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Analysis of Road-Cut Slope in Calcareous Rocks and Stabilisation by Shotcreting and Rock Bolting, Dehradun-Mussoorie Road, Uttarakhand

Virat Singh Chauhan, Md. Rehan Sadique, Mohd. Masroor Alam

Aligarh Muslim University

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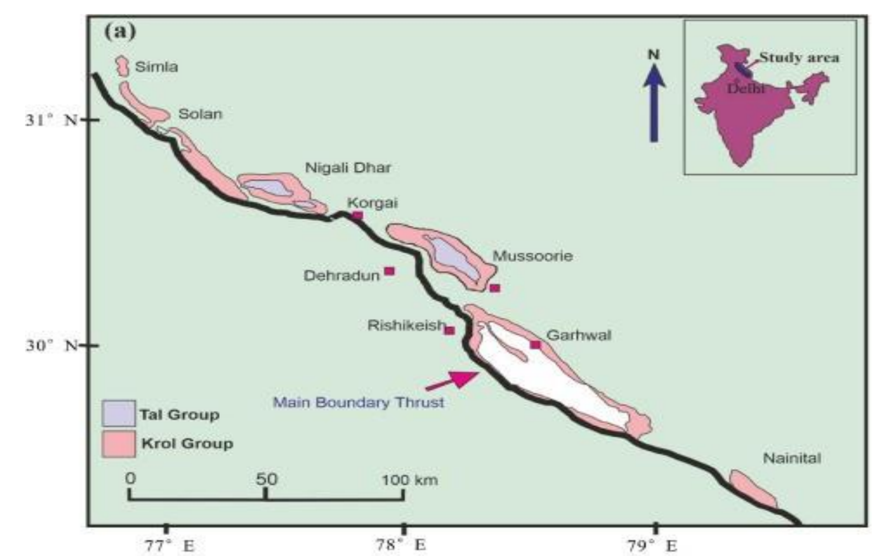
Abstract – In this study, analysis and stabilisation of four road-cut slopes in the lesser Himalayan region near Mussoorie, along Dehradun- Mussoorie Road, are investigated using the shotcreting and rock bolting technique. The rocks studied are calcareous in nature with varying rock mass properties. The exposure is along the road cuts with slope varying from 70^0 to 90^0, showing toppling to wedge failure. The stability analysis is performed through the Finite Element Analysis (FEA) and Factor of Safety (FOS) is evaluated using the Shear Strength Reduction Technique. The evaluation considers various conditions, including unreinforced slopes and slopes reinforced with rock bolts and shotcrete, to thoroughly assess the effectiveness of rock bolting in enhancing stability. The results indicate that rock bolting combined with shotcreting improves slope stability by approximately 10–40% across the different slopes analyzed.

Keywords: Dehradun-Mussoorie Road, Limestone, Road-Cut Slope, FOS, Rock Bolting.

I. Introduction

Rock Bolts are one of the widely used methods of stabilisation in case of rocky slopes, tunnels, underground structure, mining etc. The technique works by transferring load from the unstable slope surface to the interior stable slope with the help of high yield strength deformed bars in combination with shotcreting (Hoek & Bray, 1981). This combination results in the increment in the shear strength and overall stability of the rock mass (Hoek et al., 2000). Rock bolts are particularly effective in fractured or jointed rock masses where they act by tying and reinforcing the jointed rock mass, thus reducing displacement, and preventing failure (Singh and Goel 2011). The effectiveness of rock bolting largely depends on several factors such as the length, spacing, orientation, and anchorage methods of the bolts, as well as the geological conditions of the slope (Singh and Goel 2011). The geological condition of slope is governed by strength of rock and overall character of rock mass. The analysis of rock bolting can be done by using Numerical Modelling techniques, such as the Finite Element Method (FEM) combined with the Shear Strength Reduction (SSR) technique (Jing & Hudson, 2002) to evaluate the factor of safety of the slope.

