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Assessment of Slopes through Geomechanical and Kinematic Analysis along NH-5 in the adjoining areas of Waknaghat, Himachal Pradesh, India

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ABSTRACT

The Northwestern part of lesser Himalaya is susceptible to geohazards like, landslides, earthquake and flood etc. This study is focused on the assessment slopes by using geomechanical and kinematic analysis on stretch along National Highway- 5 (NH-5) from Kandaghat to Waknaghat, Himachal Pradesh, India. NH-5, also known as Hindustan-Tibet highway, is of strategic importance and connects Kinnaur district to the rest of India. It is one of the important highways, which carries millions of tourists, acts as a main means of transporting the men and material all through the region including border areas. The incidence of landslides in the study area has been escalating since the highway construction started. However, the incidences of the landslides have reportedly increased due to the subsequent unplanned anthropogenic activities including the recent widening of the highway. The joint data has been collected from different locations in the study area and the stereographic projection has been plotted with the help of data for calculating different type of failure (Planar, Wedge and Toppling) using kinematic analysis. Further Rock Mass Rating (RMR) and Slope Mass Rating (SMR) have been carried out to describe the different classes of slopes. On the basis of RMR study, all the five rock slopes fall in fair RMR class. Based on kinematic analysis, 3 rock slopes form wedge failures, one rock slope form planar failure and one rock slopes forms both planar and wedge failure.

Keywords: RMR, SMR, Kinematics, Planar failure, wedge failure.

Introduction

The Highway network plays a very important role for socio-economic development of a nation. However, the problem of the slope failures is commonly observed along the road infrastructure due to natural and manmade causes such as precipitation, toe erosion, poor drainage system, construction, widening of road and other development activities etc.

The incidences of Slope failures are increasing every year throughout the Himalaya due to its tectonically active nature, precipitation (Kundu et al. 2017; Singh and Kumar, 2020) and poor management practices. Several natural hazards are connected to one another which get initiated by different locational elements such as drainage pattern, slope, height etc. variation in geomorphology, land use land cover, geology and hydrological condition in the proximity of an area have been proposed as triggering factors for landslides (Varnes 1984; Anabalagan, 1992; Hutchinson, 1995; Bhattacharya, 2018; Singh and Kumar, 2020). Unplanned anthropogenic activities, mechanical excavation and blasting of cut slopes during road construction and widening work are also one of the major causes of the slope instability.

The characterization of rock mass is simple and mainly used to determine the different types of slope failure along with their preventive measures (Bartarya and Valdiya,1998; Starkel, 1972; Virdi etal., 2015). A variety of different techniques are used to determine the Slope Mass Rating (SMR), Rock Mass Rating (RMR), and Kinematic analysis (Sarkar et al. 2018; Sarkar and Singh, 2009; Vishal et al.2010; Singh et al. 2010; Umrao et al. 2011; Trivedi et al. 2012; Sarkar et al. 2012; Singh et al. 2013; Gupta et al. 2013a, b; Vishal et al. 2015; Sarkar et al. 2015).

Emphasizing on slope mass rating (SMR) is an important and widely accepted technique; mainly applied for the characterization of rock slope using the rating of rock mass (RMR). Whereas RMR technique, introduced and timely modified by Bieniawski (1973, 1974, 1976, 1979, 1989) is based on field observation and laboratory study including data collection of site slopes, strength of exposed rock mass on slope face, condition of discontinuities, spacing of discontinuities, orientation of discontinuities, and ground water condition.

Romana (1985) developed an equation for SMR system to improve the accuracy of rock stability evaluation by adding quantitative adjustment factor based on the relationship of orientation of discontinuities, face slope and method of excavation for rock slope to the basic RMR. Both SMR and RMR techniques have been adopted by various researchers all over the world (Umrao et al. 2011; Kumar et al. 2017; Basahel and Mitri 2017; Singh and Kumar 2020).

