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Geological Assessment of A Slide Zone on SH-36, Near Kalimath in Rudraprayag District, Uttarakhand, India

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Abstract

A landslide zone stretching nearly 400 m along the SH-36 with the length of 115 m is located nearly 8 km from Guptkashi on way to Kalimath Village in Rudraprayag District, Uttarakhand. The rocks in the slide zone vicinity belongs to Kalimath Formation of Jutogh Group that falls under the Higher Himalaya. The rocks in the slide area are characterized by intercalated sequence of quartzite, schist and gneiss with thin bands of amphibolite. Regional strike of these rocks is E-W dipping due north. The rocks are fragile due to excess seepage of water at places. There are three sets of prominent joints with some variation and random joints. The kinematic analysis indicates possibilities of toppling of the rock blocks particularly with intersection of the joint planes N010°/75° and N110°/60°, where slope is trending N250°/65°. Similarly, toppling has also been indicated by the joint plane N015°/75°, where slope is trending N165°/55°. The 'Sum of Moments' comes out to be 113.57 kN/m, and 107.2 kN/m, respectively, for these two slope conditions, which indicates unsafe slope conditions. The analysis further indicates that intersection of the joint planes N180°/60° and N110°/60° makes the host rock prone to Wedge Failure. However, the value for factor of safety comes to 1.78, which indicates comparatively safe condition as far as Wedge Failure is concerned. Further, slope stability analysis for debris slope by limit equilibrium method indicates that slope is near to equilibrium towards stability in static conditions, while it may prove to be unstable during saturated and pseudo-static conditions.

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Keywords

Landslide, Rudraprayag, Uttarakhand, Kinematic Analysis.

Introduction

There are lots of major as well as minor landslides reported in hilly areas, most of which occur in monsoon season due to heavy rainfall. These disrupt road connectivity in the mountainous terrain of the Himalaya where the roads are the only way of communication especially in interior places. The present study deals with one such situation in Garhwal Division of Uttarakhand State. The State of Uttarakhand is well known for a number of holy shrines, particularly the Kedarnath, Badrinath, Gangotri and Yamunotri in the interiors of the Himalaya, which cover the popularly known Char Dham Yatra. In addition, there are several other holy shrines at different places of Uttarakhand, which attract a number of pilgrims throughout the year depending upon the location of the holy shrine. The roads connecting various holy places are often cut-off by landslides, particularly during the monsoon by heavy rains, thereby disrupting not only the pilgrim traffic but also the local traffic.

The Study Area

The present study is restricted to a landslide on State Highway (SH)-36 leading to the famous historical and religious temple dedicated to Goddess Kali situated in Rudraprayag District of Garhwal. This temple, known as 'Kali Temple', attracts pilgrimage not only during Yatra Season but throughout the year.

This temple can be approached from Rudraprayag via National Highway (NH)-109 that goes up to Gaurikund for Kedarnath via Augustmuni, Kund, Guptkashi and Sonprayag. A road bifurcates from the NH-109 just before Guptkashi, known as SH-36 that leads to Kotma via Kalimath. The 'Kali Temple' is located along this road nearly 9 km from the starting point of SH-36, on the right bank of Kali Ganga River. The road, however, remains cut-off most of the time, particularly in the monsoon season, by a landslide zone, just nearly a km before the temple.

The slide zone has even affected the Kunjethi Village, which is located above the SH-36. This slide has remained active after the well-known massive devastative disaster of June 2013 in Uttarakhand, which has been reported by various workers, notable amongst these are: Rautela (2013); Dobhal *et al.,* (2013); IMD (2013); NIDM (2013); DMMC (2014) and GSI (2014, 2015).

Geological Assessment

The geology of Uttarakhand, in general, and Rudraprayag District, in particular, have been worked out and discussed by several workers, some of which include Valdiya (1980); Bist and Sinha (1980); Negi *et al.,* (1980); Rautela and Thakur (1999); Kumar (2005); DMMC (2014) and others.

The study area falls in the Higher Himalaya, which is characterized by the low to high grade metamorphic rocks of Central Crystalline Gneissic Complex, comprising mainly augen gneiss, mica schist, granitic gneiss with xenoliths of amphibolite, migmatite, etc. Based on the lithology and tectonic set up, these rocks have been divided into different litho-units, viz. Vaikrita Group and Jutogh Group, The rocks of these two groups have been separated by the Vaikrita Thrust.

The rocks of Jutogh Group overlie the Garhwal Group of rocks along the Main Central Thrust (MCT), which marks the boundary between the Lesser and the Higher Himalaya. Jutogh Group is divided into lower Okhimath and upper Kalimath formations. The lower boundary of the Garhwal Group is marked by the North Almora Thrust. The Garhwal Group of rocks are represented by a thick succession of low grade metasedimentaries comprised of quartzite, slate, phyllite, metabasics and carbonate rocks, which are divided into five formations, viz., Rudraprayag, Lameri, Gwanagar and Patroli formations, in an ascending order.

The rocks in the vicinity of the slide zone belongs to the Kalimath Formation of Jutogh Group. The rocks in the slide area are characterized by intercalated sequence of quartzite, schist and gneiss with thin bands of amphibolite. The gneiss is mainly coarse grained biotite gneiss.

At places the quartzite show thinly foliated nature. Regional strike of these rocks is persistently trending in E-W direction, dipping due north. The rocks are mostly buff-brownish in colour, coarse to fine grained, weathered to massive in nature. At certain locations the rocks are found to be fragile due to excess seepage of water.

As mentioned earlier, Kunjethi Village is located nearly 100 m above the road on the lower slopes of N-W trending ridge dissected by many spurs. Most part of the Kunjethi Village has been washed-off with the slide, which was located on the slope wash material and debris slope. Even a foot-track passing through the middle of the village has been cut-off by the debris slope.

