JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.97, February 2021, pp.145-150

Slope Stability Analysis Based on Rock Mass Rating, Geological Strength Index and Kinematic Analysis in Vindhyan Rock Formation

Saurabh Kumar* and Hemant Kumar Pandey

Civil Engineering Department, Motilal Nehru National Institute of Technology Allahabad, Prayagraj - 211 004, India
E-mail: *saurabhkumar@mnnit.ac.in*; hkp@mnnit.ac.in*

ABSTRACT

The Rock Mass Rating (RMR), Geological Strength Index (GSI) and kinematic analysis are widely employed in geotechnical engineering practice. The RMR and GSI both are used for rock mass characterization while the kinematic analysis is applied to identify the mode of failure of slope based on rock discontinuities and slope face characteristics of rock.

An attempt has been made to analyze the RMR, GSI and Kinematic Analysis using in-situ data corresponding to Vindhyan sandstone. The data has been collected from outcrops at seven different locations in and around Markundi hill along SH-5, Chopan, Sonbhadra. The relationship between RMR and GSI for Vindhyan sandstone in the study area has been attempted using generalize equation proposed by Hoek (2013) while the kinematic analysis has been applied to decipher the weak zone of failure using RocScience Dips software.

The lowest RMR value estimated is 35 for location S-4 and the highest RMR value is 58 for location S-1. Other locations viz, S-2, S-3, S-5, S-6 and S-7 have the RMR value from 42 to 49 which infers that the Vindhyan sandstone existing at Markundi is characterized by both poor as well as fair rock mass.

The GSI value of the location S-1 is estimated as 34 (minimum) and 46 (maximum) of location S-4. GSI value of the same rock formation also corroborates that the rock mass belongs to poor as well as fair rock mass.

The wedge failure is inferred due to intersection of two sets of joints oriented in north-west and north-east direction. The line of intersections of these two discontinuities are observed in wedge shaped block. It is concluded that the locations under investigations have tendency of wedge failure.

INTRODUCTION

Road widening activities have exposed a continuous stretch of about 5-6 km of highly jointed rock mass along SH-5 at Markundi hill in Sonbhadra district, U.P., India. In addition to this, the blocks of rock mass have also become unstable along the joint planes due to blasting and mechanical excavation. However, in similar cases as mentioned above the occurrence of the large slope failure is uncommon while detachment of the rock mass blocks known as "Rockfall" is commonly observed (Anbalagan et al., 2001).

Landslide encompasses rockfall, toppling, wedge and debris flow which are the different varieties of mass movements (Kahlon et al., 2014). Weathering, anthropogenic activities and tectonic movement are common slope affecting factors. The rock mass characterization is very important and essential requisite to understand the slope failure and its preventive measures (Bartarya and Valdiya, 1998; Starkel, 1972; Virdi et al., 2015)

Rock mass rating (RMR) is undoubtedly a helpful tool for rock mass characterization commonly used for planning and design in engineering applications introduced by Bieniawski (1974) later modified many times over the years. The applicability of RMR_b has certain limitation to address the engineering geology problems. Therefore, combination of geological strength index (GSI) and RMR_b is necessary to understand the behavior of fractured/jointed rock mass. The rock quality designation (RQD) is one of the most important parameter to assess the RMR_b as well as GSI (Zhang, 2015). RQD has been estimated using volumetric joint of rock mass in the study area (Palmstrom, 1974). The method for getting estimates of the strength for rock mass is primarily based on an assessment of the interlocking of rock blocks and their surfaces (Hoek and Brown, 1980)

GSI is an important input parameter of the Hoek-Brown failure envelope (Hoek and Brown, 1980) which varies between 0 and 100 and also reflects the description of rock structure and block surface conditions (Vasarhelyi, 2016). GSI is frequently applied nowadays as engineering index for the categorization of rock mass quality. This act as input file into the continuum numerical analysis codes and closed type solutions supported by the Hoek–Brown failure criterion (Marinos and Hoek, 2001; Marinos et al., 2005; Marinos et al., 2006). The precise determination of GSI value is very necessary for the precise calculation of the failure envelope or the deformation moduli of the rock mass.

