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The Assessment of Slope Stability along NH-22 in Rampur-Jhakri Area, Himachal Pradesh

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Abstract: The present paper demonstrates the assessment of slope stability analysis between Rampur to Jhakri road section along National Highway (NH-22), Himachal Pradesh, India. The different types of slope failures have affected most part of slopes which causes considerable loss of life and property, inconveniences such as disruption of traffic along highways. The poorly designed rock slopes for road widening or construction purposes may weaken the stability of the slopes. A detail field investigation has been carried out to collect the representative rock samples for determination of physico-mechanical properties of rock and joint data for kinematic analysis. The rocks exposed in the area are highly jointed quartzite and quartz-mica schist of Rampur-Larji Group of Palaeoproterozoic age. The continuous slope mass rating (CSMR) technique has been applied for the assessment of slope stability analysis at five vulnerable locations and the results shows slopes are partially stable to unstable. Kinematic analysis mainly shows wedge type of failure along with few toppling and planar failures. The existing slope required immediate treatment to prevent the failure for its long term stability.

Keywords: SMR, Kinematic Analysis, Slope Stability, Rampur, Himachal Pradesh.

INTRODUCTION

Rock slope instabilities are one of the most devastating natural hazards along the road cut hill slopes. The probability of failure increases day by day in geodynamically active mountain like Himalayas (Sarkar et al. 1995, 2012; Pradhan et al. 2011, 2014; Rautela et al., 2005; Sharma 2006, Chauhan et al. 2010). The unplanned excavations of rock slopes for construction, rapid expansion of hydropower projects, inadequate road maintenance or expansion of road networks without proper understanding of geological or geotechnical details of the area may damage the stability of the slopes (Gorsevskiet al., 2006, Kainthola et al. 2012a, 2012b; Singh et al. 2013a). The stability problem of slope causes a great loss of lives and resources in the Rampur-Jhakri region especially during the monsoon (Sarkar and Singh, 2008 a, b). Slopes fracturing by tectonic activity, subsequent weathering and erosion processes accompanied by anthropogenic factors leads to frequent slope failure in this high relief mountain system (Starkel, 1972; Bartarya and Valdiya, 1989; Virdi et al., 1995). So, there is a need of rock mass characterization for the stability assessment of the slope.

A number of techniques are adopted for the assessment of slope stability such as limit equilibrium, rock mass classification, kinematic analysis and numerical modeling (Sarkar et al. 2008; Sarkar and Singh, 2009; Vishal et al. 2010; Singh et al. 2010; Umaro et al. 2011, Trivedi et al. 2012; Sarkar et al. 2012; Singh et al. 2013a; Gupte et al. 2013a, b; Vishal et al. 2015). Among these one of the most widely accepted method is slope mass rating (SMR) to characterize the rock slope which is based on the rock mass rating (RMR). RMR system is (Bieniawski, 1979, 1989) based on both field and laboratory study, which includes strength of the rocks, discontinuity spacing, discontinuity condition and also groundwater condition. SMR is calculated with the use of RMR along with some adjustment factors which are more decision based (Romana, 1985, 1993).The multidimensional visualization techniques of various rock mass classifications (Q, RMR, RMi and GSI) adopted by several workers (Anbalagan et al. 1992, Cai and Kaiser, 2006, Sonmez and Ulusay, 1999) in order to support the field engineers to identify the important controlling parameters and the same methodology has been used by Tomas et al. (2007) for the visualization of continuous SMR (CSMR). The CSMR result in more precise value of SMR by providing unique value to each adjustment factor of slope.

In the present study, landslide vulnerability has been carried out along NH-22, the road cut sections between Rampur to Jhakri area in Himachal Pradesh, considering various geological and geotechnical parameters. The rocks are highly jointed, so kinematic analysis has been done to find out the type and the probable direction of failure. The results indicate that the continuous SMR method has been adopted to characterize the stability of rock slopes in the area under investigation.

STUDY AREA

The study area falls in the toposheet No. 53 E/11 between the latitudes 31°30' - 31°27' and longitudes 77°39'- 77°42' (Fig.1). The nearest railway station is Shimla located at an approximate distance of 160 km from the study area along Tibet- Border road (NH-22). It lies in the lesser Himalaya, between the Dhauladhar range in the south and the higher Himalayan range in the north. The Satluj river is the main drainage in the catchment area with headwaters located in the highlands of Tibet. The area under investigation lies in the seismic zone five (Narula et al., 2000).

