Slope stability assessment of Hathi Parvat landslide along Badrinath route on National highway-58

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Abstract

The paper deals with the slope stability assessment of the Hathi Parvat landslide along Badrinath route (NH-58) near Marwari Bridge in Chamoli district, Uttarakhand. The slide occurred on the southern slope of a ridge locally known as Hathi Parvat during the peak yatra season, which left thousands of pilgrims stranded on both side of the landslide. It was a rockslide, which had severely damaged about 100m of road stretch. It not only created problems to the moving vehicles but also enhanced risk and further instability of the hill slope. The gneissic rock mass is exposed all along the road section as well as in upper reach with thin mica schist bands. The rock mass is hard, compact and jointed with foliation dipping into hill i.e. 55° towards N5°W. In addition to foliation joint, the rock mass is also traversed by five sets of prominent and a random joint set. For deciphering, the geo-scientific cause, the joint data have been collected and analyzed kinematically which reflects that landslide has occurred primarily due to planar failure along valley dipping joint planes (J2). To evolve site-specific remedial measures suitable to the existing geo-environmental condition, kinematic analysis of joint data and estimation of factor of safety (FOS) have been worked out. The paper presents various solutions to restore hill slope stability.

Keywords: Slope stability, landslide, FOS.

1. Introduction:

Slope stability is the resistance of inclined surface to failure by sliding against slope or collapse. In Uttrakhand problem of slope instability is a serious issue especially during monsoon season. India is a holy land of pilgrimages among which mostly are located in Himalayan region. Badrinath is one among the famous Char dhams situated in Uttarakhand where thousands of devotees come to pray every year. A landslide occurred on 19.05.2017 in the afternoon, along Badrinath route on the National Highway-58 (Fig.4D) near Visnuprayag in Chamoli district, Uttarakhand. The slide occurred on the southern slope of a ridge locally known as Hathi Parvat during the peak yatra season, which left thousands of the pilgrims stranded on both side of the landslide. The landslide is located at latitude 30º 33´ 48.4"; longitude 79º 34´ 08"and falls in part of Survey of India Toposheet number 53N/10. The landslide occurred at about 10.5 km from the Joshimath town towards Badrinath on the right bank of the Alaknanda River, about 800m downstream of Visnuprayag. The National Highway No. 58 (NH-58) which connects Rishikesh with Joshmath can approach by all-weather road (Fig.1). The nearest railhead is at Rishikesh, which is about 270 km, and the nearest airport is at Dehradun, which is about 300 km away from Joshimath.