Kinematic analysis is purely geometric which is very useful to evaluates the sites and types of failure alongwith its directions in jointed rock mass. Angular relationships between discontinuities and slope surfaces (dip of rock formation) are applied to determine the potential sites of slope failures as well as their modes (Kliche, 1999; Umrao, 2011). To determine the possible mode of failure prevalent in an area, kinematic analysis is performed to provide a correlation between the discontinuity orientation and the surface topography. Under the present study, the RMR_b and GSI have been estimated to infer the nature of the rock mass viz., fair and poor rock mass. Seven locations have been selected and identified in the study area for the estimation and analysis of RMR_b, GSI and kinematic analysis. The categorization of rock mass falling in the study area has also been carried out. The GSI value gives a numerical representation of the overall geotechnical quality of the rock mass. The GSI is also estimated by field observation from same location with the help of Hoek-Brown (2013) equation (Hoek, 2007). Kinematic analysis has been performed using the RocScience Dips Software.

STUDY AREA

Markundi hill is located near Chopan along SH-5 in Sonbhadra district, (U.P.), India. The SH-5 is lifeline of Uttar Pradesh, Bihar and Jharkhand as for as transportation is concerned. The SH-5 also connects

0016-7622/2021-97-2-145/$ 1.00 © GEOL. SOC. INDIA | DOI: 10.1007/s12594-021-1645-y

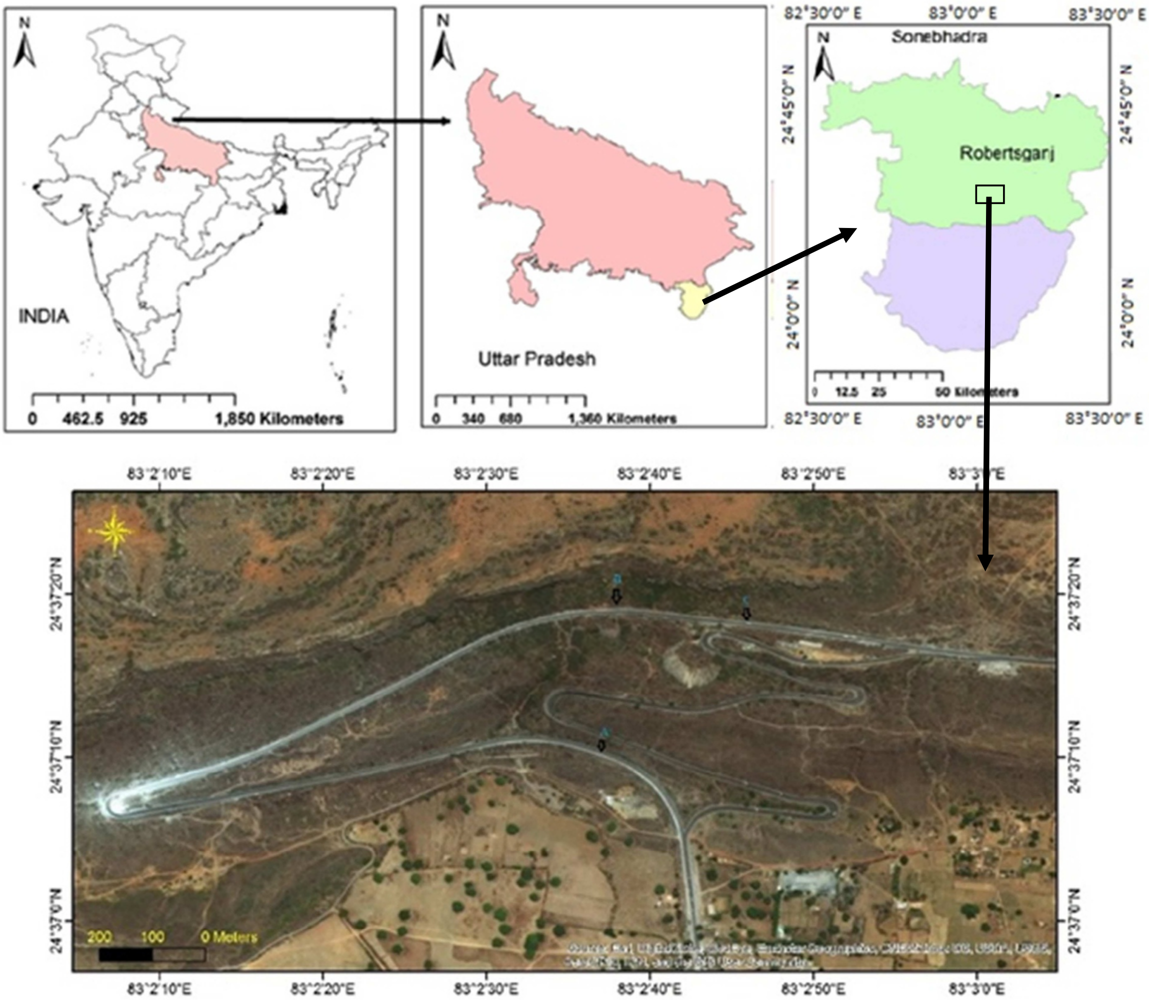

Fig.1. Location Map showing the different locations under study area.

Uttar Pradesh to Madhya Pradesh and Chhattisgarh. The rock detachment is normally observed at Markundi hill but sometimes rock fall and slide are also noticed during rainy season which obstructs the movement of vehicles on the SH-5. The study area is bounded between Latitude 24°37'3" to 24°37'25" N and Longitude 83°3'3" to 83°2'4" E (Fig.1) which falls under Survey of India Toposheet no. 63P/2 (Kumar et al., 2019).

Geological Setup