GEOLOGY OF THE AREA

The river Satluj cuts the topography exposing the basement rocks in the form of windows consisting of Shali and Rampur formations which is overlain by Chail and Jutogh formations. The junction between these lithounits is marked by Chail and Jutogh thrusts (Sharma, 1977). The main rock types exposed along NH-22 are quartz mica schist, quarzite and gravely-sediments of Paleoproterozoic age belong to Rampur-Larji window Group (Fig.2). The Rampur Formation tectonically rest over the Shali Formation along a thrust and is made up of volcanics at the lower level and Rampur quartzite at the top (Misra and Tewari, 1988). Rampur quartzite is intruded by the Bandal granite. Chail thrust between Rampur Group and Chail Group of rocks was also referred as Kullu thrust (Bhargava and Bassi,1994) which defines the boundary between green-schist facies rocks of Rampur and low-grade metamorphic of Chail Group rocks. This thrust plays a major role in the neo-tectonics of the area and is still active. Rocks of Rampur Formation consists of massive quartzite with chlorite schist and meta-basics and further intruded by Bandal granite.

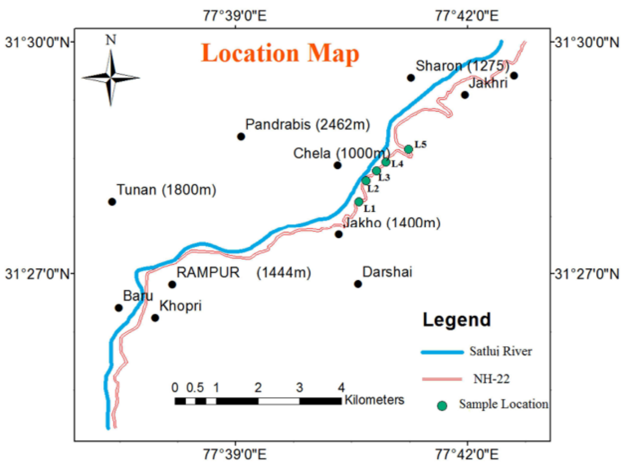


Fig.1. Location map of the study area

METHODOLOGY

The detailed field investigations were conducted along NH-22 to measure the attitude of discontinuities present in the rock mass and also collect the representative samples for finding the SMR. Laboratory analysis was also done to evaluate the strength parameters as per ISRM (1981) suggested methods.

Romana (1985) established a relationship to find SMR using basic RMR and suggested some adjustment factors depending on the joint-slope relationship and another factor depending on the method of excavation. The relationship defined by Romana is as follows

$$SMR = RMR_{basic} + (F_1.F_2.F_3) + F_4 \quad \text{(i)}$$

RMR basic is computed by adding the ratings of five parameters (Bieniawski, 1979,1989) which are uniaxial compressive strength (UCS), rock quality designation (RQD), joint or discontinuity spacing, joint condition and groundwater condition. The rock mass classes are determined from the total ratings.

Thus RMR_{basic} is calculated for the determination of slope mass rating (SMR). The other parameters have been calculated for determination of SMR are F1, F2, F3 and F4, where F1, F2 and F3 are adjustment factors related to joint orientation with respect to slope orientation and F4 is the correction factor for method of excavation. The SMR system gives adjustment factors, field guidelines and recommendations on support methods which allow a systematic use of geomechanical classification for slopes. The continuous SMR method provides unique value of each adjustment factor unlike a range as in SMR.