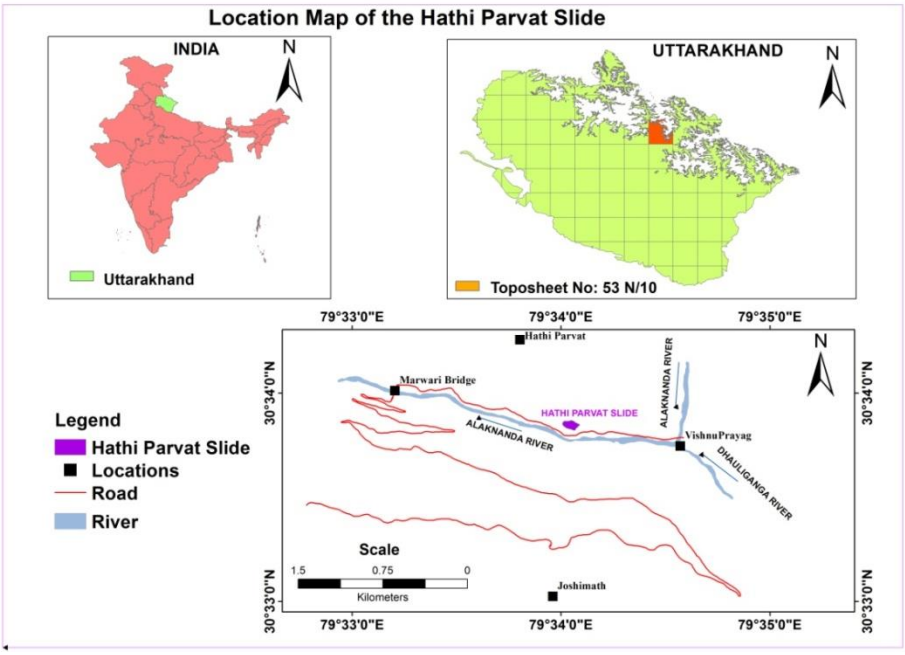


Figure 1 Location map of the Hathi Parvat Landslide

2. Geology of the Landslide Area:

The Hathi Parvat slide area is located within the Uttarakhand segment of the Main Himalayan Belt. The Himalayan Metamorphic Belt is one such tectonic slice of regional magnitude within the Main Himalayan Belt, comprising the Central Crystalline Group of rocks with syn- to post- granitoids, basic rocks and migmatisation. The area exposes Central Crystalline Group of rocks, which are thrusted over the Garhwal Group of rocks represented by the Chamoli and the Pipalkoti Formations, along a northerly dipping major tectonic discontinuity known as Main Central Thrust (MCT) passing south of the study area (GSI Special Publ. 26, 1989; Kumar, G, 2005).

The rock exposed near the landslide is quartzo-feldspathic gneiss with lenticular bands of quartzite showing well-developed foliation/gneissosity defined by alternating light and dark bands and schistose interbands. The rock mass is hard, compact and jointed, with foliation/gneissosity dipping into the slope i.e. 55° towards N5°W (Fig.4C). Besides, the foliation/gneissosity, the rock mass is also traversed by five sets of prominent joints with one random joint set. The study area falls under seismic Zone V of Seismic Zoning map of India.

3. Description and factors influencing the stability of the slide:

The landslide (Fig.4C) is a rock slide, occurred along steep/ escarpment having angle more than 45^0. The general ground slope in the area is about 57^0 toward $S10^0W$. The rock slide has a width of about 100 m, length ~150 m and height ~80 m (Fig.4A). The area is barren with sparse vegetation cover at places. The gneissic rock mass is exposed all along the road section as well as in upper reach with thin mica schist bands. The material involved in the slide comprises of angular rock blocks and fragments of gneisses and mica schist. The slided

materials are accumulated on road side as well as below the road level i.e. on right bank of river (Fig. 4E, F).

The triggering factor seems to be rainfall and uncontrolled blasting, un-scientific and unplanned road widening activities without any proper slope protection measures have loosened the rock mass and reduced its shearing strength which accentuated the failure during first phase of heavy rainfall there. As per media report, the area has been receiving moderate to heavy rainfall and hailstorm intermittently.

4. Analysis of Results and Discussion:

This work has focused on the rock mass characterization by kinematics analysis (stereographic projection) of the discontinuities. FOS has been calculated for the outcrop according to Hoek and Bray (1981). Based on the preliminary assessment, it seems that the landslide has occurred due to planar failure along valley dipping joint (J2) and few wedge failures; in combination with road cutting activities. For appreciating the geo-scientific cause, the joint data have been collected and analyzed kinematically, which are shown in Fig.2 & 3.