In the current study, landslide stability assessment has been analysed for geo-mechanical classification of the cut slopes by using RMR and SMR system along NH-5, the road cut sections between Kandaghat to Waknaghat area in the state of Himachal Pradesh. In addition to this,

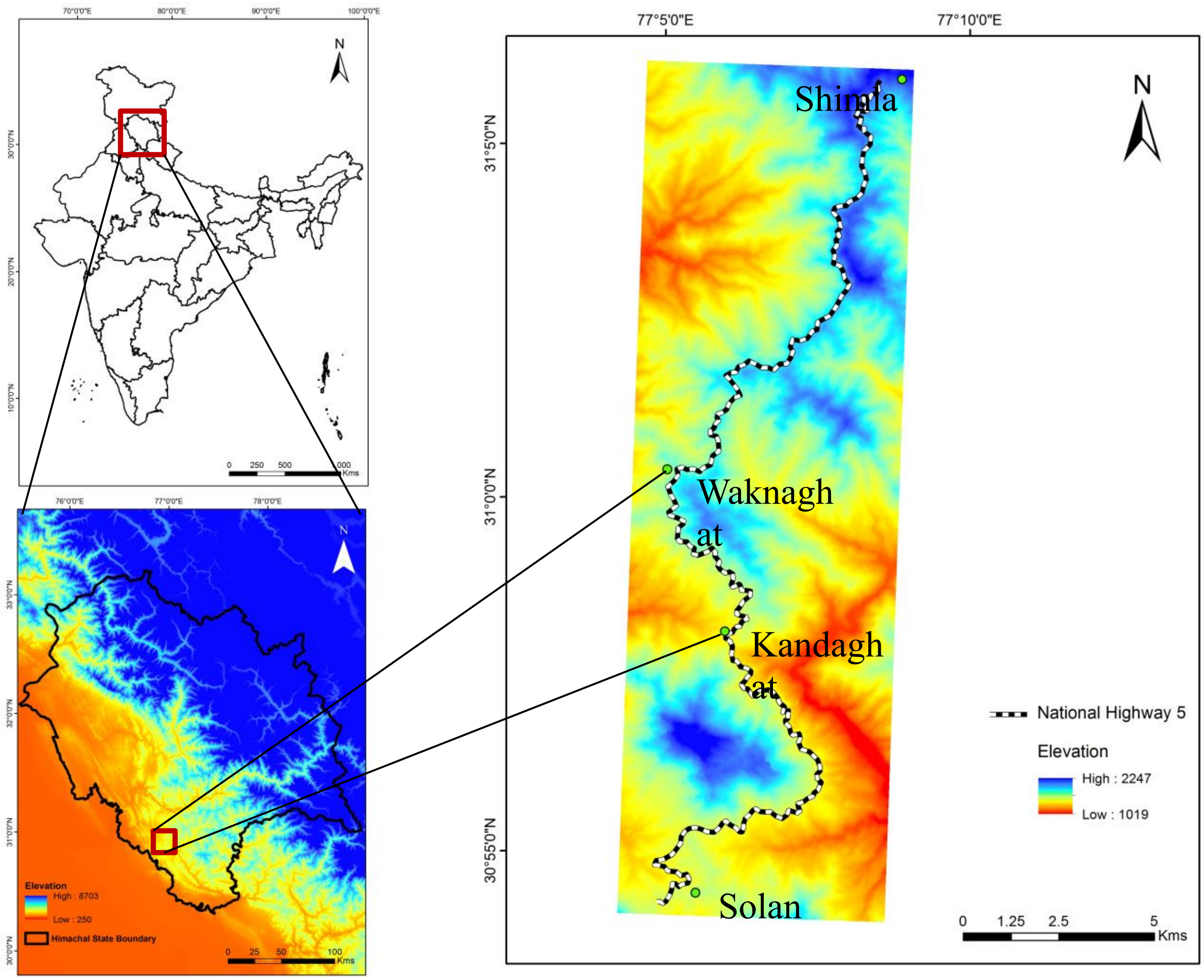

Fig. 1: Study area along NH-5 shown over the SRTM-DEM (30 m).