The adjustment rating for discrete SMR is the product

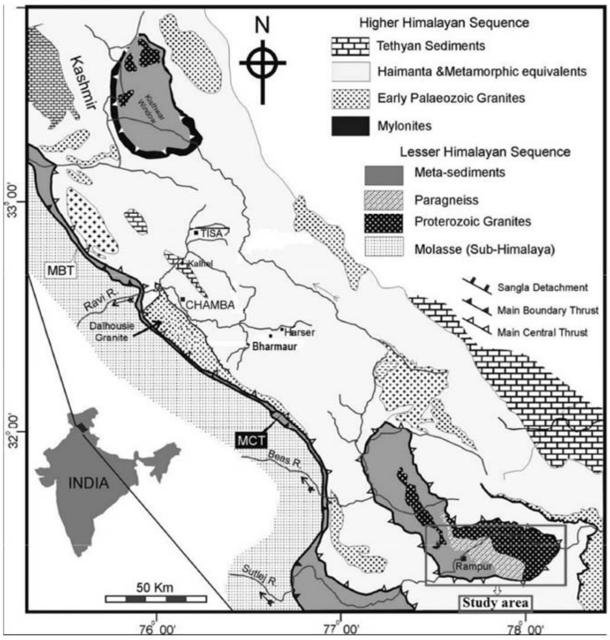


Fig.2. Geological setting of Rampur-Larji Window Zone (after Frank et al., 1995; Sharma and Bhola, 2005)

of three factors proposed by Romana (1985) as follows:

F_1 depends upon the parallelism between joints and strikes of the slope face. The value of F_1 ranges from 0.15 to 1.0. The value is 0.15 when the angle between the critical joint plane and the slope face is greater than 30° and the failure possibility is very low, where as the value is 1 when both are near parallel. Initially, the value of F_1 was established empirically, but subsequently it was found to match approximately the following relationship.

$$F_1 = (1 - \sin A)^2 \qquad \text{(ii)}$$

where, A denotes the angle between the strikes of the slope face (α_s) and that of the joints (α_j)

F_2 refers to joint dip angle (β_j) in the planar failure mode. The value of F_2 also ranges from 0.15 to 1.0. It is 0.15 when the dip of the critical joint is less than 20° and 1.0 for the joints with dip more than 45°. F_2 remains 1.0 for the toppling mode of failure.

$$F_2 = \tan^2 \beta_j \qquad \text{(iii)}$$

F_2 refers to the relationship between the slope face and joint dips.

F_3 indicates the relationship between the slope face and dip of plunge of intersection of two joints, where the slope dip is 10° more than the joints. The condition is very unfavorable. For the toppling failure unfavorable conditions depend upon the sum of dip of joints and the slope ($\beta_j + \beta_s$).

For CSMR, the adjustment factors F_1, F_2 and F_3 are calculated by using the following equation proposed by Tomas et al. (2007).

$$F_1 = \frac{16}{25} - \frac{3}{500} \arctan\left[\frac{1}{10}(|A| - 17)\right]$$

Where F_1= adjustment factor

$|A| = |\alpha_j - \alpha_s|$ for planar failure

$|A| = |\alpha_i - \alpha_s|$ for wedge failure

$|A| = |\alpha_j - \alpha_s - 180|$ for toppling failure

α_j, α_s & α_i are dip direction of joint, slope and plunge direction intersection of two joint planes.

$$F_2 = \frac{9}{16} + \frac{1}{195} \arctan\left(\frac{17}{100}B - 5\right)$$

Where B is equals to dip (β_j) of joint for planar failure and toppling to dip on plunge of line of intersection for wedge failure.

$$F_3 = -30 + \frac{1}{3} \arctan(C)$$

$$F_3 = -13 - \frac{1}{7} \arctan(C\text{-}120)$$

where, C is an angular difference of dip of joint and slope (β_j-β_s) for planar failure. C is different of dip of plunge of line and dip of slope (β_i-β_s) for wedge. For toppling, C is defined as sum of dip of joint and slope (β_j+β_s).

F_4 refers to the adjustment factor for the method of excavation has been fixed empirically for natural slope +15, pre-splitting +10, smooth blasting +8, normal blasting or mechanical excavation 0, deficient blasting -8.

RESULTS AND DISCUSSION

The main objective of this study is to assess the vulnerability condition along NH-22 between Rampur-Jhakri area using kinematic analysis and CSMR approach. The road cut sections provide the best outcrops for determining the lithological variations, weathering conditions, structural and geological characteristics of the outcrops, rock excavation to record discontinuities and joint patterns. The investigation consists of five rock slopes along the NH-22. The observed joints and slope parameters at different locations is given in Table 1.