The rocks in general belong to Kaimur Group of upper Vindhyan Supergroup and can be classified under Dhandraul quartzite and Scarp sandstone formations. Topographically, the area is characterized by rugged and undulating hills which have been cut haphazardly leading to the increased incidence of block failures intermittently. The cut slopes are on the top of Markundi fault which separates Kaimur sandstone from the Bijawars basement. The signatures of deformation can be verywell observed along the cut slope in the form of variation in block size (Kumar et al., 2019).

The rock samples and data are collected from the different locations of the Markundi hill. Which are mark as probable locations in view of failure for the study. The physical status of the cut slope faces of the seven locations are shown in Fig.2(a-g).

METHODOLOGY

The data pertaining to the nature and volume of the joints have been collected near the Markundi hill at seven different locations along the SH-5. The RMR_b and GSI were estimated on the basis of data collected in the study area. The joint wall condition and RQD are common factors considered for RMR_b and GSI. The methods used to calculate the RMR_b and GSI value are explained below:

Rock Mass Rating (RMR)

Bieniawski (1976) published the details of a rock mass classification known as the geomechanics classification/ RMR_b system (Bieniawski, 1976). Although, the modified RMR_b (Bieniawski, 1979) is used to classify the rock mass on the basis of five parameters viz. strength of intact rock, RQD, spacing of discontinuities, condition of discontinuities and groundwater conditions (Bieniawski, 1979). The equivalent IS code for obtaining the value of RMR_b is IS:13365 part 3 (IS, 1997) has been used while some of the parameters have been determined in the field itself. Experiments were conducted to determine the strength of the samples by uniaxial compression test as per IS: 9143-1979 in the laboratory (IS, 1979). RQD has been estimated on the basis of volumetric joint count. The approximate relationship between RQD and Joint volume (Jv) (ISRM, 1978) used in the present study is given in the following equation

$$RQD = 115 - 3.3\ Jv \qquad \text{(Eq.1)}$$

Jv is defined as the number of joints intersecting a volume of $1m^3$, where the jointing occurs mainly as joint sets. The volumetric joint (Jv) count was introduced by Palmstrom in 1974

$$Jv = 1/S1 + 1/S2 + 1/S3 + \ldots 1/Sn \qquad \text{(Eq.2)}$$

where S1, S2 and S3 are the average spacing for the joint sets.

