Slope Stability Analysis and Suggestive Measures for an Active Landslide in Indian Himalaya

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Abstract. Landslides are frequently occurring phenomena in Indian Himalayas causing considerable loss of lives and property every year. There are several active landslides along the major highways which pose recurring problems to the traffics particularly during the monsoon season. One such landslide has been studied in detail for planning and design of suitable control measures. The paper presents the geo-investigation and slope stability analysis carried out to arrive at suitable control measures. Geotechnical investigation and slope stability analysis were carried out to assess the present stability condition of the landslide. The results of the analysis have shown that the landslide is presently active and it needs suitable control measures to minimize the landslide activities. Soil nailing was one of the options found to be suitable for reinforcement of loose debris material on the uphill slope. It was observed that the stability of the slope significantly improves when soil nailing measure was considered.

1 Introduction

Landslide disasters causing loss of life and property are enormous in Indian Himalayas. The complex geology and tectonic set up supplemented by heavy rainfall and anthropogenic activities made the Himalayan region very prone to landslides. There are many locations where human lives are in danger due to landslides. A large number of slope failures have affected the major highways in the Himalayas, which are also important routes for pilgrims. One such National Highway (NH-58) Rishikesh-Badrinath road in the Alaknanda river valley is very prone to landslides particularly in the vicinity of Main Central Thrust (MCT) zone. A few hazard zones were identified as most potential zones, where number of landslides is affecting the traffic and thereby posing threats to lives (Sarkar et al. 2005). Such landslides were mapped on the high resolution CARTOSAT I remote sensing image and a small segment of this region is shown in the Fig. 1. In the present study, one active landslide in this region near Pipalkoti along the same highway has been investigated for stability analysis and suggestive control measure (Fig. 2).

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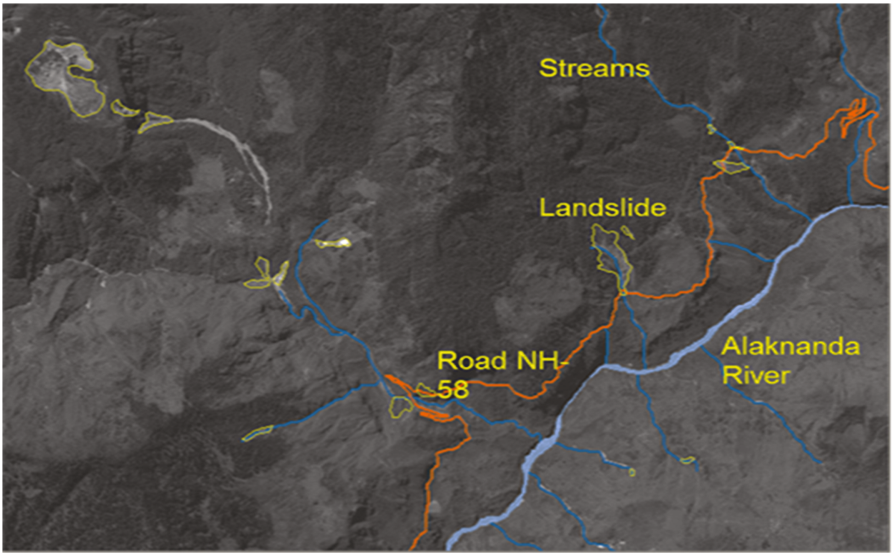

Fig. 1. Landslides along National Highway (NH-58) mapped on satellite image (Sarkar et al. 2013)

Fig. 2. A panoramic view of the landslide

2 Landslide Description

The studied landslide is a debris slide including debris materials and a few rock boulders on a steep slope. The rock types exposed in the slide area are dolomites which primarily consist of calcites and quartz. Topographic survey of the landslide was carried out to know the topographic features and to generate a contour map on 1:500 scale with 1 m contour interval. A DEM was prepared in GIS from the contour map and a slope map was generated. From the slope map it was observed that maximum area in the landslide site is having the slope angle 35–45°, however, there are a few escarpments with very steep slope of 45–60°. The landslide is divided into two parts by a seasonal drain. The road has been severely damaged on the downhill slide due to the ongoing landslide activities (Fig. 3).

Fig. 3. Highway at risk due to debris slide

The detailed sub-surface geological investigation of the landslide has indicated four different types of materials with the same litho-units of dolomitic limestone. The top layer is a soil layer having silty clay. The next layer is a debris material comprising of soil with rock fragments of dolomitic limestone which is followed by highly weathered soft dolomitic limestone. The bottom stratum is the fresh hard dolomite. The thickness of debris material was found to be around 8–10 m.