Kinematic analysis has also been done to identify the mode and the potential direction of failure. It has been observed and reported that various landslide activities occur in the area and create hardship to the travelling public as well as who are living close to the NH-5. The NH-5 is of utmost strategic importance to the nation. Keeping that in mind, the road must be guarded with preventive measures in order to make it robust, resilient and environment friendly highway.

STUDY AREA

The study area is located between Kandaghat and Waknaghat towns on the Kalka-Shimla National Highway-5 in Himachal Pradesh. The area is situated between 77°4'0''E to 77°7'0''E Latitude and 30°58'0''N to 31°7'0''N Longitudes and falls under Survey of India Toposheet no. 53E04 and 53F01.

GEOLOGY OF THE AREA

The research area belongs to Lesser Himalayan, is having rocks of proterozoic age. In geological literature this area is broadly defined as Jutogh, Jaunsar, Shimla and Baliana group of rocks shown in Fig 2. As the many authors already mentioned the Himalayan orogeny was happened in polyphase deformation and resulting in to development of several regional thrusts which are trending mainly from NW-SE (Juthogh thrust, krol thrust, chail thrust and main boundary thrust etc.) Simla Group is further classified into four Formations such as (i) Basantpur Formation; (ii) Kunihar Formation; (iii) Chhaosa Formation; (iv) Sanjauli Formation (Geological Survey of India 1976; Ghosh 1991; Mukhopadhyay et al. 2016; Mukhopadhyay and Banerjee 2016; Thorie et al. 2018, 2020; Mazumdar et al. 2021). Krol Formation is separated by Giri Thrust from the rocks of Shimla Group. Presently the study area which is in the close proximity of the Giri Thrust is suffering from a large number of landslides every year.

METHODOLOGY

In the current study, the methodology for assessment of cut slope stability along NH-5 from Kandaghat to Waknaghat were conducted through detailed field investigations using rock mass rating and slope mass rating including kinematic analysis of discontinuities involved in the failure.

Rock Mass Classification (RMR)

The rock mass rating (RMR) is a geo-mechanical classification system which is mainly based on the field observations and laboratory investigations. In RMR, mainly five parameters suggested and modified by Bieniawski (1979 and 1989) given in Table 1; namely Uniaxial compressive strength (UCS) of rock mass, rock quality designation (RQD), spacing of discontinuities, condition of discontinuities and Ground water condition.

According to their respective values and conditions, ratings have been given to each parameter. The sum of these five factors, which ranging from 0 to 100 (as per Table 2) determines the RMR_{basic} value which indicates the rock mass's quality.

Slope Mass Rating (SMR)

Romana (1985) developed a formula for calculating Slope mass rating (SMR) by using Bienawski's rock mass rating (RMR) and suggested some adjustment factors for joint/slope relationship and another factor related to the method of excavation. Based on slope mass rating, Romana (1985) has further classified slope mass into five classes of stability namely, completely unstable, unstable, partially stable, stable and completely stable. The relationship for SMR is as follows:-

$SMR = RMR_{basic} + (F1 \times F2 \times F3) + F4$ equation………… (1)