Fig.2.(a – g). The field photograph showing the natural as well as artificial rock cut slope at different locations along SH-5 under study area.

Geological Strength Index

The GSI is most commonly used method (Hoek et al. 2013), since the estimated values can be applied in the practical engineering directly especially for the closely jointed and heterogeneous rock mass. Therefore, it overcomes the deficiency of RMR_b method. The GSI values are estimated from the rock mass structure, the discontinuities surface condition and the deformation modulus (Hoek and Brown, 1997)

Meanwhile it is necessary to determine the affiliation between RMR_b and GSI simultaneously. Hoek et al. (2013) recommended the following formula (Eq. 3) for GSI calculation:

$$GSI = 1.5\ (Joint\ wall\ condition) + 0.5\ RQD \qquad \text{(Eq.3)}$$

Kinematic Analysis

Kinematic analysis was made to illustrate the potential for various modes of rock slope failures (plane, wedge) that occur due to the presence of unfavorably oriented discontinuities (Hoek, 2007). The analysis was based on Markland's test as described by Hoek and Bray (1981). A wedge failure may occur when the line of intersection of two discontinuities forming the wedge-shaped block plunges in the same direction as the slope face and the plunge angle is less than the slope angle but greater than the friction angle along the failure plane (Yoon et al., 2002)

Rock Science Dips 6.0 software has been used for kinematic analysis of rock cut slope in the study area. In this software, input of the slope orientation and friction angle are provided. In turn a template is overlaid on the stereonet highlighting the critical zone. The intersections of plane or number of poles in the critical zone is automatically calculated and displayed in the legend.

RESULTS

Rock mass characterization was carried out by applying RMR_b as well as GSI methods. The rating value has been assigned to each parameter for the locations under study area is given in Table 1. Rating was given according to the average value of mean discontinuity spacing (mm), roughness, separation, continuity of joints and groundwater condition. RQD values were estimated on the basis of volumetric joint count in the field. RQD itself enables to demonstrate the present condition of rock mass. The variation in RQD as estimated in study area is an indication of varying block size and also responsible for irregular RMR_b.

Hoek (2013) equation as developed for the GSI on the basis of several studies has also been used for the Vindhyan sandstone in the study area (Markundi). The linear regression analysis has been carried out which shows that most of the sampling points are either following or very close to the best fit line (Fig.3). The equation has been derived (Eq. 4) for the study area taking into consideration of Hoek's (2013) equation.

$$RMR_b = 1.3776GSI - 7.9675; R^2 = 0.8191 \qquad \text{(Eq.4)}$$

An attempt has also been made to establish the relationship between GSI and RMR in the study area. The linear regression analysis has been carried out which shows that most of the sampling points are either following or very close to the best fit line (Fig.3). On the basis of graphical relationship between the RMR and GSI, the rock mass under study area belongs poor to fair rock mass.

The perusal of stereonet reflects that the study area is prominently characterized by wedge failure (Fig.4).

On the basis of site investigations, the kinematic analysis was performed considering the attitude of rock beds and joints. Kinematic analysis of slopes at seven locations has been conducted using RocScience Dips software to understand the nature of failure. The intersection of the two joints (W1 and W2) falls in the failure envelope shown in yellow colour and critical zone show in pink colour (Fig. 4) marked by slope face and friction angle. The location-1 and location-3 show wedge failure in north-west direction. The location-2 and location-6 show the wedge failure in critical condition along the north. The location-4, Location-5 and location-7 show the wedge failure in both failure envelope and critical zone in opposite directions (toward north and east directions).

Table 1. Rock Mass classification based on RMR_b and GSI values in study area.