Rocks are intermittently exposed in patches within the slope. Slope varies from moderately gentle to steep. Similarly, rocks are also exposed along the road and below the road in patches. Debris as well as river borne material (RBM) are exposed at the river bed.

The geological map of the slide zone has been given in Fig 1.

The Km 8 Slide Zone is a stretch of nearly 400 m along the road (SH-36) and is restricted between the two prominent drains on either side. The length of the slide is 115 m. Majority of the area is covered with dense vegetation and soil cover. Toe is often affected by the river, particularly in the monsoon.

Further investigations show that the groundwater is playing a major role in the activation of slide. The major patch, which is affected by the slide, has crown elevation of 70m and mainly contains debris slide. The slide that pass through the road is characterized by dormant as well as active debris slide. The slope of the slide varies from 45° to 60°. The rocks are highly jointed, fractured and even show shearing effect at few places.

At least three sets of prominent joints have been observed with some variation and random joints. The prominent joints are:

J1 - N0°/45°
J2 - N70°/50°
J3 - N180°/60°

Details of the joints are given below in Table 1.

Further, four geological cross-sections have been prepared to understand the lithological and slope relation along with the joint pattern. The section lines have been shown in the Geological Map (Fig 1) and the cross sections have been shown in Figures 2 to 5.

Kinematic Analysis

Kinematic analysis, which includes Markland's Test described by Hoek and Bray (1981), was carried out to understand the hill slope stability in the Slide Zone. The rocks in the area are highly jointed as such the rock breaks into pieces of varying size and gets deposited as debris along the hill slope.

The joint planes as mentioned above in Table 1, have been plotted on the stereo net and are shown in Fig 6.

Analysis was carried out for likelihood of Topple Failure in two different slope conditions. Firstly, Topple Failure analysis, where the slope is **N250°/65°,** shows that:

i) The joint planes N070°/50° and N070°/45°, which appeared vulnerable to toppling in N070° direction, fall just outside the critical zone for Topple Failure (Fig 7; the shaded triangle). Hence, toppling may be ruled out due to these two joint sets.

ii) Intersection of joint planes N010°/75° and N110°/60° fall within the critical area for Topple failure (Fig 8a). It tends N081°/56°, indicating likelihood of toppling towards N081°.

In case of Topple Failure, the "Sum of Moments" determines the likelihood of toppling. Hence, determination of "Sum of Moments" was undertaken to analyze possibility of Topple Failure of these blocks. A value of "Sum of Moments" equal to 0.0 indicates no likelihood of toppling. Positive values of "Sum of Moments" indicate likelihood toppling.

The input parameters for analysis of "Sum of Moments" in case of Topple Failure is shown in Fig 8b, where the value of "Sum of Moments" comes out to be 113.57 kN/m, which indicates unsafe slope conditions.

Secondly, analysis was carried out for the situation where slope is trending **N165°/55°**. It shows that:

i) The joint plane N015°/75° passes through the critical zone for Topple Failure (shaded triangle in Fig 9a). Hence, toppling is possible here.

The input parameters for analysis of "Sum of Moments" in case of Toppling Failure is shown in Fig 9b, where the value of "Sum of Moments" comes out to be 107.2 kN/m, indicating unsafe slope conditions.

ii) On the other hand, Wedge Failure is indicated by the intersection of joint planes N180°/60° and N110°/60° that lie very close to the critical zone (Fig 10a). The likelihood of Wedge Failure is analyzed for the Factor of Safety through the software. The input parameters for determination of Factor of Safety are shown in Fig 10b.

The analysis gives the value of 1.78 for the Factor of Safety, which indicates safe conditions as far as Wedge Failure is concerned.

The field photographs of the landslide zone have been shown in Figs 11 and 12.

Table.1 Details of Joint Sets at Km 8 (Kalimath) Slide Zone

Joint sets	Joint plane (Dip Dir/ Amt)	Spacing	Aperture	Continuity	Roughness	Weathering Condition	Infilling
J1	N0°/45° (FJ)	<0cm	<1cm	Prominent	Smooth	Slightly Weathered	Weathered Material
	N10°/75°	10cm	0.5cm	Often	Smooth, Planar	Slightly Weathered	Weathered Material
	N0°/27°	>30cm	Nil	Often	Smooth	Fresh	Nil
	N0°/60°	>20-<30cm	Nil	Often	Smooth	Fresh	Nil
	N15°/75°	10cm	0.5cm	Often	Smooth	Slightly Weathered	Fine Silt and Clay
	N20°/45°	>40cm	Nil	Often	Smooth	Fresh	Nil
J2	N70°/50°	5cm	<1-0.5cm	Prominent	Smooth, Planar	Slightly Weathered	Weathered Material
	N70°/45°	5cm	<1-0.5cm	Prominent	Smooth, Undulating	Slightly Weathered	Weathered Material
J3	N180°/60°	<20-30cm	Nil	Prominent	Smooth, Planar	Fresh	Nil
	N200°/25°	5-10cm	<1cm	Often	Smooth, Planar	Slightly Weathered	Weathered Material
Ran-dom	N110°/60°	<20-30cm	Nil	Often	Smooth	Fresh	Nil