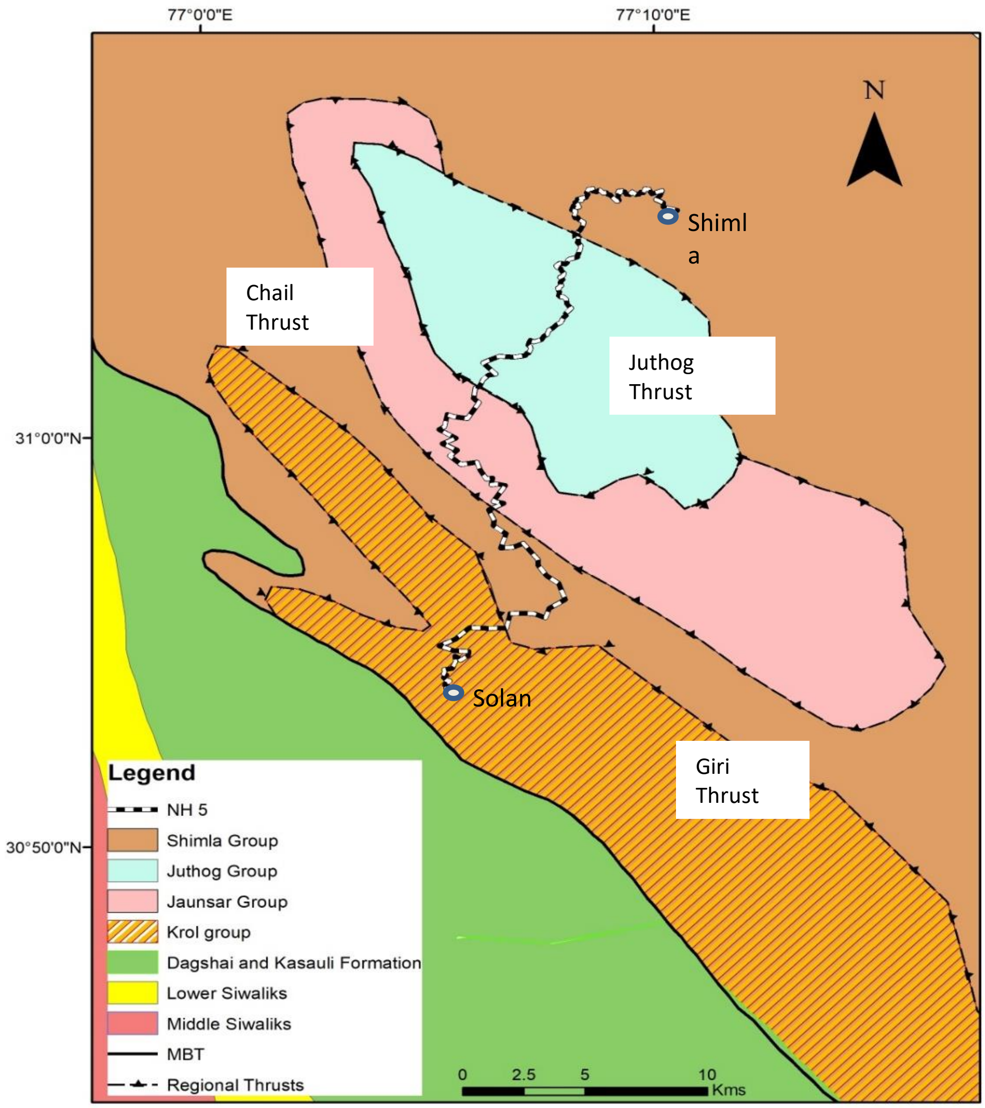

Fig. 2: Geological map of the Study area (Source: http://bhukosh.gsi.gov.in/Bhukosh/Map)

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Table 1: Rock Mass Rating System (After Bieniawski 1989)

Parameters			Ranges of values					
Strength of intact rock material	Point-load index	>10 Mpa	4-10 MPa	2-4 MPa	1-2 MPa	For this low range uniaxial compressive test is preferred		
	UCS	>250 MPa	100-250 MPa	50-100 MPa	25-50 MPa	5-25 MPa	1-5 MPa	<1 MPa
Rating		15	12	7	4	2	1	0
Drill Core Quality(RQD)		90-100%	75-90%	50-75%	25-50%	< 25%		
Rating		20	17	13	8	3		
Spacing of Discontinuties		> 2m	0.6-2.0 m	200-600 mm	60-200 mm	< 60 mm		
Rating		20	15	10	8	5		
Condition of Discontinuties		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation <1mm Slightly warthered walls	Slightly rough surfaces Separation <1mm Highly weathered walls	Slickensided surfaces or Gouge 5mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation >5mm Continuous		
Rating		30	25	20	10	0		
Ground water conditions	Inflow per 10 m tunnel length (1/m)	None	<10	10-25	25-125	>125		
	(Joint water press)/(Major principal σ	0	< 0.1	0.1-0.2	0.2-0.5	> 0.5		
	General condition	Completely dry	Damp	Wet	Dripping	Flowing		
Rating		15	10	7	4	0		

Table 2: Rock mass classes determined from total ratings (Bieniawski 1989)

Rating	100-81	80-61	60-41	40-21	< 21
Class number	i	ii	iii	iv	v
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

Where, RMR_{basic} is evaluated by adding the rating of first five parameters of RMR1989 and F1- shows the parallelism between the slope face and joint dip directions, F2- Reflects the joint dip amount for a planar failure or the plunge of two joints at an intersection for a wedge failure, F3- Depends on the slope and relative dip of the discontinuity and F4- Adjusting factor for the excavation technique.