Loca-tions	RQD	SD	CD	UCS	GWC	RMR_b	Rock Mass Class	Jc	Hoek (2013)
S-1	17	10	15	4	12	58	Fair rock	25	46
S-2	13	8	15	2	10	48	Fair rock	22	39.5
S-3	13	5	12	2	10	42	Fair rock	20	36.5
S-4	8	5	10	2	10	35	Poor rock	20	34
S-5	13	8	11	4	10	46	Fair rock	22	39.5
S-6	13	8	12	4	12	49	Fair rock	25	44
S-7	8	5	15	2	13	43	Fair rock	20	34

The remedial measures to prevent the slope failure in the study area includes the wire netting and construction of retaining wall which would stabilize the natural slope and arrest the stone bocks respectively. Rock-bolting with wire mesh at location 1 and 6 is most suitable remedial measures. The wire netting is most suitable and feasible at locations-2, 3,4,5 and 7.

CONCLUSION

Since the study area is characterized by Vindhyan sandstone (Markundi) which has been undergone deformation and fracturing has necessitated to estimate the RMR_b as well as GSI to classify the rock mass. The RMR_b and GSI were estimated for Vindhyan sandstone at different locations (S1 to S7.)

Analysis of the results concludes that the rock mass (Vindhyan sandstone) belongs to "fair rock" under rock mass classification at six locations (S-1, S-2, S-3, S-5, S-6 and S-7). However, the rock mass (Vindhyan sandstone) at location no. S-4 belongs to "poor rock" under rock mass classification.

The study was performed to identify the safe zones and vulnerable zones for sliding particularly at the Markundi hill along SH-5. Kinematic analysis of slopes at different locations under study indicates that slopes are unstable and failure have been observed. On the basis of Kinematic analysis and field observations, the location-2, location-4, location-5, location-6 and location-7 show that there is maximum probability of criticalwedge failure whilesimple wedge failure is predicted atlocation-1 and location-3. It is concluded that the rock mass along the SH-5 at Markundi hill, Sonbhadra district, U.P. falls

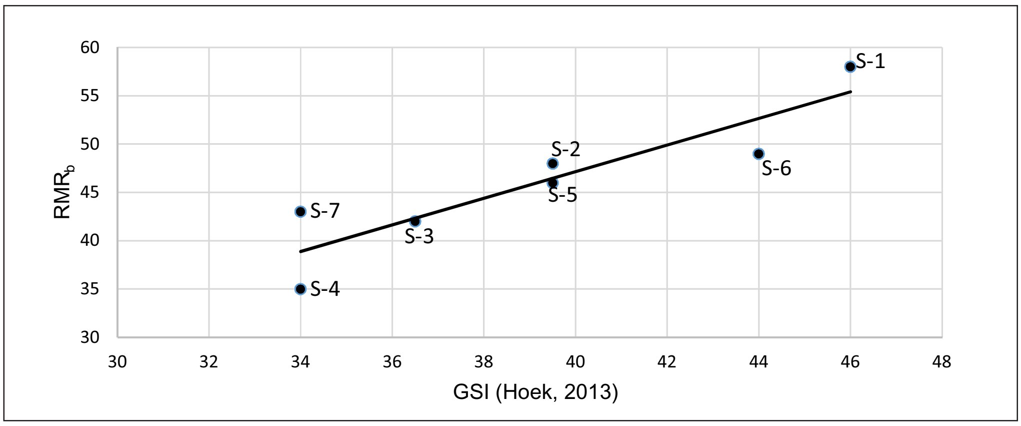

Fig.3. Graphical relationship between RMR_b and GSI (Hoek, 2013) for the Vindhyan Sandstone at Markundi

