Post-Earthquake Stability and Rehabilitation of Mountain Trails ('Unnat Goreto') in Gorkha and Rasuwa Districts, Nepal

Bikash Adhikari[1], Ram Chandra Tiwari[2], and Aanchal Tiwari[2*]

[1]Department of Environmental Science and Engineering, Kathmandu University, Nepal
[2]Department of Civil Engineering, Institute of Engineering, Pulchowk Campus, Tribhuvan University, Nepal

(*Corresponding E-mail: 079mstre001.aanchal@pcampus.edu.np)

Abstract: This study evaluates the stability of 2017-rehabilitated Unnat Goreto trails in Gorkha and Rasuwa, Nepal, post-2015 Mw 7.8 earthquake, using 2D FEM in Rocscience Phase2 with SRM (Mohr–Coulomb and Hoek–Brown) under static and pseudo-static (EQx = 0.1 g) loading. The Gorkha trail is stable statically, marginally safe at 0.1 g, but unstable under higher seismic loads, while Rasuwa trails are more stable. Soil-bioengineering measures and dry stone retaining walls (Types 1–3), along with mule loads and track components, enhanced the factor of safety, emphasizing integrated geotechnical, bioengineering, and structural interventions for long-term stability in seismically active mountainous regions.

Keywords: ***Mule Track, Stability analysis, Safety factor, Finite element method, Earthquake.***

Introduction

This study analyzes 125 km of rehabilitated mule trails in Gorkha and Rasuwa, integrating engineering and bioengineering measures like footbridges, handrails, rest areas, and slope stabilization. Using Rocscience Phase2 and field data, it demonstrates improved stability under static and seismic conditions. Based on Google imagery and global guidelines (USDA, 1984; Minnesota, 2006; Trail Design, 2009), this is the first study on mountain trail stability in Nepal (Table 1).

Table 1, Mule Trail construction in the affected area in Gorkha and Rasuwa Districts.

S. No.	Major components of the trail construction	Detail
1	Trails (km)	125 (Gorkha: 70, Rasuwa: 55)
2	Foot bridge/truss bridge (Total Nos. and Total span (m))	9 (Gorkha: 5, Rasuwa: 4), 180
3	Rest areas/pedestrian rest shed (Nos.)	15 (Gorkha: 8, Rasuwa: 7)
4	Handrail and handholds in critical sections (m)	840
5	Bioengineering works on landslides (sq. m)	8,000
6	Geohazard mitigation works (m)	750

Trail construction in Gorkha and Rasuwa (125 km) followed DoLIDAR norms (DoLIDAR, GoN, 2010), with 1.5 m width, erosion control, drainage, and geotechnical assessments. Key features include flagstone paving, retaining walls, 9 footbridges, 840 m handrails, 15 rest areas, and bioengineering of 8,000 m² to stabilize 41 critical landslides, ensuring safety across cliffs and narrow passages.

Material and Method

Slope stability was analyzed using the 2D finite element program Rocscience Phase2 (Rocscience, 2012). The Strength Reduction Factor (SRF) was determined through the Shear Strength Reduction (SSR) method (Matsui and Sam, 1992) to evaluate critical safety factors. Mitigation models for critical trail slopes followed Popescu (2001) and DoR, GoN (2007). In Phase2, ground surface stresses were computed with a horizontal-to-vertical stress ratio ($\sigma H/\sigma V$) = 1.0 (Pal et al., 2012). Soil and rock properties were obtained from field data and literature: soil parameters from Krahenbuhl and Wagner (1983), and rock parameters from Griffiths and Lane (1999), Hoek and Diederichs (2006), and Deere and Miller (1966). The Mohr–Coulomb criterion was applied for soil and debris, the Generalized Hoek–Brown for bedrock, and Patton's (1966) criterion for discontinuities.

Mule load analysis (Figure 1) considered an average mule-load system of 240 kg (180 kg mule + 60 kg load), producing pulling forces of 120 N on flat terrain, 424.5 N on a 15° incline, and 708.5 N on a 30° incline, assuming average acceleration of 1 m/s² and neglecting friction.

Results and Discussion

The computational results of landslide slope stability for three critical Mule Trail sections in Gorkha and Rasuwa (2017) were computed as shown in the typical result in Figure 2. Analyses considered static and pseudo-static seismic loading (EQx = 0, 0.1, 0.2, 0.3), dry stone walls (Types 1–3), and 1 m soil-bioengineering layers. Critical sections include Kulkung Gang, Gorkha (28°13'28.46" N, 84°53'32.36" E), Rasuwa Loop-1 at 118 m (28°7'37.43" N, 85°16'30.8" E), and Loop-2 at 102 m (28°1'10.58" N, 85°15'7.86" E), selected from a total of 41 rehabilitated stretches. Results show slopes are safe under static conditions, marginally safe at EQx = 0.1, but unsafe under higher seismic coefficients. Factor of Safety improves with vegetated slopes and dry-stone wall variations. Shear strain plots and SRF vs Umax(m) identify elasto-plastic transition points where material shifts from elastic to plastic behavior.

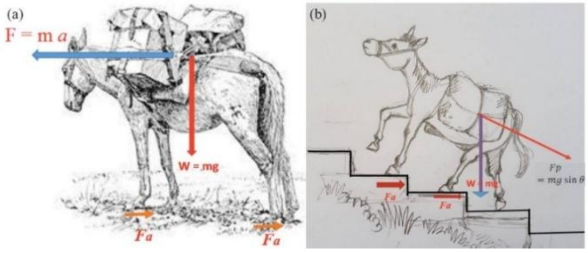

Figure 1, Mule load analysis: (a) Walking in the plain trail and (b) Walking in the steep trail.

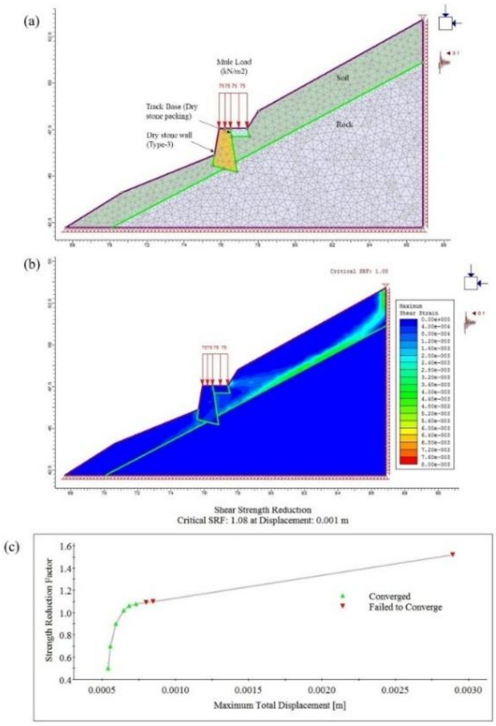

Figure 2, Typical stability analysis of Mule Trail at 102m big landslide, Rasuwa loop-2 (28-1-10.58N, 85-15-7.86E): (a) Landslide slope model, (b) Strain plots (kN/m2) and (c) Strength Reduction actor, SRF (nos.) vs U_{max} (m).

Conclusion

The stability of Mule Trails in Gorkha and Rasuwa was analyzed using 2D FEM, focusing on critical stretches. Trails were stable under static conditions but unstable under seismic loading; however, stability improved significantly with dry stone walls and soil-bioengineering measures.

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