Kinematic Analysis

The present study is concerned with the RMR of road cut slope face. For this, the identification of the different type of failure (Plane failure, Wedge failure, Toppling) is important criteria to analyse the stability of slope. The Inter-relationship between the slope face and orientations of the different discontinuities used to calculate the potential mode of failure refers as kinematic analysis. With the help of stereographic projection of the slope geometry and the joint data, the mode of failure in rock slopes is easily determined. The analysis of the different possible mode of failure and the vulnerable zone has been carried out for all the locations in the study area.

Result and Discussion

The primary objective of this research is to evaluate the assessment of stability condition along NH-5 between Kandaghat to Waknaghat using RMR_{basic}, SMR, and Kinematic analysis. The data was taken from the five landslide locations for rock cut slopes along NH-5. The excavated rock cut slopes provides the structural and geological characteristics of the outcrops, lithological conditions and joint data along with RMR classification.

The RMR classifications was calculated by using RMR_{basic} including five parameters and have been assigned corresponding rating value to each parameter during the field observation. The value of UCS of the rock masses was evaluated by using the field estimates of Uniaxial Compressive Strength (Hoek and Brown, 1997). Joint volume (Jv) was calculated by counting the total number of joints in 1m volume metric cube. The value of Jv was used to calculate the RQD. Thus the values calculated for all the investigated slopes were 13. Rating for spacing of discontinuities varies from 8 to 10. Then rating of condition of discontinuities was evaluated which ranges from 10 to 20. Since, all the slopes were completely dry then the rating given for fifth parameter (Ground Water) was evaluated as 15. Finally rating for five parameters were added to get the RMR values which ranges from 41 to 60. On the basis of RMR evaluated rock masses in the study area for locations LS 1, LS 2, LS 3, LS 4 and LS 5 can be classified as fair.

The results for SMR values were determined for all five slopes by using equation no.1. The values of rating F1, F2, F3 and F4 evaluated for slopes LS 1, LS 2, LS 3, LS4 and LS 5 as (0.15,0.85 and -60), (0.15,0.85 and -60; 0.15, 0.7 and -60), (0.15, 0.7 and -60; 0.15, 0.7 and -60), (0.7, 0.7 and -60) and (1.0, 0.85 and -50;

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0.15, 0.4 and -60) respectively. The rating of F4 factor was taken as Zero (0) as the method of excavation for the cut slopes was mechanical. The discontinuities and their orientation were plotted by using kinematic analysis plots. All these plots (Fig. 4) represent different probable modes of failures such as wedge type of failure at the locations 1, 2, 3; planar failure at 4; and both planar and wedge failures at 5. According to the standard description of slope mass (SMR) by Romana 1985, the evaluated SMR values for slope LS 1, LS 2, LS 3, LS 4 and LS 5 are 44.35, 37.35 & 38.7, 40.7, 20.6 and 2.5 & 41.5 respectively. Now SMR signifies that LS 1 is partially stable, LS 2, LS 3 and LS 4 are unstable and LS 5 is partially stable (wedge) to completely unstable (planar) following class iii and iv (Table 3).