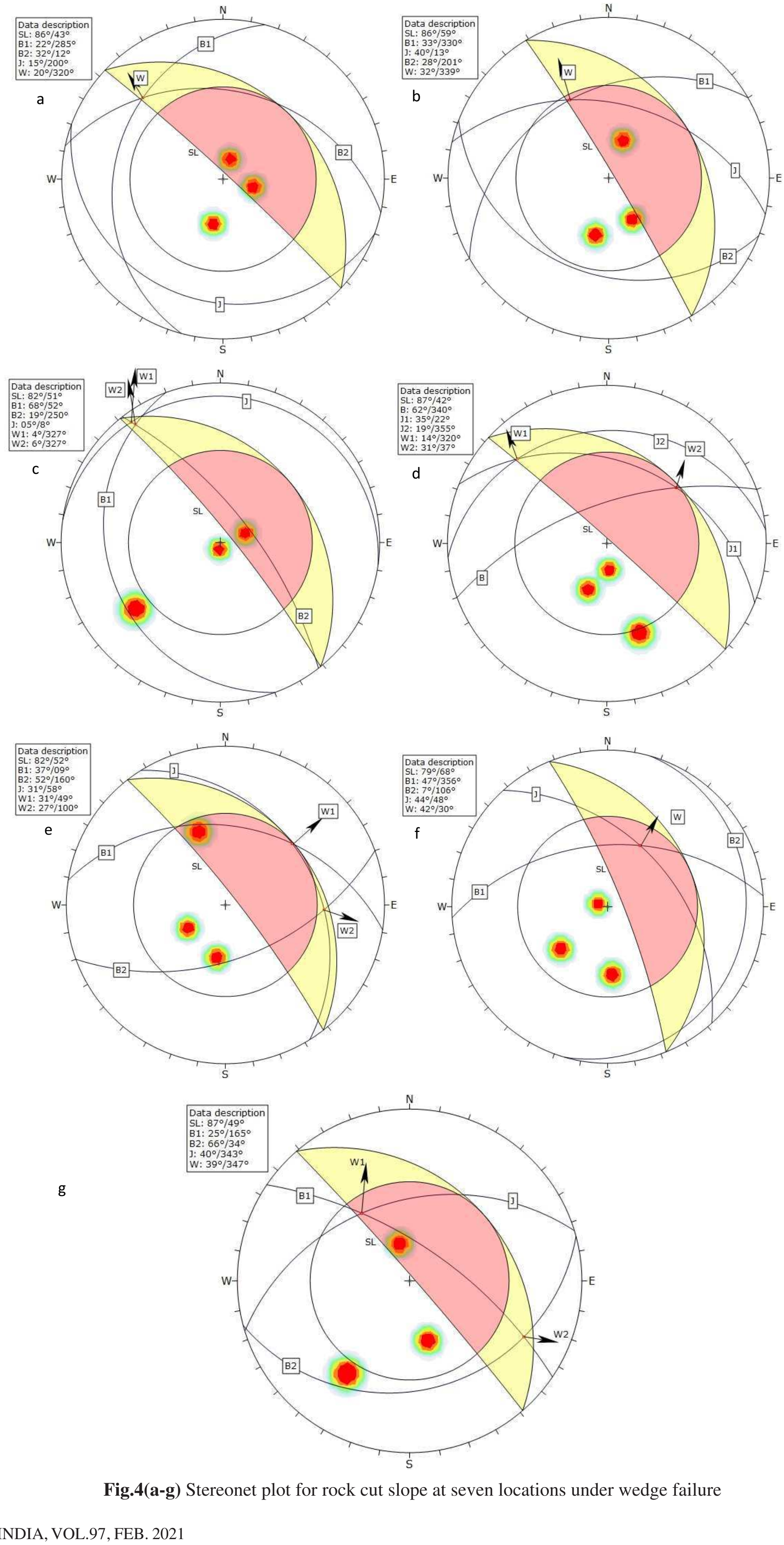

Fig.4(a-g) Stereonet plot for rock cut slope at seven locations under wedge failure under partially stable and unstable condition which requires attention regarding its prevention so that major incident does not occur in future.

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(Received: 16 September 2019; Revised form accepted: 19 September 2020)