KINEMATIC ANALYSIS

The most causative factors of slope failure in the study area are multiple joint sets, weathering of the rock mass and high intensity of rainfall. Kinematic is the most simplified failure analysis in terms of joint sets, bedding plane, cut

Table 1. Joints and slope data at different locations

Loc. No.	Orientation of slopes (S_L) (Dip/Dip direction)	Orientation of joints			
		J1 (Dip/Dip direction)	J2 (Dip/Dip direction)	J3 (Dip/Dip direction)	J4 (Dip/Dip direction)
L1	72°/296°	79°/100°	50°/210°	36°/235°	-
L2	80°/304°	37°/39°	30°/235°	73°/149°	-
L3	84°/285°	35°/36°	54°/235°	85°/324°	-
L4	85°/317°	48°/22°	78°/320°	34°/224°	-
L5	83°/226°	40°/42°	84°/299°	40°/258°	80°/155°

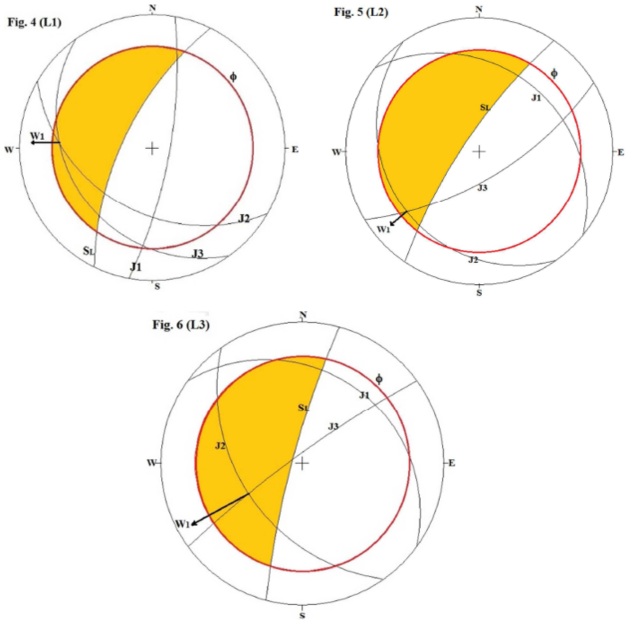
slope and angle of internal friction but it is only suitable for preliminary design (Hoek and Bray, 1981; Coggan et al., 1998). The analysis has been carried out in the study area to locate the vulnerable zone and potential mode of failure for all five locations.

At the first location (L_1), the orientation of slope (S_L) is 72° due 296°; angle of internal friction (Φ) is 25°; joint planes J_1, J_2 and J_3 are 79° due 100°, 50° due 210° and 36° due 235° respectively (Fig.3). According to joint-slope orientation relation, there are chances of wedge failure (W_1) in between J_2 and J_3 in west direction (Fig.4).

At the second location (L_2), the orientation of slope (S_L) is 80° due 304°; angle of internal friction (Φ) is 25°; orientation of joint planes J_1, J_2 and J_3 are 37° due 39°, 30° due 235° and 73° due 149° respectively. According to joint-slope orientation, there are chances of wedge failure (W_1) in SW direction (Fig.5).

At the third location (L3), slope (S_L) dipping at 84° due 285°; angle of internal friction (Φ) is 25°; joint planes J_1, J_2 and J_3 are dipping at 35° due 36°, 54° due 235° and 85° due 324° respectively. There are chances of wedge failure (W_1) (Figs.6-7) in between J_2 and J_3 based on the joint-slope relationship and the potential direction of wedge failure is towards SW direction.

At the fourth location (L4), slope (S_L) orientation is 85° due 317°; angle of internal friction (Φ) is 25°; joint planes J_1, J_2 and J_3 are 48° due 22°, 78° due 320° and 34° due 224° respectively.



Figs.4-6. Kinematic plot of slope and joint data at **(4)** L1, **(5)** L2 **(6)** Kinematic plot of slope and joint data at L3.

The J_1 and J_2 form the wedge (W_2) (Figs. 8-9) with potential failure direction in NE whereas there is also a chance of wedge failure (W_1) between J_2 and J_3 in SW direction. Here, J_2 is running parallel to the slope face and susceptible to the planar failure (P_1) in the NW direction.