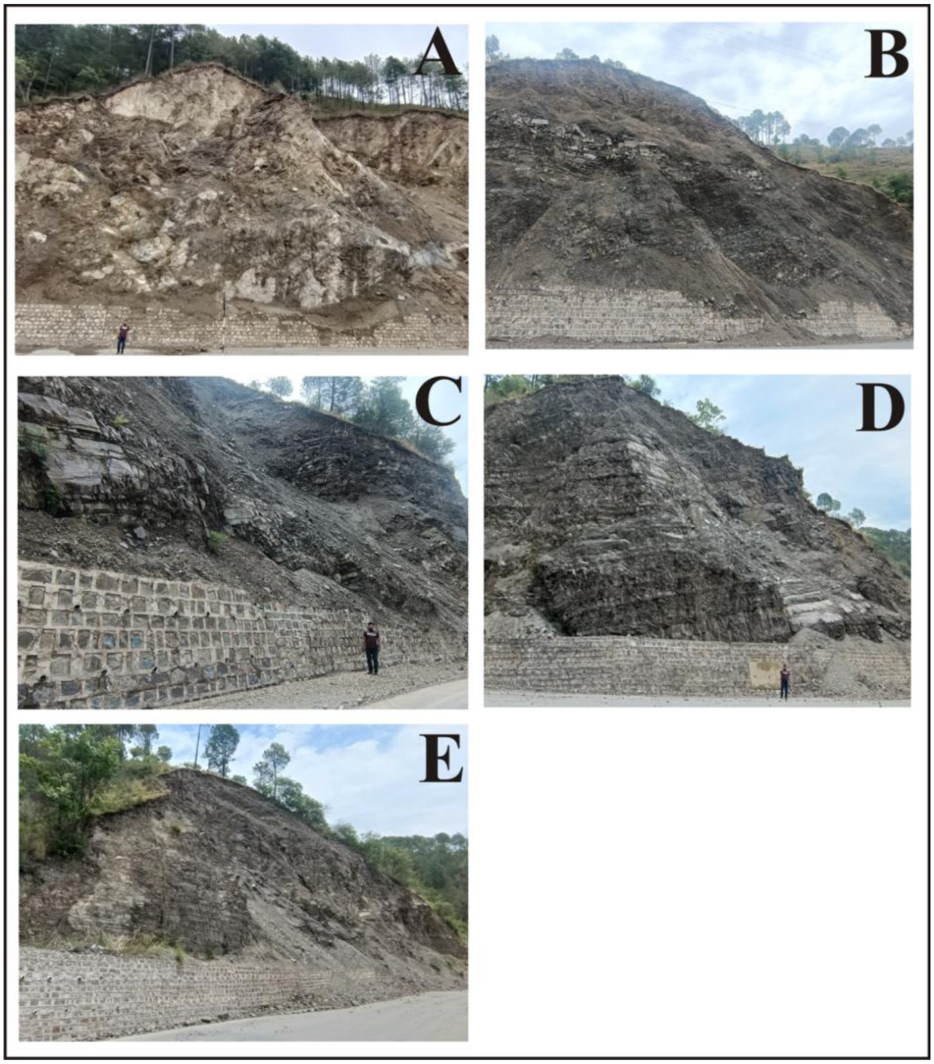

Fig: 3 Field photographs showing conditions of rock mass along NH- 5 under study area.