Figure.1 Geological Map of the Slide Zone

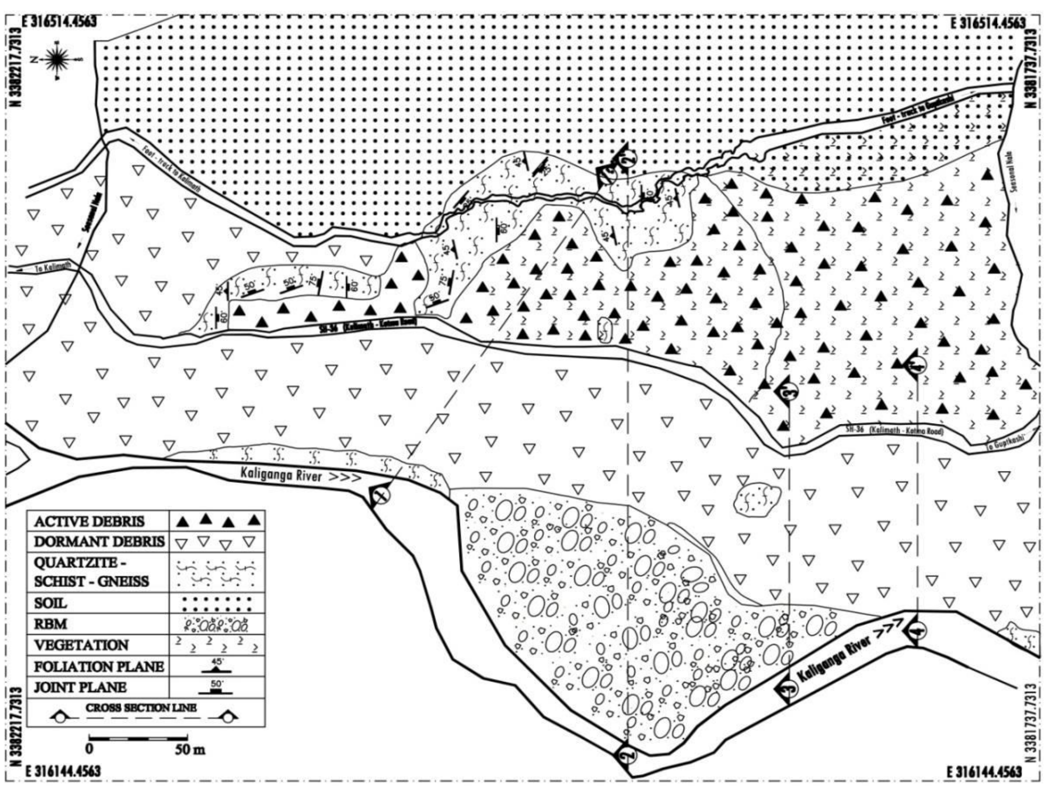

Figure.2 Geological Cross-section along 1-1'

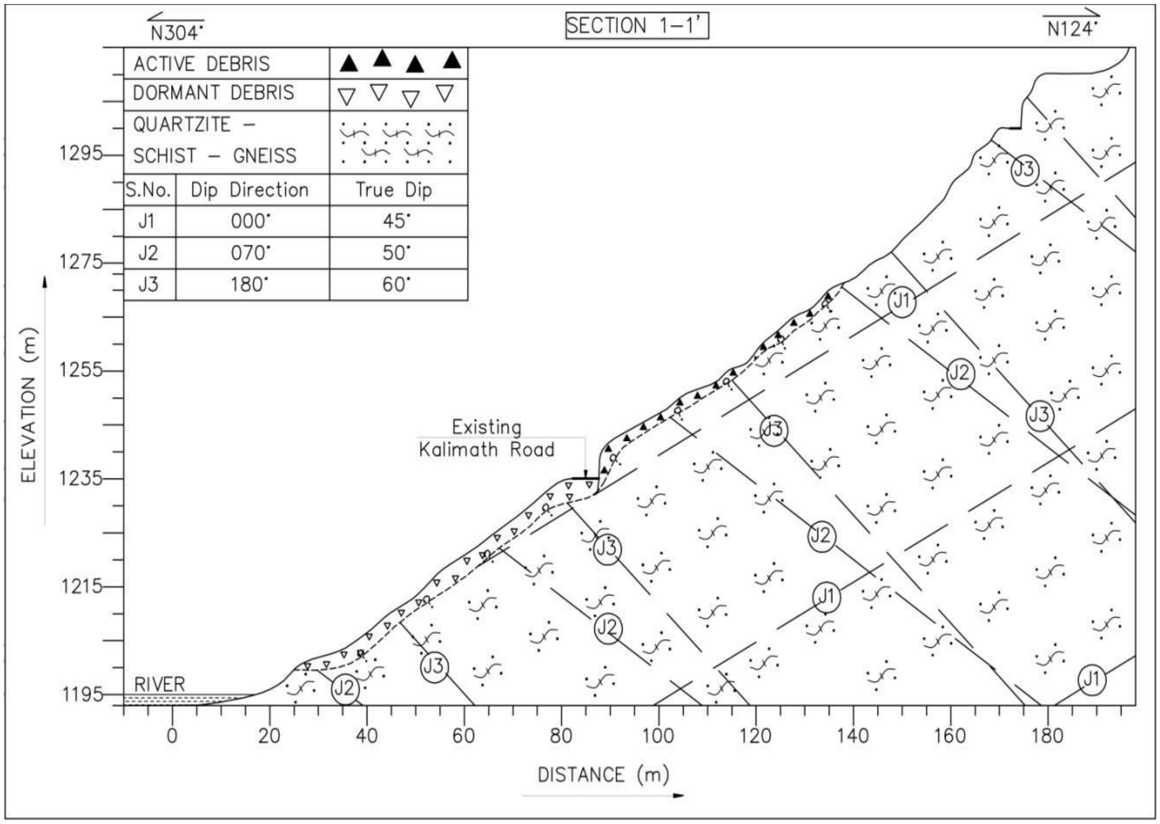

Figure.3 Geological Cross-section along 2-2'