The current study focuses on the stability analysis of four road-cut slopes along NH-707A near Mussoorie along Dehradun-Mussoorie Road, Uttarakhand (Fig. 1a). The rocks are largely calcareous and include largely limestone with some dolomite intercalations (Jiang et al.). The rock sequence stratigraphically belongs to Krol Formation, encircling the Mussoorie Syncline (Fig. 1b). The rocks are moderately strong with less than 40 MPa of compressive strength. The rocks show loss of strength due to random cracking at microscopic scale as well as due to weathering when dolomitised and comes down to 30 MPa. The roadside view of the four locations is shown in Fig. 2.



(a)

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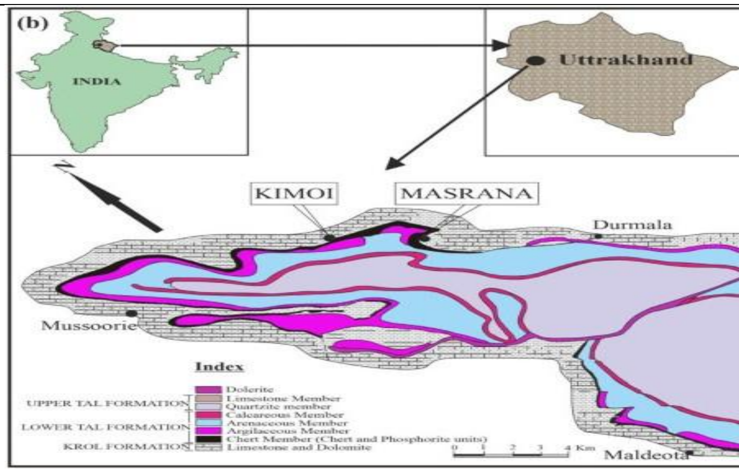

(b)

Fig. 1: (a) Map showing the distribution of the various synclines within the Krol Belt which contains Tal Group (modified after Jiang et al., 2002); (b) Geological Map showing Mussoorie location of the section examined (modified after Khan et al., 2016).

The studied slopes are found to have slope varying from 70^0 to 90^0 (> 45^0). The rock mass comprises three discontinuity sets with varying spacing, forming rectangular to cuboid-shaped with volumes ranging from 0.08 to 0.2 m³ at locations L1, L3, and L4. Location L2 experiences wedge failure along three sets of conjugate joints, resulting in the formation of large prismatic wedges with volumes ranging from 2 to 8 m³. While toppling failure is observed at locations L1, L3, and L4.