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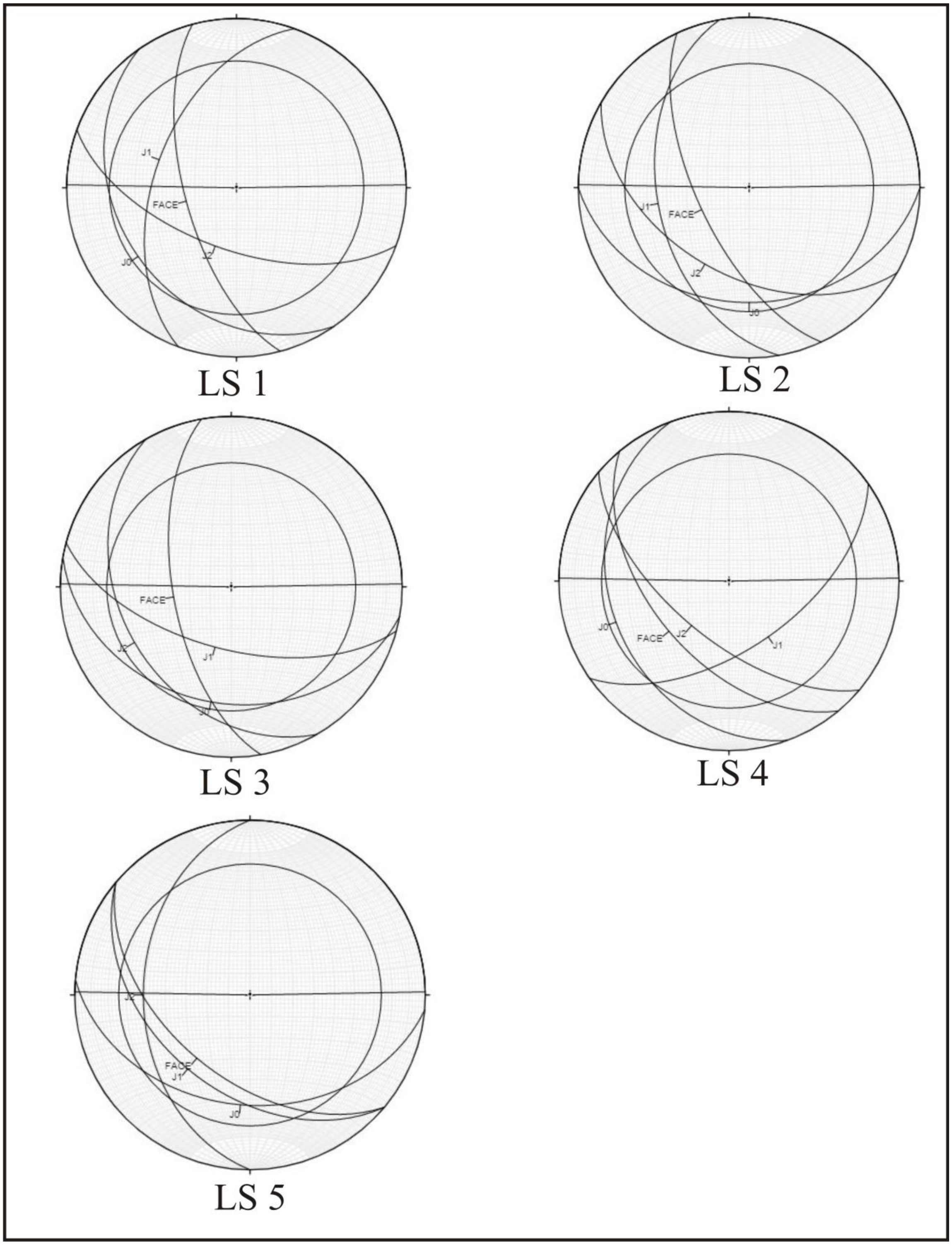

Fig: 4 Kinematic plots for five locations (LS 1 to LS 5).

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Table 3: The evaluated results of the SMR system for identified road cut slopes.

Location No.	RMR	Failure type	F1	F2	F3	F4	SMR value	Class	Stability
LS 1	52	Wedge 1	0.15	1	-60	0	44.4	iii	Partial stable
LS 2	45	Wedge 1	0.15	1	-60	0	37.4	iv	Unstable
		Wedge 2	0.15	1	-60	0	38.7	iv	Unstable
LS 3	47	Wedge 1	0.15	1	-60	0	40.7	iv	Unstable
		Wedge 2	0.15	1	-60	0	40.7	iv	Unstable
LS 4	50	Planar	0.7	1	-60	0	20.6	iv	Unstable
LS 5	45	Planar	1	1	-50	0	2.5	v	Completely unstable
		Wedge 1	0.15	0	-60	0	41.4	iii	Partial stable