Fig.7. Road cut section shows wedge failure

Fig.3. Rockfall along the road cut section

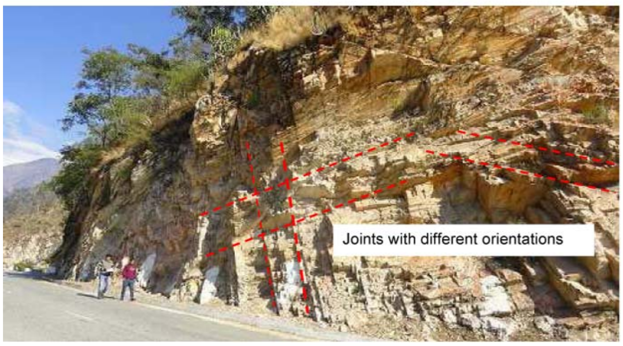
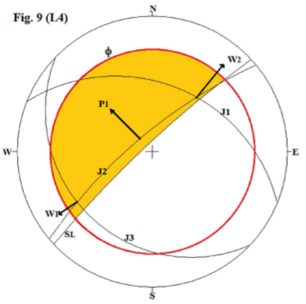
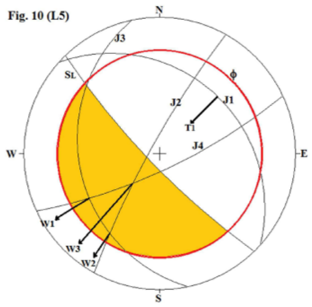


Fig.8. Multi-orientated joints in Quartzite





Figs.9-10. Kinematic plot of slope and joint data at **(9)** L4, **(10)** L5

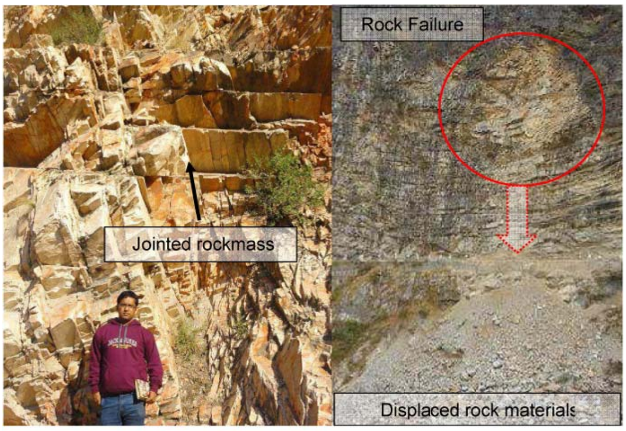


Fig.11. Highly jointed and depleted rock mass at L5

Location fifth (L5) has the slope (S_L) orientation 83° due 226°; angle of internal friction (Φ) is 25°; joint planes J_1, J_2, J_3 and J_4 have the orientation of 40° due 42°, 84° due 299°, 40° due 258° and 80° due 155° respectively (Figs.10-11).

The J_1 shows the toppling failure (T_1) with potential failure direction in SW as both J_1 and slope faces are steeply dipping and opposite to each other. The joint sets J_2, J_3 and J_4 gives rise to three wedge failure (W_1, W_2 and W_3) with potential failure in SW direction.

CONTINUOUS SLOPE MASS RATING (CSMR)

The CSMR technique is the most useful method to classify road cut section by evaluating SMR followed by RMR in the present study. The most important advantage is to provide the slope description, stability condition and observed failure in a sophisticated manner. So, CSMR has been calculated for all five given locations by using the calculated basic RMR values on the basis of five earlier mentioned parameters. UCS has been calculated by laboratory experiments in universal testing machine (UTM). RQD has been calculated from the relation given by Palmstrom (1982) as RQD = 115 – 3.3 J_V where J_V is

Table 2. Rock Mass Rating (RMR) for five locations of Rampur-Jhakri area

Loc. No	Rock type	UCS	RQD calculated from Jv	Joint spacing	Joint condition	Ground water condition	RMR_{basic}
L1	Quartzite	7	8	8	18	15	56
L2	Quartzite	7	8	8	16	15	54
L3	Quartzite	7	13	15	14	15	64
L4	Quartzite	12	13	10	12	15	62
L5	Quartzite	12	20	10	18	15	75

volumetric joint count. The calculated RMR values for all five locations are given in Table 2. As per rock mass classification (Bieniawski, 1989), the rock mass in L_1 and L_2 can be classified as average rock (Class III) whereas the L_3,L_4 and L_5 belongs to good rock (Class II).