Table-1
Characteristic of Joints

Sl. No.	Joint Number	Attitude		Characteristics				Responsible discontinuity/intersection of discontinuities	Possibility of Failure	FOS	Remarks
		Dip amount	Dip Direction	Spacing (in cm)	Continuity/ Persistence (in m)	Aperture/Opening	Condition				
1.	J_1	55^0	$N355^0$	2-60	>6m	Tight	MSP-RU				Foliation, hillside dipping
2.	J_2	55^0	$N185^0$	5-200	> 8m	Open >5cm	SP-MSP	Wedge Planar	J2, J3	1.80 0.63	Valley side dipping, unstable
3.	J_3	65^0	$N300^0$	5-30	< 2m	Tight to open 0.5mm-1cm	RU	Planar	J2, J3	0.63	Oblique, downstream dipping, unstable
4.	J_4	72^0	$N275^0$	25-100	>6m	Tight	SP-MSP	Wedge	J4, J5	2.56	Downstream dipping, Slickensides, stable
5.	J_5	65^0	$N140^0$	5-20	>1m	Tight to open < 0.5mm	MSP-RU		J4, J5	2.56	Oblique, Upstream dipping, stable
6.	J_6	77^0	$N105^0$	5-300	>5m	Tight	RU				Oblique, Upstream dipping

Remarks: RU: Rough Undulatory, MSP: Moderately Smooth Planar, SP: Smooth Planar.

The kinematic analysis shows that, the joint J2 is most crucial planar fabric in rock mass which attributed to planar failure in unstable Zone-I. This has also been observed in field, along which the rock mass got slided. In addition to this marginal wedge failure has also been observed due to intersections of some other prominent joint planes. The stereographic projection (Fig. 2) shows that the intersections of joints J4 & J5 and Joints J2 & J3 are falling on margin of unstable zone. However, the analysis shows no toppling failure (Fig. 3). Since, rock mass is jointed, having opening more than 5 cm at places and dislodged, the valley dipping joints are loosened further due to blasting, fluctuation in temperature and ingress of water due to sudden spurt in rainfall in the area. The surface runoff while passing through these joint planes results in decrease of shear strength of rock mass, which leads to sliding along unfavorably oriented joint planes (Figs. 2 & 3).

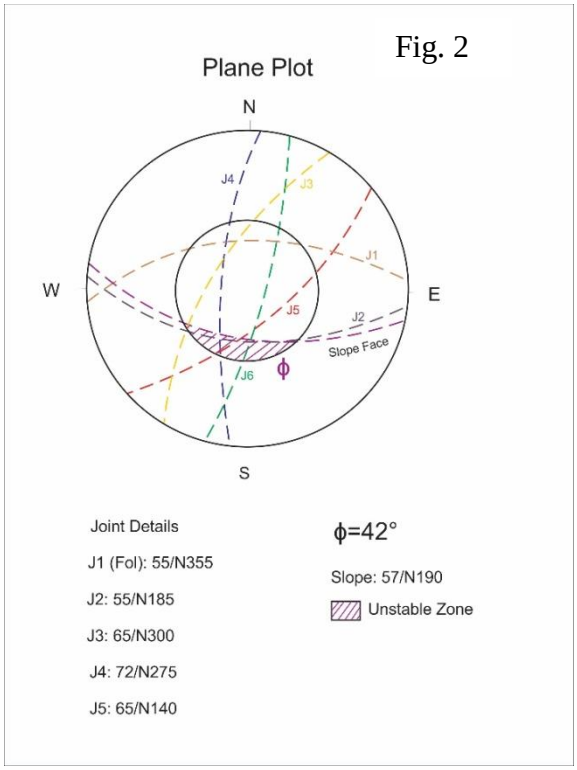
FOS of a rock slope is the ratio of resisting forces to driving forces. If FOS is less than or equal to 1, the slope will fail. If FOS is much larger than 1, the slope will be quite stable. However, if the FOS is slightly greater than 1, small disturbance may cause the slope to fail (Hoek and Bray, 1981). To analyse various modes of rock slope failures (planar wedge and toppling), Markland's test has been performed as described by Hoek and Bray, (1981). Various mode failure has occurred due to presence of various unfavourable oriented discontinuities (Hoek, 2007). Kinematics refers to the motion of bodies without reference to the forces that causes them to move (Goodman, 1989). It is one of the most useful techniques in the recent years to investigate possible failure modes of rock masses which contain discontinuities (Hussain et.al. 2015).