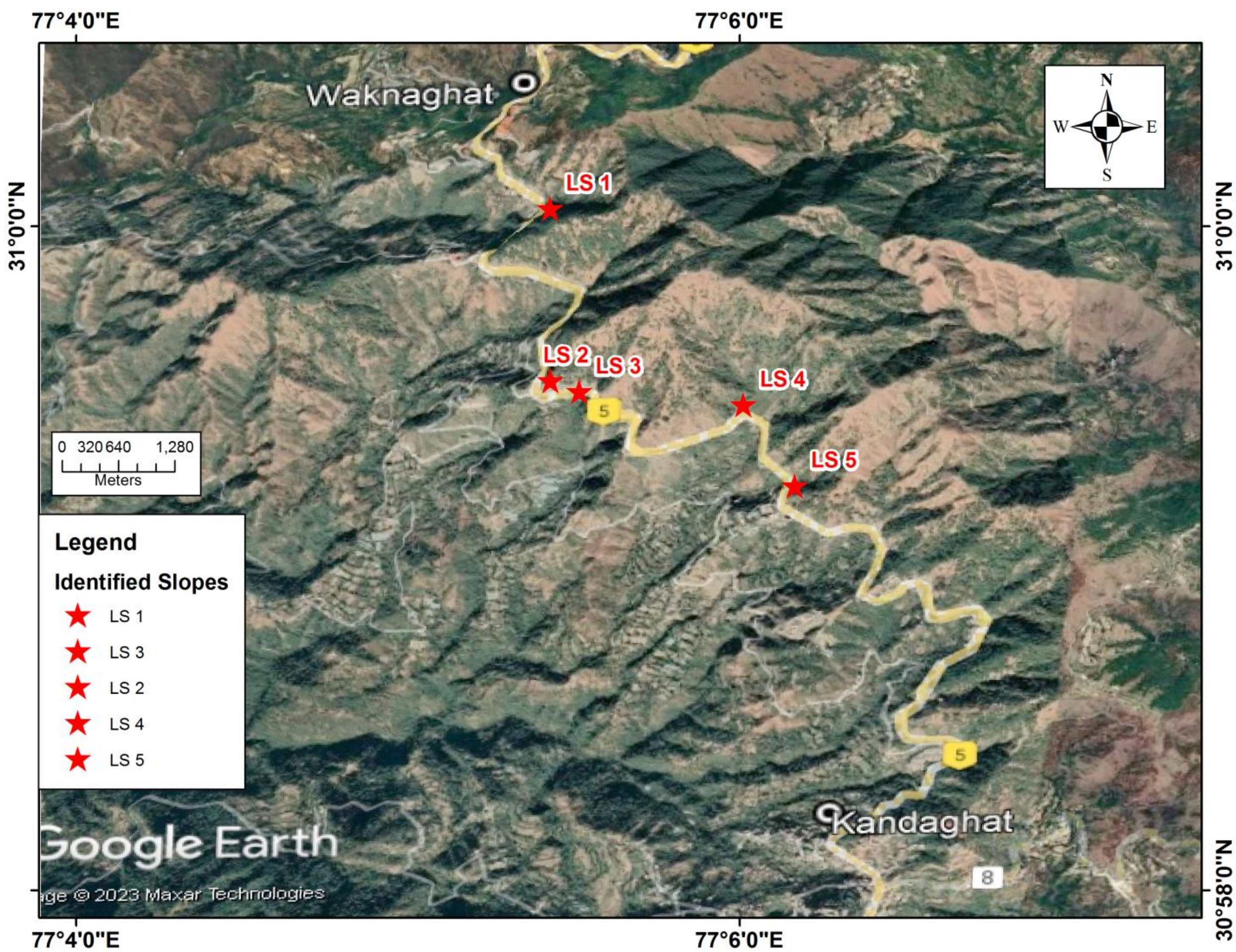

Fig: 5 Showing location of the identified slopes in the study area

Conclusions:

The final outcome of the current study concludes that the rock mass conditions of identified slopes (LS 1, LS 2, LS 3, LS 4 and LS 5) shown in Fig. 5, belongs to class (iii) under RMR system. The rocks in the concerned area are foliated, fractured and disintegrated. There are three sets of discontinuities in the region. All the five slopes have been assessed by using kinematic analysis and SMR along Nh-5 from Kandaghat-Waknaghat are partial stable to unstable. These identified slopes in the study area requires appropriate treatment for making disaster resilient, safe, smooth and environment friendly highway.

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