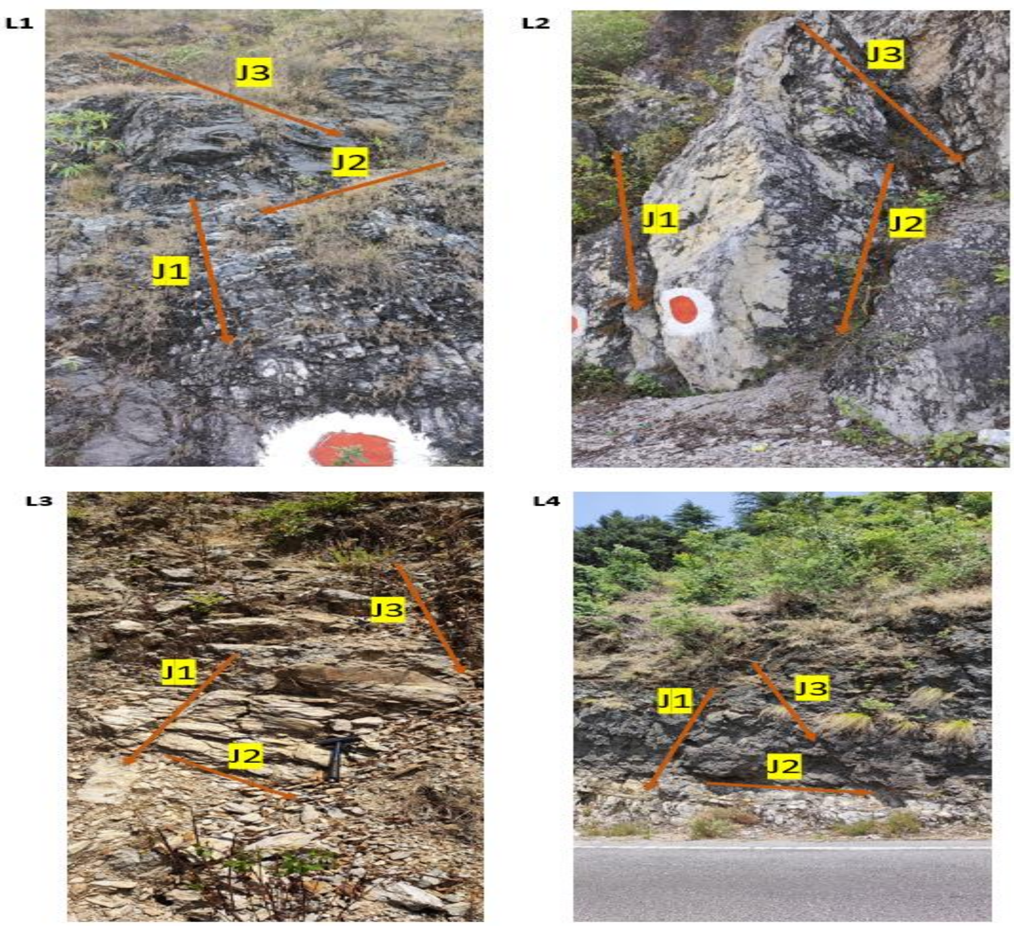

Fig. 2: Roadside view of the four road-cut slope locations.

The rocks are Micritic Limestones, moderately to highly weathered due to their presence in the humid tropical conditions. The rocks show micro-fractures which are sealed with Calcite-Quartz veins (Fig. 3), suggestive of intense compressive tectonics involved along the convergent plate margin, characteristic of Himalayan Tectonics.

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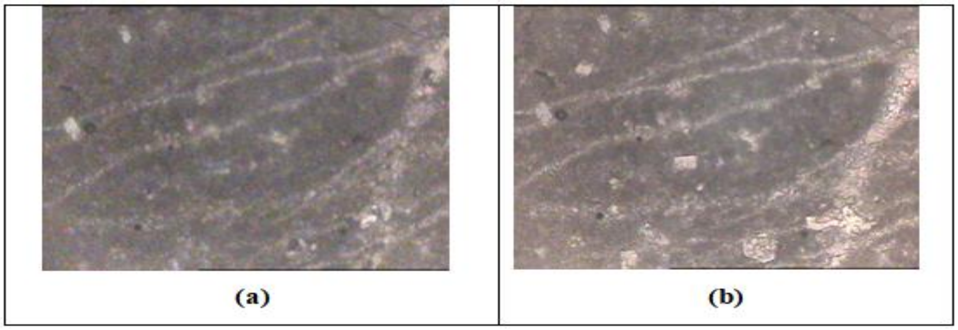

Fig. 3: Photomicrograph of Krol Limestone with Micro-Crystalline Calcite interspersed with micro veined cracks of calcite and quartz. (a) Under Non-Polarised and (b) Under Polarized Light (60 X Magnification).

The analysis is performed on Rocscience RS2 software. The analysis is carried out in two stages: first, without reinforcement, and then with reinforcement applied using shotcrete and rock bolting. The stability assessment is done to comprehensively evaluate the effectiveness of rock bolting in enhancing the stability of the slope.