3 Geotechnical Investigation

To assess the geotechnical characteristic of the landslide site, samples were collected to evaluate its physical and engineering properties. Various test such as grain size analysis, moisture content, Atterberg limits, specify gravity, bulk density, dry density, void ratio, relative density and direct shear tests were carried out (Table 1). The grain size analysis shows that the material is dominated by gravels and sand size particle. There is no clay content which indicates that the slide material has no cohesion. Direct shear tests were carried out using a large shear box apparatus, as the slide materials contain a significant amount of gravels and sands. The direct shear tests were conducted on samples at four different normal stress (σ_n) levels. The samples were prepared in the shear box having size 300 mm × 300 mm at the minimum densities of the respective samples. The tests were conducted at normal stresses of 0.5, 1.0, 1.5 and 2.0 kg/cm^2 which approximately correspond to anticipated normal stress in the field. For a given value of the applied constant normal stress, shear stress was applied by shearing the specimen at a rate of 0.2 mm/min. The tests were conducted up to failure. The direct shear test results thus obtained are plotted (Fig. 4) to obtain shear parameters i.e. cohesion and angle of internal friction (c & Φ) which are presented in Table 2.

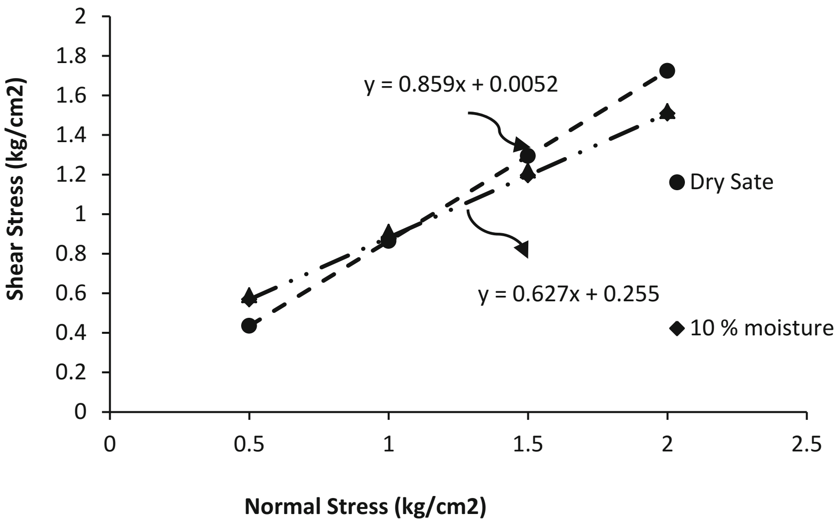

Fig. 4. Shear envelope of sample obtained from direct shear test

Table 1. Physical properties of soil samples

Sample	IS classification	Particle size distribution (%)			Physical properties		
		Gravel	Sand	Silt & Clay	Max. density	Min. density	Specific gravity
1	GP-GM	56	27	17	2.198	1.95	2.66
2	GM	42	37	21	2.04	1.81	2.67

Table 2. Results of shear test

Sample	At dry state		At 10% moisture	
	c	Φ	c	Φ
1	0.005	40.69	0.255	32.12
2	0.09	42.61	0.28	32.04

From the above data it can be said that there is an increase in cohesion ‘c’ and decrease in angle of internal friction “Φ” with increase in moisture content. The shear strength of the sample decreases with increase in moisture content. Hence, it can be inferred that the debris material loses its shear strength as the moisture content increase towards saturation.

4 Slope Stability Analysis and Mitigation Measures

Stability analysis of the landslide was carried out to know the state of stability condition of the landslide so that suitable control measures can be designed. The failure mechanism of the slide appeared to be a circular failure as observed from the field observations. Limit equilibrium methods were used to determine the factor of safety of the landslide slope under different condition. The analysis was carried out for two most probable failure profiles. Two sections as shown in the Fig. 5 of the slide area were selected to carry out slope stability analysis. Factor of safety were calculated using GeoStudio software (SLOPE/W) at different moisture conditions and without earthquake and with earthquake loading. The results of the analysis are shown in the Fig. 6 and the values of factor of safety are tabulated in the Table 3. From the table it can be inferred that the factors of safety of both the sections are marginally stable under dry and static conditions but it drastically decreases in the range of 0.8 to 0.5 under partial saturation and earthquake loading. Selection of an appropriate remedial measure depends on several factors such as engineering feasibility, economic feasibility, social

