

Low-Cost Landslide Mitigation Measures for Roadside Slopes: A Case Study of Jamunedanda, Pyuthan, Nepal

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Abstract: Roadside landslides are a recurrent problem along mountain highways in Nepal, where weak geological materials, steep terrain, rainfall infiltration and concentrated runoff can interact to reduce slope stability. This paper presents a field-based case study of the Jamunedanda landslide at Ch. 27+800 of the Bhaluwang–Chakchake–Liwang–Darebot Road (NH-53), Pyuthan, Nepal. The investigation combined desk study, topographic survey, engineering-geological mapping, field geotechnical testing, laboratory testing, infiltration assessment and numerical slope-stability analysis. The site is characterized by highly weathered and fragmented black shale with colluvial and gravelly slope materials, erosional gullies, tension cracks and tilted trees. Laboratory results showed natural moisture contents of 4.88–14.88%, specific gravity of 2.64–2.74 and bulk density of 1.51–2.00 g/cm³, while grain-size analysis indicated predominantly SP, SW and GP-type materials. Preliminary PLAXIS 2D analysis indicated marginal natural-condition stability. The mitigation concept combines slope trimming, 12 m soil nails/anchors, gabion or masonry retaining structures, horizontal drains, check dams, surface drainage and bioengineering. The case demonstrates the value of combining structural reinforcement, water management and erosion control for stabilization of constrained Himalayan roadside slopes.

Keywords: Landslide Mitigation, Roadside Slope, Engineering Geology, Anchoring, Gabion, Drainage, Bioengineering, Nepal Himalaya.

Introduction

Landslides are broadly recognized as slope movements involving the downward movement of rock, soil, or debris under gravitational influence (Cruden and Varnes, 1996). Landslides along Himalayan road corridors result from the interaction of geological structure, weathering, slope geometry, rainfall infiltration, surface runoff and human modification. Recent investigations of active landslides along Himalayan road corridors in Nepal have also highlighted the importance of understanding site-specific geological and geomorphological conditions for assessing slope instability (Dahal et al., 2024). The Jamunedanda landslide is located at approximately 27°58'17.4" N, 82°49'24.6" E, around Ch. 27+800 of the Bhaluwang–Chakchake–Liwang–Darebot Road (NH-53) in Pyuthan District. The site lies at about 800 m elevation

in a subtropical climatic setting and forms part of a strategically important mountain road corridor.

The project investigation records Jamunedanda within the Lakharpata Formation, comprising fine-grained grey limestone and dolomitic limestone with thin intercalations of black to grey shale. The occurrence of limestone, dolomitic limestone and shale at Jamunedanda reflects the complex stratigraphic and tectonic setting of the Nepal Himalaya described by Dhital (2015). A thrust is reported approximately 3 km north of the site and a fault approximately 85 m west of the landslide. At the site, the crown exposes highly weathered to moderately weathered black shale, while the body and toe are dominated by colluvial material. Pencil cleavage and heavy fragmentation weaken the shale mass. Erosional and dry gullies, tension cracks and tilted trees were observed during engineering-geological mapping, indicating active or previously active slope deformation.

The objective of this paper is to document the investigation and mitigation approach adopted for Jamunedanda, emphasizing the integration of reinforcement, toe support, drainage, runoff control and bioengineering. The case is presented as a practical engineering case study rather than as a new analytical method.

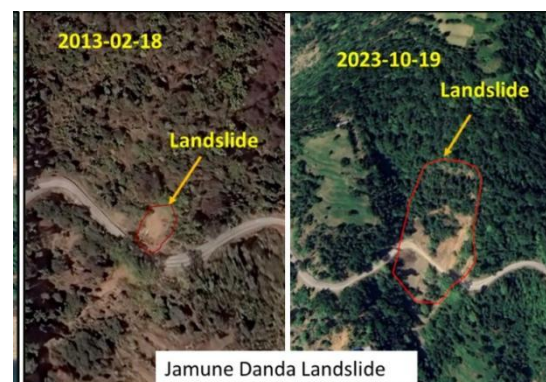


Figure 1, Time-series Google Earth imagery showing the development of the Jamunedanda landslide (2013–2023), from the project investigation report.