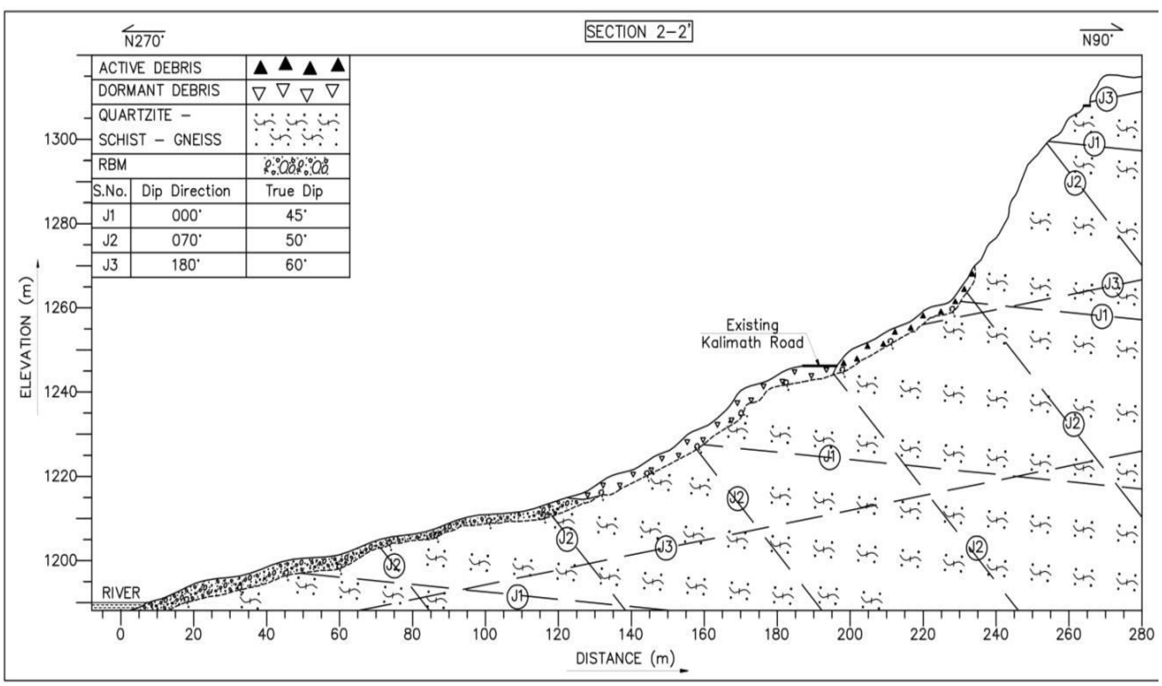

Figure.4 Geological Cross-section along 3-3'

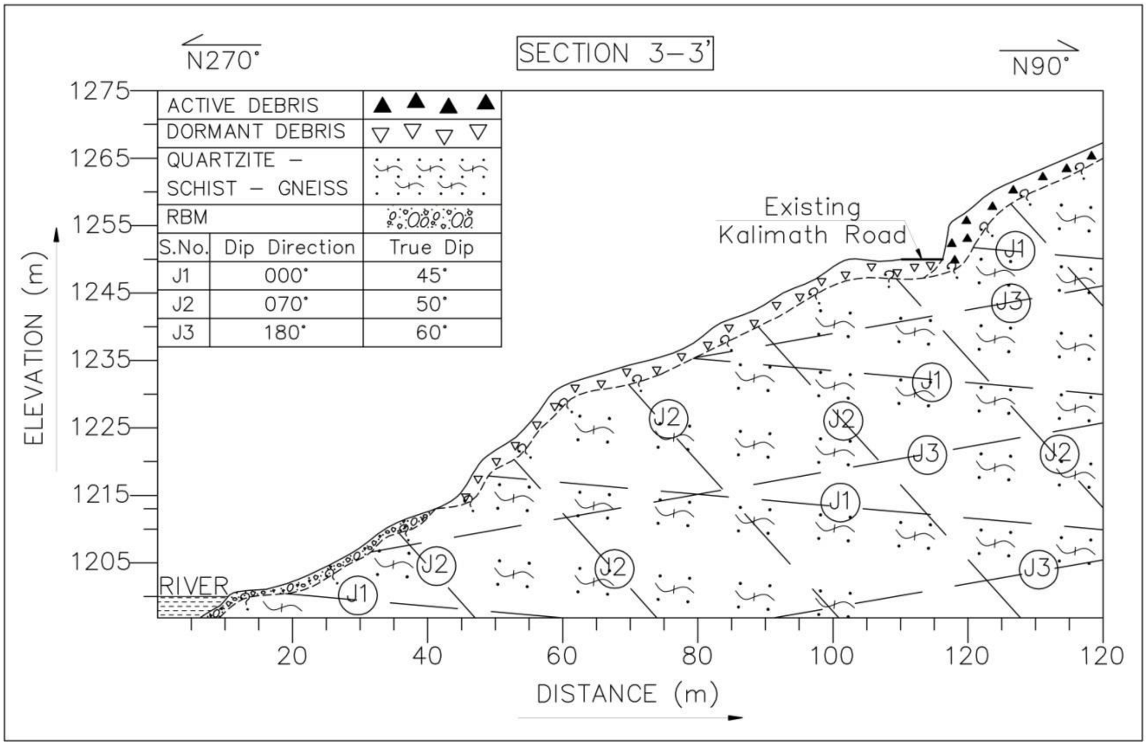

Figure.5 Geological Cross-section along 4-4'

