, kinematic analysis, limit equilibrium slope stability analysis, and Electrical Resistivity Tomography (ERT). These methods are used to evaluate surface and subsurface geological conditions, identify possible failure mechanisms, and assess the stability of slopes near the bridge sites. The study also emphasizes the importance of appropriate drainage management, bioengineering measures, and detailed geotechnical investigations to support safer infrastructure development in the geologically complex Himalayan region.

Introduction

The Himalayan region is highly susceptible to slope instability due to active tectonic movements, steep terrain, complex geological structures, and fragile rock masses. These geological and topographical conditions create significant challenges for infrastructure development, particularly in mountainous areas where roads and bridges are constructed along unstable slopes. Road infrastructure in central Nepal frequently faces geological hazards such as landslides, rockfalls, and slope failures, which threaten human safety, damage infrastructure, and disrupt transportation connectivity. The presence of highly fractured, weathered, and foliated rock masses further increases the vulnerability of slopes, particularly where geological discontinuities influence overall rock mass stability.

Geological setting

The study area lies within the Kalitar Formation of the Bhimphed Group (Kathmandu Complex). The formation comprises a thick metamorphic succession of mica schists, micaceous quartzites, and chloritic-sericitic schists with subordinate garnetiferous and carbonate bands. The rock mass is very thinly foliated, highly fractured, and slightly to highly weathered. Micaceous quartzite dominates up to 2ND Pile, transitioning to moderately to highly weathered chloritic and sericitic schist towards the bridge end. Bedrock predominantly dips towards the southeast, obliquely cutting the north-to northeast-trending hill slope.

Methodology

Detailed engineering geological mapping was carried out along the bridge slope. Discontinuity data were collected using scanline surveys. Kinematic analysis was performed using stereographic projections (Dips). Rock mass parameters were estimated using RocLab based on the Hoek–Brown criterion. Limit equilibrium slope stability analysis was conducted using Slide for a high slope along the Pile. Electrical Resistivity Tomography (ERT) was employed to delineate subsurface moisture zones, weathered horizons, and potential slip surfaces.

Results and discussion

Field observations reveal that the exposed rock mass is very thinly foliated, highly fractured, and slightly to highly weathered. Three major discontinuity sets plus one random set were identified. Joints are closely spaced, smooth undulating in schist and rough planar in quartzite, often filled with argillaceous material and stained by iron oxides. Kinematic analysis indicates no possibility of planar failure, medium possibility of wedge failure, and high possibility of toppling failure.

Rock mass characterization using RocLab yielded a Geological Strength Index (GSI) of 40–45, with uniaxial compressive strength ranging from 0.396 MPa to 4.133 MPa and deformation modulus of 2311–2362 MPa. Limit equilibrium analysis for a ~50 m high slope at Pile P4 yielded a Factor of Safety (FS) of 1.411 under static, dry conditions. ERT investigations effectively delineated subsurface moisture zones, weathered horizons, and potential slip surfaces, corroborating field observations of heterogeneous and adverse rock mass conditions.

Conclusion

The study recommends comprehensive slope stability analysis extending 50 m upslope and 150 m downslope of the major bridge, detailed topographic surveys, ERT-guided subsurface investigation, eco-friendly construction practices, systematic drainage management, bioengineering with deep-rooted vegetation, and structural analysis of bridge foundations considering the prevailing geological conditions. The findings contribute to understanding cascading mountain hazards in the Himalayan region and provide a geotechnical risk-assessment framework for infrastructure development in tectonically active terrains.

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