Methodology

The investigation followed a staged engineering-geological and geotechnical workflow. Desk study included review of existing geological, topographic, climatic and landslide information and interpretation of time-series satellite imagery. A total-station survey was then conducted to establish the landslide geometry and key topographic features. The surveyed area included approximately 12,450 m² at Jamunedanda.

Engineering-geological mapping at approximately 1:1000 scale documented lithology, weathering, discontinuities, cracks, gullies, drainage features, springs, old landslide masses and other geomorphic indicators. More than 200 discontinuity measurements were collected at representative rock exposures for rock-mass characterization and kinematic assessment. Field tests included USCS soil classification, relative-density assessment, Schmidt hammer testing and infiltration testing by the inverse-borehole method.

Laboratory testing included natural moisture content using ASTM D2216, specific gravity using ASTM D854, bulk density and grain-size analysis. Ten surface soil samples were evaluated. Stability assessment included kinematic and block-based considerations and preliminary numerical modelling using PLAXIS 2D. The numerical model used the site geometry and available material parameters; the project report notes that some subsurface conditions and groundwater assumptions were necessarily based on the available investigation data and expert assessment.



Figure 2, Field investigation activities including Schmidt hammer testing and in-situ USCS soil classification.



Figure 3, Infiltration assessment at Jamunedanda using the inverse-borehole method.

Results

The engineering-geological investigation identified a shallow landslide involving both rock mass and soil. Highly weathered black shale occurs at the crown, while colluvial and gravelly materials dominate the body and toe. The presence of dry gullies and concentrated runoff provides preferential pathways for erosion and infiltration. The project report also records tension cracking in the central body and tilted trees as geomorphic indicators of movement. These conditions require stabilization measures that address both the mechanical weakness of the slope and water-related processes.

Laboratory results show a heterogeneous but predominantly coarse slope mantle. Natural moisture content ranged from 4.88% to 14.88%, specific gravity from 2.64 to 2.74, and bulk density from 1.51 to 2.00 g/cm³. Sieve analysis showed 0.36–4.94% fines, 22.83–70.38% sand and 24.69–76.78% gravel among the ten samples. The reported classifications were mainly poorly graded sand with gravel (SP), well graded sand with gravel (SW), poorly graded gravel with sand (GP), and locally silty gravel (GP-GM).

The numerical assessment was preliminary because comprehensive subsurface investigation was not available at the time of modelling. The project report gives a natural-condition factor of safety of approximately 1.09 in its Jamunedanda discussion and also contains a table reporting 1.17 for the original condition and 1.68 with anchoring. Because these values are not fully consistent within the source report, they are treated here as preliminary design-analysis results rather than measured field performance. The analysis nevertheless indicates that reinforcement was considered beneficial to slope stability.

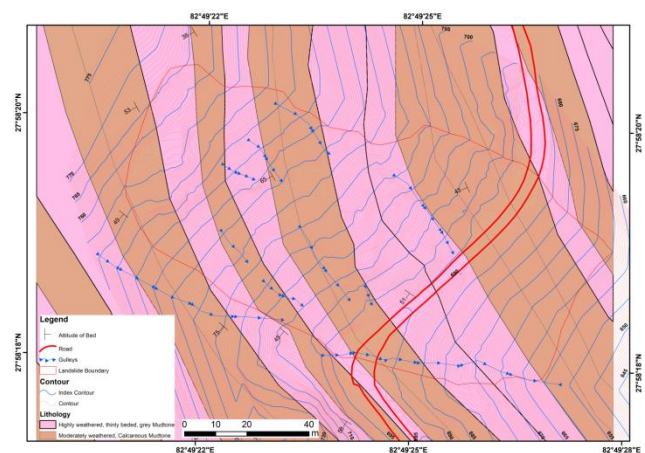


Figure 4, Lithological map of the Jamunedanda landslide area showing weathered shale, road, gullies and landslide boundary.