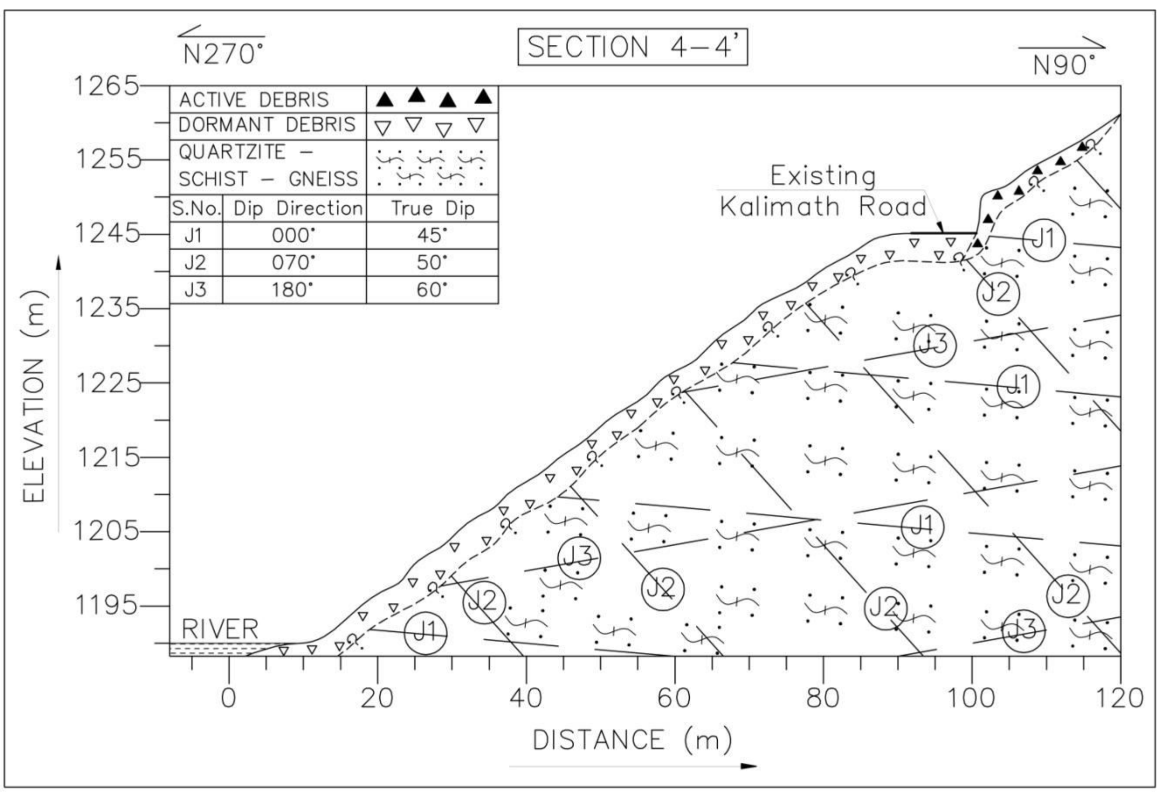

Figure.6 Joint planes plotted on stereo net

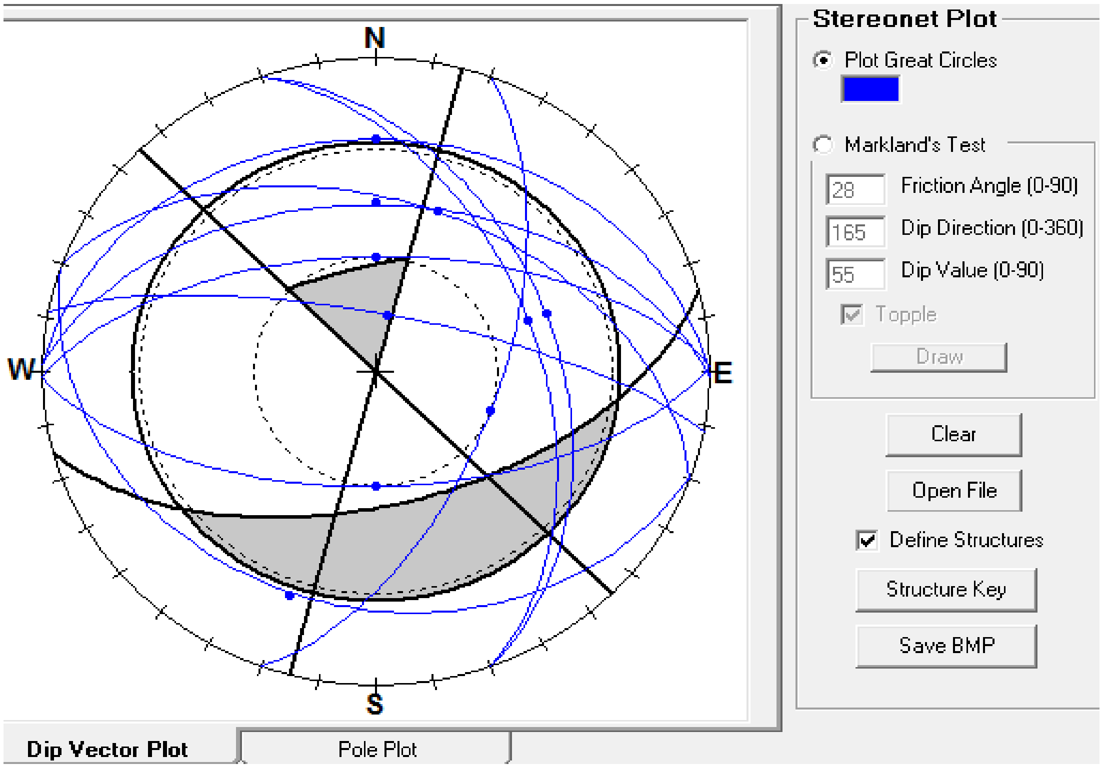

Figure.7 Topple Failure for joint planes trending N070°/50° and N070°/45°

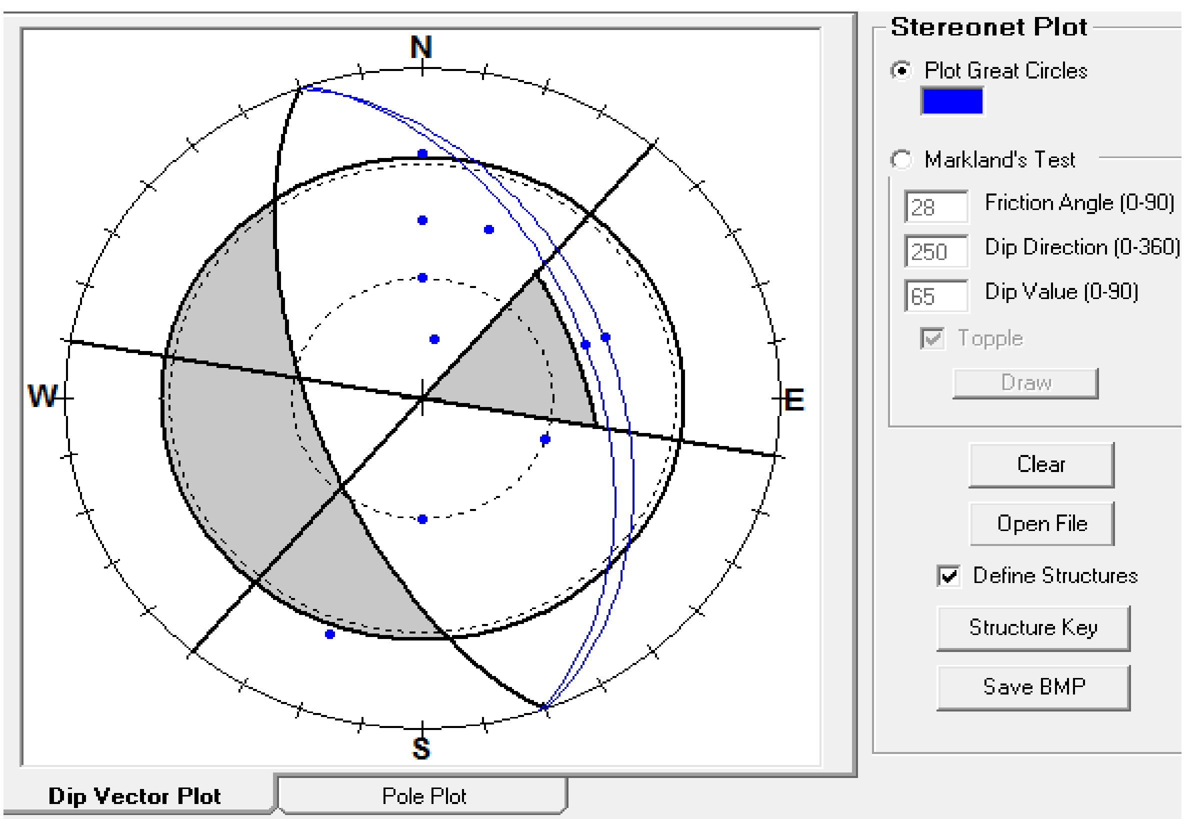

Figure.8a Topple Failure for joint planes trending N010°/75° and N110°/60°

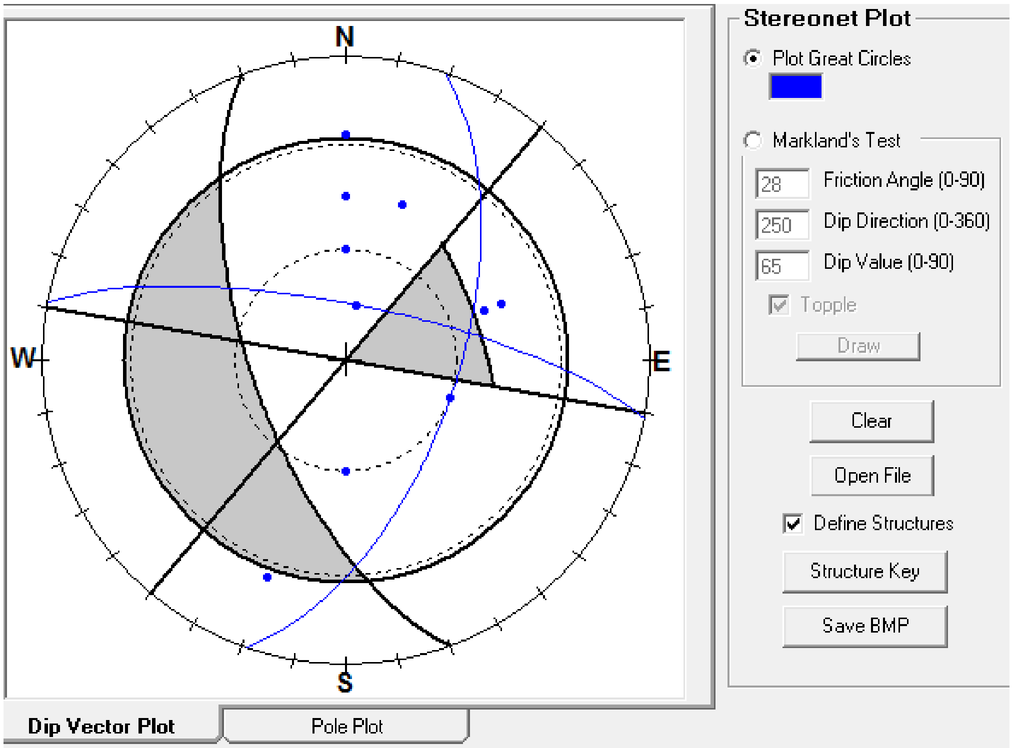

Figure.8b Analysis for Sum of Moments in Topple Failure

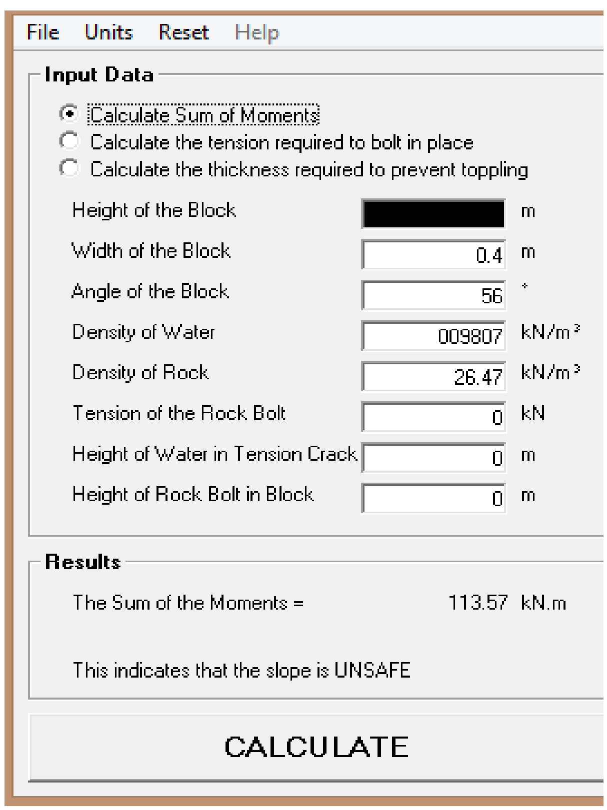

Figure.9a Topple Failure for joint plane trending N015°/75°