$$\text{F.O.S for Wedge failure} = \frac{\sin\beta * \tan ø}{\sin(\xi/2) * \tan\theta} \quad \text{….(1)}$$

$$\text{F.O.S for Planar failure} = \frac{[cA + (W\cos\Psi - U - V\sin\Psi)\tan ø]}{(W\sin\Psi + V\cos\Psi)} \quad \text{….(2)}$$

Where:
β is the angle of intersection line of discontinuity and the bisector.
Ø is the frictional angle.
ξ is the wedge angle.
θ is the plunge of intersection line of two discontinuities.
c is cohesion.
A is the area of the block.
Ψ is dip of failure plane.
W is the weight of sliding block.
U is the uplift force due to water.
V is force due water pressure in tensile crack.

Putting the values in equation 1 and 2, the FOS for wedge failure is greater than 1 i.e. 1.80 and 2.56 which is at margin and stable zone respectively and F.O.S for planar failure 0.63 which is unstable.



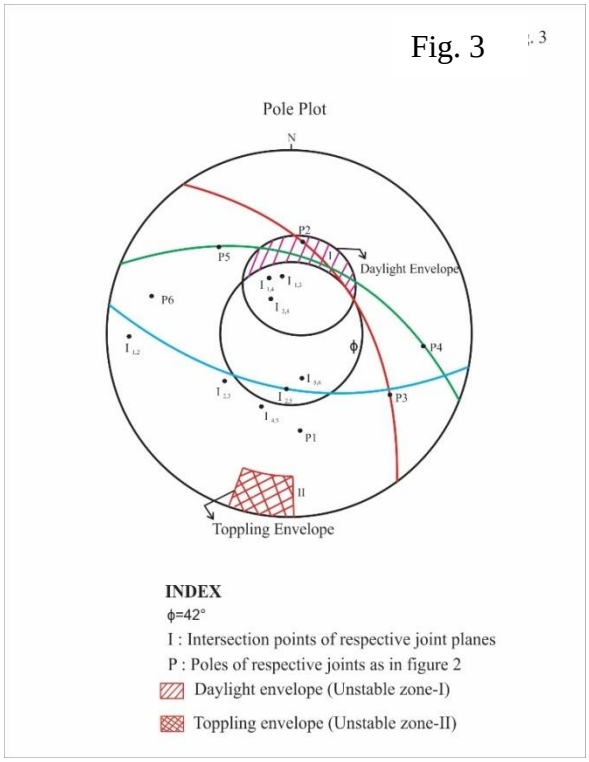


Figure 2 and 3 Stereographic projections of Joint planes and Topography showing their mutual kinematic relations.

Figure 4 (A) Hathi Parvat slide along National highway (NH-58), (B) Synoptic view of Hathi Parvat slide (from opposite end), (C) Different Jointsets observed at Hathi Parvat slide, (D) Upstream view of the Hathi Parvat slide, (E) View of the slidedrock blocks and (F) Closer view of the Hathi Parvat slide.

Based on analysis of the structural data, effective solutions to tackle slide would be rock bolts at right angle to the foliation joints and valley dipping joint planes, shotcrete with wire mesh to prevent weathering, construction of concrete breast wall and flood protection wall etc. As the area exhibits steep topography with jointed rock mass uncontrolled blasting would lead to widening of joints and detachment of distressed rock mass, therefore controlled and designed blasting techniques needs to be adopted.

5. Conclusion:

After evaluating the landslide by recording morphometric, geomorphologic, geological parameters, rain fall and anthropogenic activity such as road cutting and blasting triggered the slide and the main cause of slide is planar failure along steep valley dipping joint planes and also the wedge failure due to the intersection of the various joints. Toe cutting and negative slope have been formed during unplanned/ un-designed road widening, which facilitated day lighting of valley dipping joint planes, which became instrumental and vital reasons for such type of failure on steep slopes. During rains, percolation of water along these joint planes led to lowering of shear strength of the rock mass resulting failure.

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