The mitigation strategy was developed as an integrated system. Unstable rock and soil were to be removed by scaling and controlled slope-geometry modification. Soil nails/anchors of 12 m length at approximately 2 m spacing were proposed in vulnerable crown and body portions. Retaining structures

approximately 3 m high were proposed at the hillside of the road and within the landslide body to provide toe support and retain displaced material. Horizontal perforated drains of approximately 15 m length at 15 m spacing were proposed to intercept subsurface water and connect it to the road drainage system. Check dams were proposed in the principal gullies, with small gullies treated using stone riprap. Bioengineering measures, including live fascines, stakes, brush layering, seeding and local vegetation establishment, were proposed to reduce surface erosion and improve long-term surface protection

The combination of reinforcement, retaining structures, drainage and bioengineering is particularly relevant for steep roadside slopes where space for large-scale regrading is limited. Mechanical measures address the unstable mass and provide direct support, while drainage reduces the influence of infiltration and concentrated runoff. Bioengineering provides progressive surface protection and erosion control as vegetation becomes established.



Figure 5, Jamunedanda slope before/during construction.



Figure 6, Jamunedanda slope after construction and completion of the mitigation works.

Mitigation and construction measures

The mitigation and construction works were implemented as an integrated system combining reinforcement, toe support, water management and biological erosion control. Unstable soil and rock were removed by excavation and scaling before stabilization. The design basis included 12 m soil nails/anchors at approximately 2 m spacing in vulnerable crown and body portions, retaining structures of about 3 m height, and horizontal drains of approximately 15 m length at 15 m spacing. In the completed works, both 6 m and 12 m anchors were installed according to local slope conditions and reinforcement requirements.

Gabion structures were constructed along the hillside and valley-side portions of the road-slope interface. These structures provide toe restraint, retain eroded or displaced material and permit drainage through their permeable construction. Surface-water pathways were controlled using drains, check dams and cascades/chutes, while horizontal drainage was incorporated where required to intercept subsurface water. These measures were intended to reduce infiltration, prevent concentrated runoff erosion and protect the stabilized slope during monsoon conditions.

Bioengineering was implemented over the upper and middle slope to provide surface erosion control and progressive vegetative stabilization. Locally available species including Napier, Simali, Bhujiro and Asuro, together with other suitable vegetation, were established on the treated slope. The before/during and post-construction photographs show the change from an exposed, partly treated slope with active construction works to a stabilized slope with anchor heads, gabion structures and developing vegetation.

Implementation lessons

The Jamunedanda implementation provides three practical lessons. First, construction measures should follow site-specific engineering-geological

characterization because weak shale, colluvium and granular slope materials require different forms of treatment. Second, drainage and runoff control should be constructed together with structural reinforcement rather than added later. Third, local bioengineering species can complement anchors, gabions and drainage by reducing surface erosion and supporting progressive revegetation. Staged construction is particularly useful where access and working space are restricted by a mountain road.

Conclusion

The Jamunedanda landslide represents a roadside slope-stability problem controlled by the interaction of weak weathered shale, granular colluvial materials, steep terrain and concentrated surface and subsurface water. Engineering-geological mapping and geotechnical testing identified highly fragmented black shale, heterogeneous coarse slope materials, erosional gullies, tension cracks and other indicators of slope movement. Laboratory testing confirmed the predominantly coarse nature of the slope mantle, while the preliminary numerical assessment indicated marginal natural-condition stability.

The proposed stabilization system combines slope-geometry modification, 12 m soil nails/anchors, retaining structures, horizontal drains, check dams, surface drainage and bioengineering. The principal engineering lesson from the case is that structural reinforcement should be integrated with water management and erosion control rather than treated as a standalone measure. Seasonal inspection, particularly following intense monsoon rainfall, is recommended to verify deformation, drainage performance and vegetation establishment.

Acknowledgement

The author gratefully acknowledges Geotech Solutions International Pvt. Ltd. for technical and field support and the investigation and design team for providing access to the engineering-geological, geotechnical and design information used in this case study. Appreciation is also extended to the concerned road authorities for their cooperation during the study and mitigation planning.

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