II. Method of Analysis

To carry out stability analysis in Rocscience RS2 software, the material parameters are collected from the field surveys and laboratory studies for Slope Height, Slope Inclination, Geological Strength Index (GSI), rock mass characterization and Unconfined Compressive Strength (UCS) of the rock material. The slope is modelled using six-node triangular elements. The boundary condition is kept fixed at the bottom, while one side is restrained in one direction(Griffiths and Lane, 1999). The geometry of the model with and without reinforcement is illustrated in Fig. 4. The material model is selected as Generalised Hoek-Brown model due to the non -linear nature of the rock mass. The stability assessment is done using shear strength reduction technique (Dawson et al., 1999). The material parameters utilised for slope stability analysis are shown in Table 1.

Table 1. Slope and Rock Mass Parameters used for performing Finite Element Analysis

Parameters	**L1**	**L2**	**L3**	**L4**
Height (m)	63	66	18	15
Inclination (°)	75	70	70	90
Unit weight (kN/m^3)	27	27	27	27
UCS (MPa)	37	35	28	34
GSI	45	40	34	37
E_{rm} (MPa)	2606	1834	837	1080
Bolt Length (m)	25	25	7	6

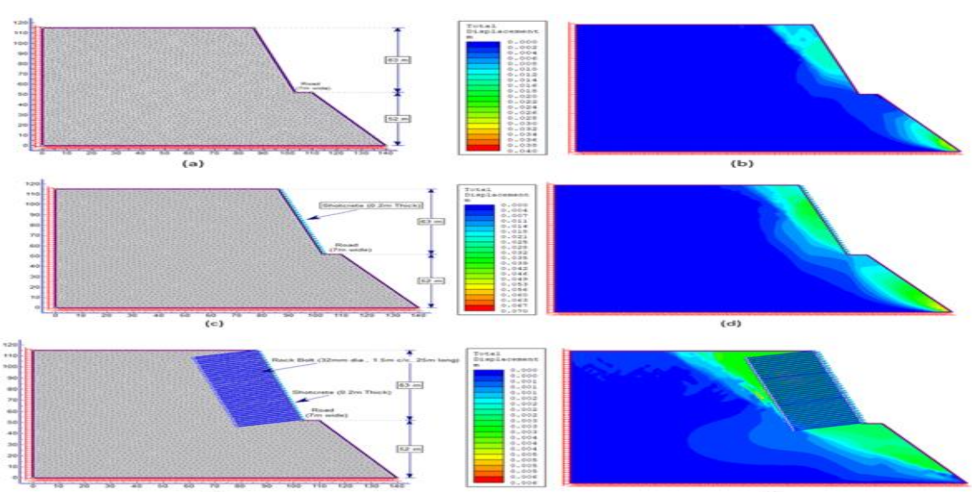

Fig. 4: (a) Geometry of the model for Location L1 without any reinforcement (b) Total Displacement profile for L1 (c) Geometry with Shotcrete (d) Total Displacement with Shotcrete (e) Geometry with Shotcrete and Bolts (f) Total Displacement with Shotcrete and bolts.

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III. Results and Discussion

The study focuses on the stability analysis of four road-cut slopes using Rocscience RS2 along Dehradun-Mussoorie Road. For analyzing the slopes, Generalised Hoek Brown model is taken as material model. The stability analysis is performed using the Shear Strength Reduction (SSR). The analysis is carried out in three stages, first without any reinforcement and second with reinforcement as shotcrete and thirdly combination of shotcreting and rock bolts.

In the first stage, when no reinforcement is applied, the calculated FOS values for the four slopes were found to be 1.14, 1.05, and 0.72, 0.83 respectively. These low FOS values indicate marginal to unstable conditions of the slopes, which are caused due to adverse orientation of discontinuities and slope, low Uniaxial Compressive Strength (UCS) of weathered limestone, Geological Strength Index (GSI), steep slope angles and tectonic activity in this region.