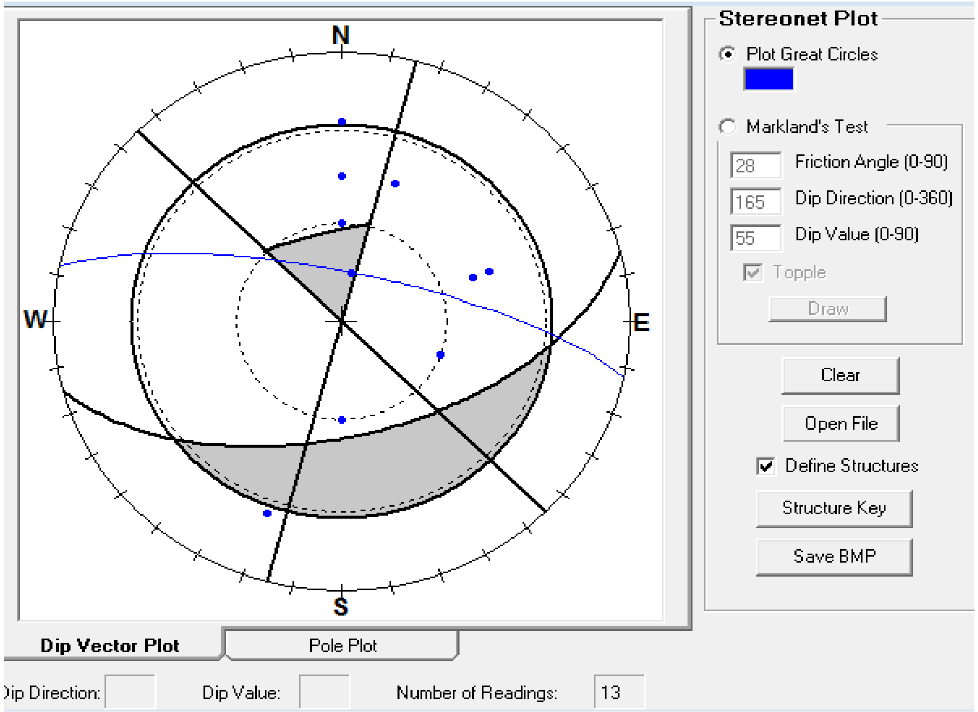

Figure.9b Analysis for Sum of Moments in Topple Failure

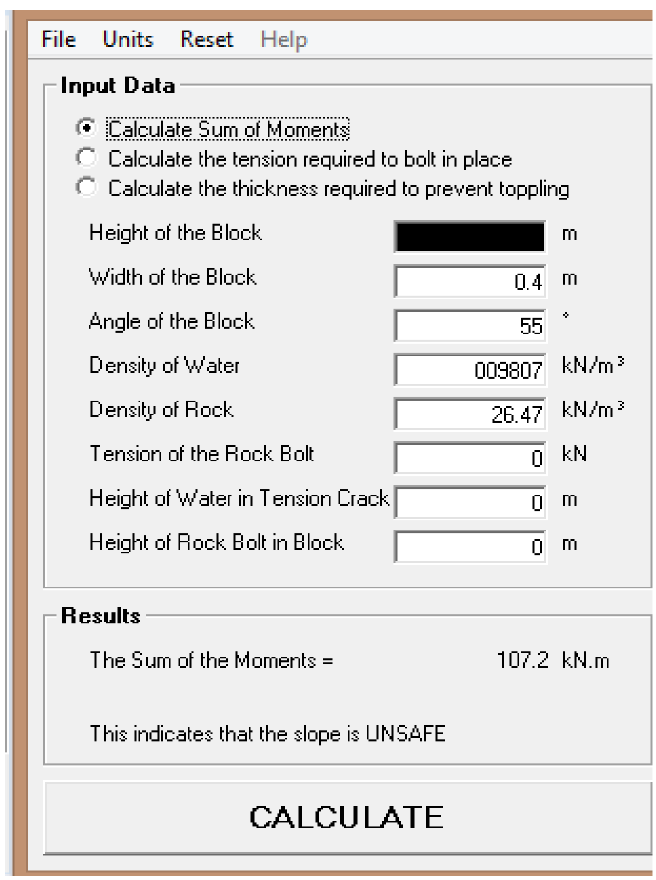

Figure.10a Analysis for Wedge Failure

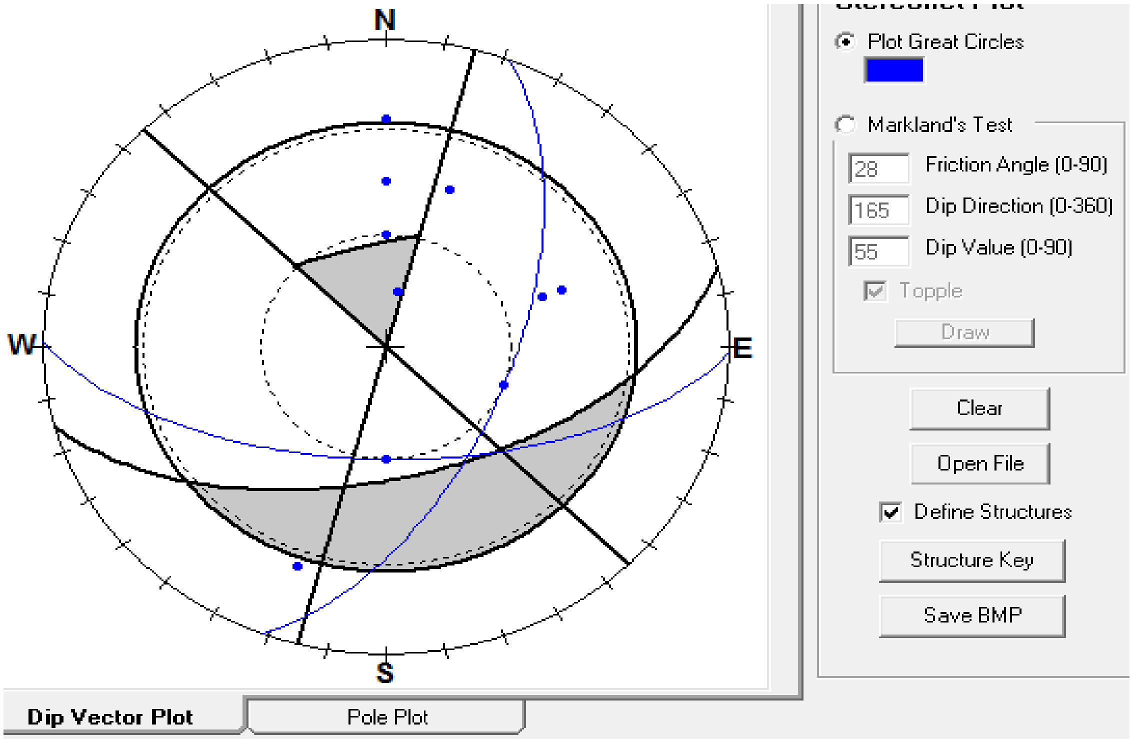

Figure.10b Analysis Sheet for Factor of Safety in case of Wedge Failure

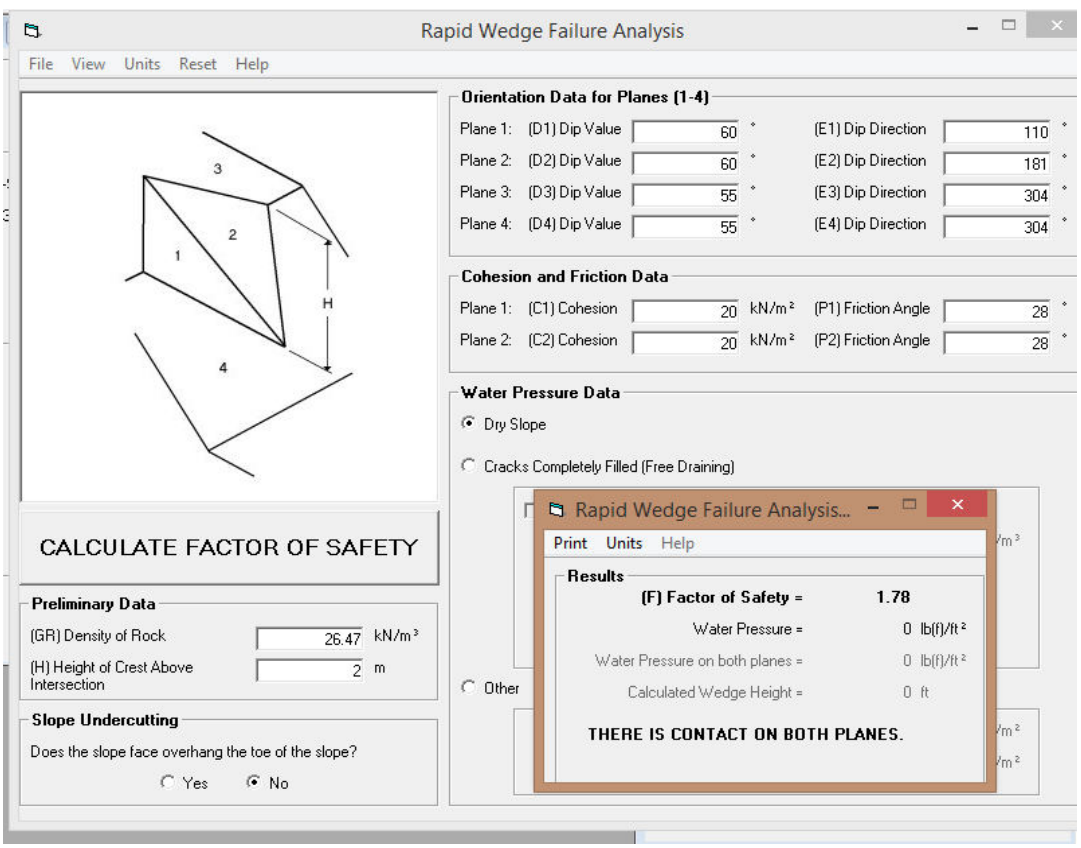

Figure.11 A view of the km 8 Slide Zone from crown to toe

Figure.12 Another end of the slide zone with steep slope. Rocks are exposed along the road, followed by debris.

Conclusion

The slide zone nearly 1 km before the Kalimath Village on SH-36 has become active after the wide spread heavy rainfall in Kedarnath and adjoining areas in June 2013. The active debris slide is mainly due to rainfall during monsoon, which has developed groundwater pour pressures in a particular direction and slope. Physical weathering and structural disposition of highly jointed and fractured rock mass facilitate recurrence of slide. In addition, some particular joints in the rock mass are prone to toppling as well as wedge failure to some extent. Toe erosion further makes this zone vulnerable and prone to active slide. Suitable mitigation measures may be taken up accordingly to check this active slide zone.

It may include drainage control of rain water; construction of gabion walls / bench walls / berms / retaining walls; setting up ring net; planting vetiver grass / geo-fabric; etc. at suitable places.

Statement and Declarations

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