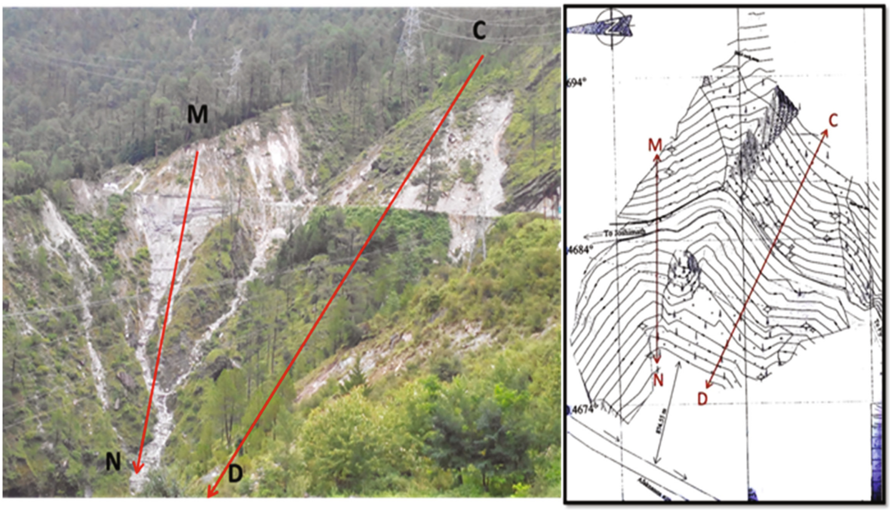

Fig. 5. Sections for stability analysis

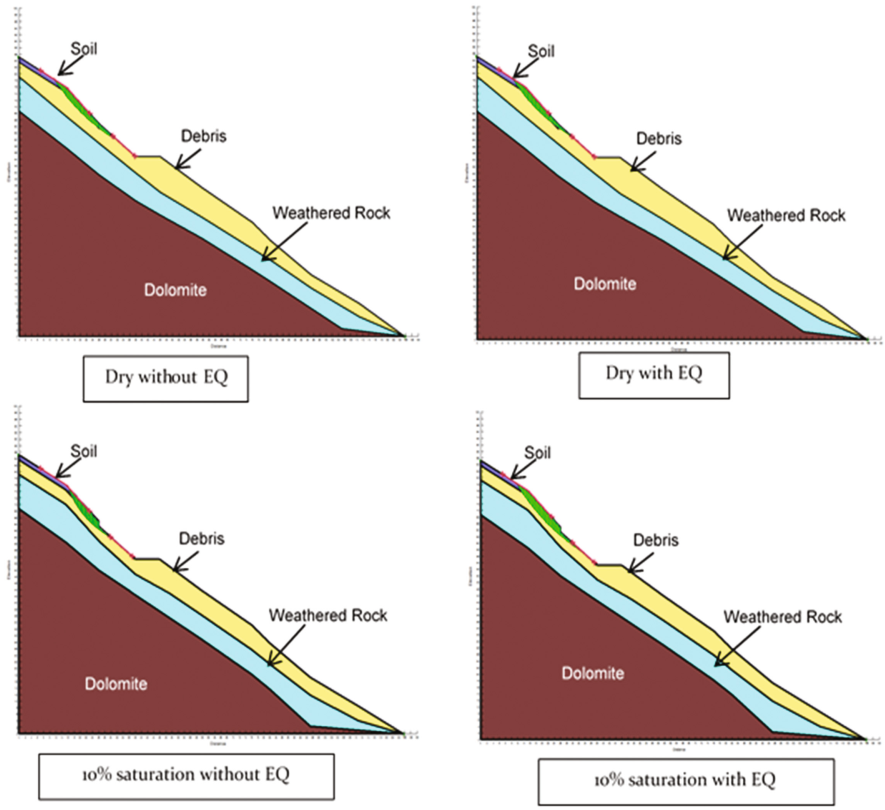

Fig. 6. Slope stability analysis without considering remedial measures

Table 3. Factor of safety of MN and CD sections

Sections	Moisture condition	Without EQ	With EQ
Section MN	Dry	0.966	0.779
	10% saturation	0.664	0.541
Section CD	Dry	1.051	0.839
	10% saturation	0.786	0.628

acceptability, and environmental acceptability (Holtz and Schuster 1996). There are various measures available for stabilizing an unstable slope. As already stated, the slope above the road comprises of loose shallow overburden of soil and debris. Hence it was thought to reinforce the slope material on the uphill slope with soil nailing.