The CSMR has been calculated for planar, wedge and toppling failures for all five locations using equation (1), the RMR values and the continuous equations adjustment factors F_1, F_2, F_3 and F_4 given by Tomas et al. (2007). Observed orientation of slope faces, joint orientation and attitude of their intersections have been applied to calculate the adjustment factors F_1, F_2 and F_3. The road corridors in hilly terrain pass through those parts where less excavation be needed due to economical as well as stability related issues. Excavation is generally done by different drilling and blasting methods. Here, the chosen highway cut slopes are natural (L1), deficiently blasted (L2 & L3) and normal blasted (L4 & L5) and their correlation factor F4 is assigned for the slopes accordingly. The calculated CSMR values are listed for five chosen locations (Table 3).

According to the standard classification for SMR values proposed by Romana (1985) which is also applicable CSMR classification, L1 gives the CSMR value 56.14 for wedge failure. So this road cut slope falls in the class III i.e. partially stable slope. At L2, value of CSMR for W1 is 40.37, classified in class III and according to this class, the slope is partially stable. L3 gives the CSMR value 44.41 which falls in the class III as partially stable zone. On the other location L4, the slope having CSMR value 55.56, 55.91 and 7.41 for existing wedge failures W1, W2 and planar failure P1 respectively. The two wedges W1 and W2 are classified in class III as partially stable and the planar failure P1 falls under class V which indicates completely unstable zone. At L5, the slope is having three wedge failures W1, W2, W3 and a toppling failure T1 gives the CSMR values 33.47, 48.96, 21.26 and 72.78 respectively. The W1 and W3 fall in the class IV which indicates unstable zone, W2 classified as class III is partially stable and T1 falls in the class II which is a stable zone. The rocks of these areas

Table 3. Results of continuous slope mass rating (CSMR)

Location No	RMR	Slope orientation	Feature	Dip	Dip direction	F1	F2	F3 (-)	F4	CSMR	Class/ Stability
L1	56	72°/296°	W1	31°	270°	0.39	0.64	59.53	15	56.14	III / Partially stable
L2	54	80°/304°	W1	30°	229°	0.16	0.59	59.62	-8	40.37	III / Partially stable
L3	64	84°/285°	W1	54°	241°	0.22	0.95	59.36	-8	44.41	III / Partially stable
L4	62	85°/317°	W1 W2 P1	33° 47° 79°	237° 38° 320°	0.15 0.11 0.97	0.72 0.93 0.99	59.63 59.50 56.85	0	55.56 55.91 7.41	III / Partially stable III / Partially stable V / Completely unstable
L5	75	83°/226°	W1 W2 W3 T1	38° 30° 65° 40°	237° 212° 221° 43°	0.82 0.74 0.94 0.11	0.85 0.59 0.97 0.87	59.58 59.64 58.94 23.22	0	33.47 48.96 21.26 72.78	IV / Unstable III / Partially stable IV / Unstable II / Stable

are highly jointed and fractured. The water percolates through these joints that weakens the rocks. Most of the slopes fall under partially stable to unstable conditions as per CSMR values. So, the suggested supports system for these locations are spot or systematic bolting, spot shotcrete, toe ditching, toe wall and or dental concrete. The CSMR class versus probability of failure has been plotted in Fig.12 based on Romana (1985) standard classification of SMR.

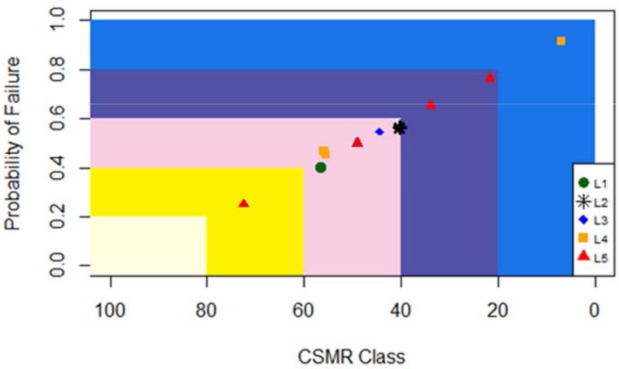


Fig.12. Plot of CSMR values of different five locations

CONCLUSIONS

The slope mass rating is the most widely used technique for rock slope assessment, whereas the CSMR system gives finer rating values than the discrete SMR. An integrated kinematic analysis and Continues Slope Mass Rating (CSMR) have been done for five vulnerable slopes between Rampur-Jhakri (NH-22) area for slope stability assessment. The CSMR and kinematic analysis shows that most of the slopes are partially stable to unstable. The results match with the field observations. These slopes require proper treatment to make it crucial road safe and long term stability for the public transport.

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