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Advancing Road Cut Slope Stability in Nepal

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Abstract: Road cut slope failures (a type of landslide) are extensive across Nepal's road network. This study implements a multidisciplinary approach (including participatory approach methods, geotechnical, geomorphological, geological fieldwork, and geotechnical numerical analyses) to assess the stability of road cut slopes across Nepal, to improve their stability through advanced design guidance for local roads. Here, we present an overview of this multidisciplinary approach.

Keywords: ***Roads, Slope stability, Landslides, Design.***

Introduction

Road cut slopes, slopes that have been excavated adjacent to a road, are susceptible to failure in Nepal due to Nepal's complex geology, active tectonism, and monsoon period (during which time Nepal receives around 80% of its annual rainfall). This susceptibility is exacerbated when the cut slopes are poorly designed and excavated, due to limited resources, as can often be the case on the Local Road Network (LRN) of Nepal (Robson et al., 2025). The LRN (consisting of the district and rural roads) makes up around 80% of the total road network of Nepal (ADB, 2021).

In this study, we implement participatory approach methods, geotechnical and geological fieldwork, and geotechnical numerical analyses, to assess the stability of road cut slope in Nepal and develop guidance that can be used by engineers to enhance the stability of local roads in Nepal.

Methodology

Our methodology is made up of four key stages that are outlined in Figure 1. Firstly, we conducted a participatory approach study to assess the use and effectiveness of current road cut slope stability practices and guidelines in Nepal. The participatory approaches involved a one-day workshop with 34 participants, six semi-structured interviews and five unstructured interviews, two one-hour focus groups, 19 questionnaires, with local, provincial, and central government engineers, consultants, and academics. Robson et al. (2025) outlines that the key finding of this study is the significant inconsistency in the use of road cut slope guidelines by government engineers, with local and provincial government engineers often using a 'rule-of-thumb' method (based on experience rather than using guidelines and geotechnical techniques) to design road cut slopes. The study also finds that local government engineers do not conduct geotechnical investigations in designing and constructing road cut slopes. This study concludes that improved guidance for local engineers is required based on rigorous geotechnical field and/or numerical analysis methods should be developed according to Nepal's geological, physiographic, and meteorological conditions, and that this guidance should be user-friendly (according to the needs and knowledge level of local road engineers).

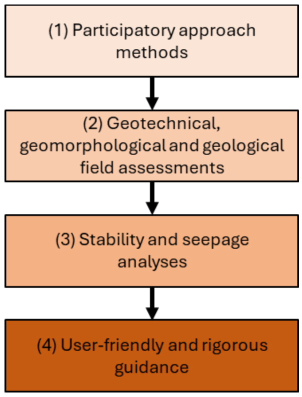

Figure 1, Methodology flowchart.

The second step in our methodology was conducting geological, geomorphological and geotechnical field assessments of road cut slopes across Nepal to establish trends in the geological, geomorphological and geotechnical features of road cut slopes. 295 road cut slope sites were visited from November 2023 to April 2024, during Nepal's dry season. The slope sites were situated across Nepal's East-West width and across the hilly physiographic regions of Nepal (the Chure, Mid-Hills, and Upper-Hills), ranging from elevations of 180 m to 3,000 m above sea level (as measured at the sites). 63 slope characteristics (including geographic location, slope and hillslope geometry, geomorphological features, geomaterial descriptions, vegetation cover, and structural interventions) were recorded using low-cost, easy-to-apply methods according to a standardized field protocol.

The height of the cut slopes ranged from < 5 m to > 60 m, with an average of 12.6 m, the angle of the cut slopes ranged from 19 to 90°, with an average angle of 68°, and the topographic hillslope angles ranged from 10 to 80°, with an average angle of 31°. Out of 295 cut slopes visited, 200 were classified as being predominantly rock (slope made up of more than 80% rock), 75 were classified as being predominantly soil (more than 80% soil or heavily weathered rock), and 20 were classified as being both rock and soil (between 20-80% rock or soil). We classified the cut slopes according to their strength using the geological hammer strength test (Hoek and Brown, 1997). 14% of sites were classified as being 'Very Weak', 21% were 'Weak', 29% were 'Moderate', 22% were 'Strong', 13% were 'Very Strong', and 1% were 'Extremely Strong'. The cut slopes were categorized according to their stability into one of the following groups based on observed slope defects: 'Stable' (22% of sites visited), 'Slightly unstable' (31%), 'Moderately unstable' (21%), 'Highly unstable' (13%) or 'Recent failure' (10%).

The third step in our methodology was to conduct numerical slope stability analyses to assess the stability of typical road cut slopes in Nepal, using our field data to guide the material selection and geometry for the analyses. To do so, we created groupings for typical soils and rocks found in Nepal and assigned strength and seepage parameters to these groups using published literature parameter values. Six soil groups were established: (1) Coarse-grained; (2) Coarse-grained with plastic fines; (3) Coarse-grained without plastic fines; (4) Silt; (5) Low plasticity clay; and (6) High plasticity clay. Six rock groups were established: (1) Calcareous (e.g. limestone, dolomite); (2) Foliated (e.g. slate, phyllite, schist); (3) Crystalline (e.g. granite, gneiss); (4) Silicious (e.g. mudstone, shale, siltstone); (5) Cemented (e.g. sandstone); and (6) Conglomerate.

To account for precipitation in our analyses, we divided Nepal into ten rainfall zones. Rainfall zones were derived by combining NASA's GPM IMERG dataset (2001–2020) (Huffman et al., 2014) at 0.1° resolution, with the established hilly physiographic regions of Nepal. The zones include: (1) Chure – High (>1,200 mm/year); (2) Chure – Medium (1,000-1,200 mm/year); (3) Chure – Low (800-1,000 mm/year); (4) Mid Hills – High (>1,200 mm/year); (5) Mid Hills – Medium (1,000-1,200 mm/year); (6) Mid Hills – Low (800-1,000 mm/year); (7) Upper Hills – High (>1,200 mm/year); (8) Upper Hills – Medium (1,000-1,200 mm/year); (3) Upper Hills – Low (800-1,000 mm/year); and Upper Hills – Very Low (<800 mm/year). We then established the worst-case monsoonal rainfall time series for each rainfall zone from 20 years (2003-2023) of data from multiple Department of Hydrology and Meteorology rain gauges (93 rain gauges in total). In addition to rainfall, we also varied the following parameters in our analyses: cut height, cut angle, topographic hillslope angle, and the position of the cut slope in relation to the topographic hillslope.

Stability analyses were conducted using GeoStudio Slope/W (Limit Equilibrium Method) and seepage analyses were conducted using Seep/W (Finite Element method). The analyses were conducted utilizing a Python batch analysis code. The results present a Factor of Safety for each parameter combination. From this we can derive what cut angle results in a stable cut slope (we define a stable road cut slope as having a Factor of Safety ≥ 1.3).

The final step of our methodology is to integrate the results from the participatory, field-based, and numerical studies to develop user-friendly guidelines presented as diagrams and questions for local engineers to design safe road cut slopes. These guidelines can also help engineers characterize slope materials.

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Conclusion

A multidisciplinary approach to advancing road cut slope stability in Nepal is presented. We began with the participatory methods approach with to identify that local government engineers often rely on "rule of thumb" rather than geotechnical investigation for cut slope design. Field data was collected from roads across Nepal to establish the typical features of cut slope that were then incorporated in the numerical models. We divided Nepal into ten rainfall zones using satellite average monsoonal rainfall distribution to incorporate rainfall in the stability and seepage analyses. All collected data are used to develop user-friendly guidelines to help local government engineers design safer cut slopes.

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