Soil nailing is an in situ soil reinforcing technique adopted for stabilizing unstable slopes (Sharma et al. 2019). It increases the overall shear strength of unsupported soils and is relatively flexible and can accommodate large settlements. Also soil nailing is more economical than conventional concrete gravity wall. The soil nail gains pull-out resistance from within the sliding soil mass in front of the slip plane and the stable soil mass located behind the slip plane. The geometric system of soil nail placements creates an internally reinforced soil mass that is stable. The soil nail acts as a passive bearing element, which relies on soil movement and subsequent active earth pressure to mobilize the shear strength along the nail whereas a tieback anchor is pre-stressed to mobilize shear strength (Junaideen et al. 2004). Soil nails were designed suitably and stability analyses were carried out in SLOPE/W module limit equilibrium method using GeoStudio software to see the efficacy of the nails. Different parameters were analyzed by the Morgenstern-Price method. The reasonable design parameters obtained by the analysis are given in the Table 4. The values of factor of safety obtained after inclusion of soil nails are given in the Table 5 and the results of the analysis are shown in the Fig. 7. It is observed from the analysis that factor of safety increases significantly after installing soil nails as stabilization measures. The factor of safety with soil nails increase to 2.4 and 2.8 in dry condition from 0.97 and 1.0 for sections MN and CD respectively. Even under partial saturation the slope is stable after inclusion of nails.

Table 4. Specification of soil nails

Nail parameters	Values
Nail diameter	25 mm
Bar capacity	415
Bond diameter	100 mm
Spacing (horizontal & vertical)	2 m each
Nail length	5 m and 6 m
Skin friction	300 kPa

Table 5. Factor of safety of MN and CD sections with soil nailing as stabilizing measures

Sections	Moisture condition	Without EQ	With EQ
Section MN	Dry	2.388	2.210
	10% saturation	1.536	1.276
Section CD	Dry	1.723	1.410
	10% saturation	1.667	1.256

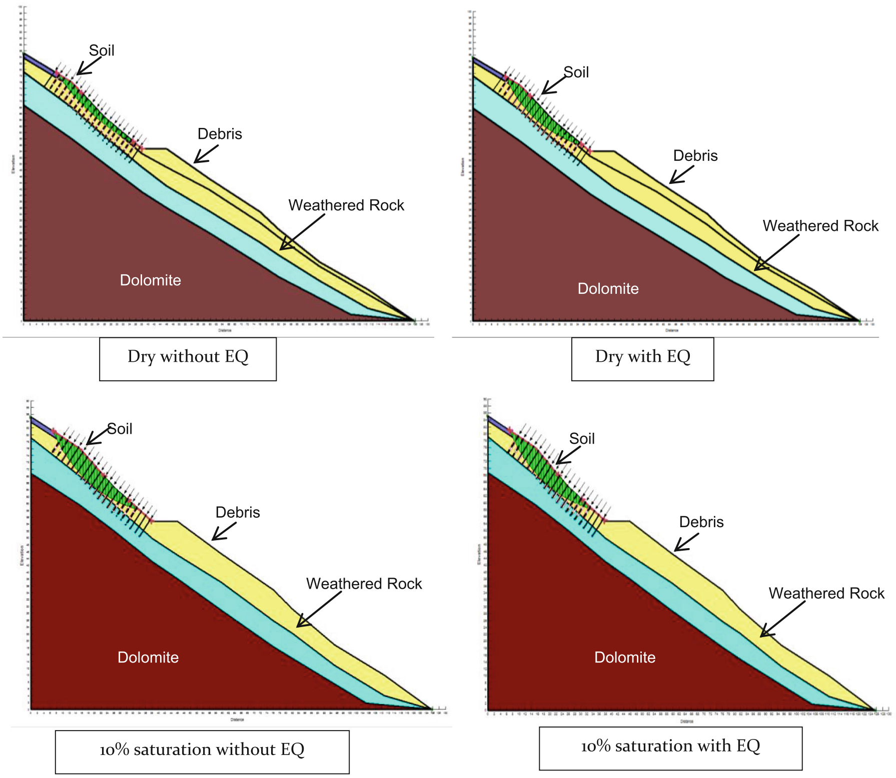

Fig. 7. Slope stability analysis with inclusion of soil nails (Geo-Slope International Ltd., GeoStudio 2007)

5 Conclusions

An active landslide along a major highway of Indian Himalayan region was investigated in detail for arriving at suitable remedial measures. Laboratory studies were conducted to determine the engineering propertied of the slope material. Stability analysis was carried out for two vulnerable sections of the landslide slope to determine the degree of instability of the slope. The factors of safety were found to be close to one which indicated the marginal stability condition of the slope. To increase the stability of the slope particularly on the uphill slope, soil nailing measure was selected. Further analysis showed that the stability of the slope has significantly increased after reinforcing the slope material with soil nails. This indicated that soil nailing could be one of the options to minimize the on-going sliding activities of the landslide. The study is being continuing for testing other measures at different locations so that a comprehensive design of control measures can be suggested.

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