In the second stage, shotcreting with a thickness of 20 cm is applied to the slope surfaces. The shotcreting resulted in a marginal increase in FOS by 10-15%. While location L1 and L2 became stable with shotcreting, locations L3 and L4 remained in the unstable category. In the subsequent stage, shotcreting is combined with rock bolts, with the bolts installed at a length equal to 40% of the slope height, diameter of 32mm, spacing 1.5m c/c and oriented at an inclination of 15° clockwise to the horizontal plane. The inclusion of rock bolts significantly improves the stability of the slopes, with FOS values increasing by approximately 20–40% as illustrated in Fig. 5. This improvement highlights the effectiveness of rock bolts in conjunction with shotcreting in enhancing the slope stability by providing additional shear resistance and restricting potential failure mechanisms.

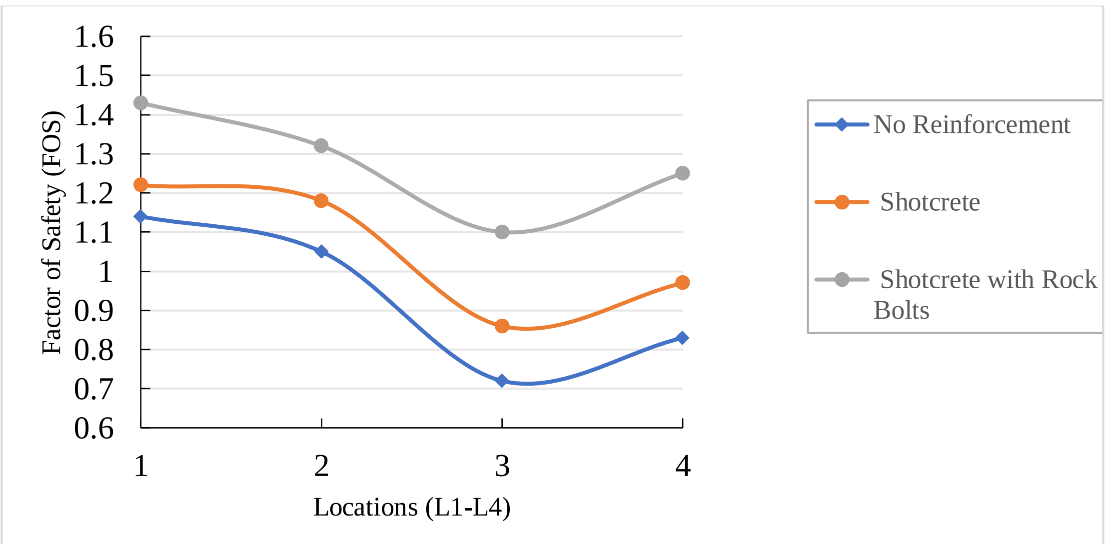

Fig. 5: Graph Showing Variation of Factor of Safety values for unreinforced and reinforced Slopes.

IV. Conclusions

This research employed Rocscience RS2 software through the Generalized Hoek-Brown model to determine stability aspects of four road-cut slopes along NH-707A in Mussoorie, Dehradun, Uttarakhand India. Three different conditions were evaluated using the Shear Strength Reduction method for determining the Factor of Safety (FOS): initially without reinforcement, with shotcreting and with shotcreting combined with rock bolt installation. The analysis performed without rock bolts produced stability results of 1.14, 1.05, and 0.72, 0.83 which indicated partial stable to unstable behaviour due to very unfavourable discontinuity orientation, low UCS, GSI values along with steep slopes in a active tectonic setup.

The application of 20 cm thick shotcreting marginally improves FOS by 10–15%, stabilizing locations L1 and L2 but leaving L3 and L4 in the unstable category. However, the combined application of rock bolts and shotcreting significantly enhances slope stability. Rock bolts with lengths measuring 40% of slope height became more effective when installed at 15° inclination thus raising the FOS by 20–40%. The performance of rock bolts becomes apparent because they provide shear strength enhancement which controls potential failure conditions. The study concludes that rock bolting is a practical stabilization technique for road-cut slopes in challenging geo-tectonic conditions, such as in Himalayan states.

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