Comparison of Slope Mass Ratings Classification Systems: A Review

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Comparison of Slope Mass Ratings Classification Systems: A Review

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Abstract. Engineering rock mass classifications are vital for empirical approach to evaluate and predict engineering behavior of a rock mass. Now well established empirical relations between behavior of the rock mass and the rock mass properties with regard to specific engineering applications have become an important tool for resolving many geo-engineering issues related to mega engineering projects. Engineering classifications of Rock Masses have been applied in tunneling and underground mining with great success for many years. Some rock mass classification systems developed originally for underground, excavations were also modified and adopted for many different applications including slope stability applications. The rocky slopes in general as well as along road and rail tracks are important locales for slope analysis and stabilization. In this study five classification systems are thoroughly studied for rock stability assessment and compared on the basis of reports of various research paper published so far. The methods are Slope Mass Rating and it's off shoots, such as Continuous Slope Mass Rating, Chinese Slope Mass Rating, Graphical Slope Mass Rating and Landslide Hazard Evaluation Factor. We have tried to work which of these method can best predict slope failure as a normal process of mass wasting and mass movement as well as triggering mechanism such as pore water pressure increase, sudden down pour, earthquakes etc. So as to work out structurally controlled failure mechanism to find suitable ways for safe rock slope cuts for road networks in hilly and mountains terrain.

Keywords: *Rock Mass Classifications*, *Slope Mass Rating, Rock Slope Stability*

Introduction

The "Brown Field" areas comprising of rocky terrains are subjected to infrastructural development as in the case of "Green Field" areas. But categorizations of "Rocky Grounds" are difficult due to lot of natural variability as compared to "Soil Ground". The engineering classification of "Rocky Ground" has been attempted first by Karl Terzaghi in (1946) known as "Rock Load Theory" for designing support for underground tunnels. This was followed by Rock Mass Rating by Bieniwaski, 1973, Rock Mass Quality by Barton et al, 1974 and became the base of future engineering classification of rock masses. These classifications were mainly for designing tunnel support system. Many of these methods have been modified by different researchers to be used for other geotechnical engineering issues, such as characterizing slopes and identifying their failure vulnerabilities.

Methods proposed and classification developed so far for slope analysis can be broadly classified in four categories they are kinematic analysis approach (based on stereo net projection), empirical methods, limit equilibrium and numerical modeling. A number of classification systems are available for analysis of slope stability, namely:

1. Slope Mass rating, (SMR, Romana et al., 1985; 2001; 2003; 2005)
2. Chinese Slope Mass Rating (CSMR, Chen, 1995),
3. Continuous Slope Mass Rating (Tomás et al.2007),
4. Graphical Slope Mass Rating (Tomas et al 2012):

5. Landslide Hazard Evaluation Factor (LHEF, 1995)

Classification systems in slope stability analysis

Slope stability is an important aspect of infrastructure development especially road and rail networks and causes immense distress in our own country (NDMA, 2009) .Rock engineering has an important part to play in stabilization of the rocky slopes. During the plan, development and post design periods of rock slope stability, designers, engineers, and geologists need to give close consideration to the rock conditions of the rock slope, to anticipate and control failure of the slope, ensure masses safety living in these landscapes and maintain road and rail network for economic activities. With passage of time and advancement in engineering and technology there is a need of classification system with uniform validity, which attracts researcher to propose a new system which could describe and hold validity in different geological and engineering aspects. It is the rock mass classification system adopted by researcher, engineers in the real field situations throughout the world as a base, with an intention to provide quantitative guidelines for analysis and practice (S.P. Pradhan et al,**2020);(** Kundu, Jagadishet al**,2017);(** Bashel,Hassan,Mitri**,2017);(** Taherniya et al 2014) and (Siddiqui et al, 2015) Though, it has various advantages as well as limitations (Pantelidis, 2010) .

According to Hack (2002), classification systems consider various parameters like geometry, slope, shear strength etc. But it is the properties pertaining to water seepage and pressures are still difficult to determine precisely, despite the fact that water is the biggest cause of slope failures. Pantelidis (2009) stated that these properties are controvertible and employed with errors. In all the above mentioned methods the designated properties and their indices may result in misinterpretation due to many varied parameters related to geomechanical properties of rock.

Rock mass classification system is used for design In geotechnical engineering for preliminary assessment and due to its simplicity (Duran &Douglas 2000), and it is the primary resource for assessment of stability based on structural and inherent parameters (Taherniya et al. 2014). These systems are serving as a foundation in the empirical designs which correlates the past experience to the present prevailing situation and state at the present site (Bieniawski 1990). Main reason for the popularity of rock mass classification systems is that they are a basic and powerful method of delineation rock mass quality and setting the basic frameworks for implementation and practice in the field (Harrison, Hudson ,2000) In tunneling and underground rock engineering these systems are applied to find the rock mass quality, in other processes and pre-design excavation (Aksoy 2008). these systems of classification plays vital role in quantification of the rock properties on the basis of past findings and experiences and for evaluation of the behavior of rock mass under external loading conditions (Milne et al. 1998). SMR provides preliminary information in the initial phase of the investigation (Romana et al. 2015).The stereographic analysis approach is quite friendly and easy to use in case of jointed rock mass for the finding and assessment of potential failure types and direction(Goodman 1976; Hoek and Bray 1981; Matherson 1988) and these systems were initially developed and used for underground excavation purposes (Hoek ,2007) and must be used for preliminary investigation purposes(Bieniawski, 1997). Rock slope and soil mass are complex, even after major researches we are still lagging in understanding its geological characteristics, mechanical properties, strength, and deformation (CHEN, 2005). SHI et al (2005) proposed the Highway Slope Mass Rating (HSMR) system based on the SMR for rock slopes of mountain highways. LI et al. (2010) proposed modified CSMR using a continuous function.) General Slope Mass Rating (GSMR) evaluates rock slope stability on the basis of number of practical engineering problem in the field and research project WU et al. (2005).

Discussion

1. Slope Mass Rating (Romana, 1985)

Slope Mass rating is the extension of one of the early engineering classification of rock masses i.e. Rock Mass Rating (RMR) by Bieniawski in 1973. Romana (1985) [9] used this engineering classification to analyze rocky slopes by following formula:

$$SMR = RMR_{Basic} + (F_1 \times F_2 \times F_3) + F_4$$

Where,RMR_{Basic} stands for Rock Mass Rating given originally in 1973 and taking into consideration five parameters plus the sixth one given by Romana (1995)

F_1, F_2, F_3 and F_4 are different functions related to slope (table 2.5), defined as:

F_1, defines angular difference between orientation of slop face and strike of most significant joint.

F_2, refers to angle of dip of most significant joint in planar and toppling mode of failure and angle of plunge of line created by intersection of two joint planes in case of wedge failure. (Romana, 1993),

F_3,defines angular difference between inclination of slope and dip of the most significant joint.

F_4, is defined as adjustment factor for the method of excavation which has been fixed empirically.

But, before employing these parameters one has to identify type of failure i.e. Planar, Wedge or Toppling failures using kinematic analysis using Stereo Nets (Figure 1).

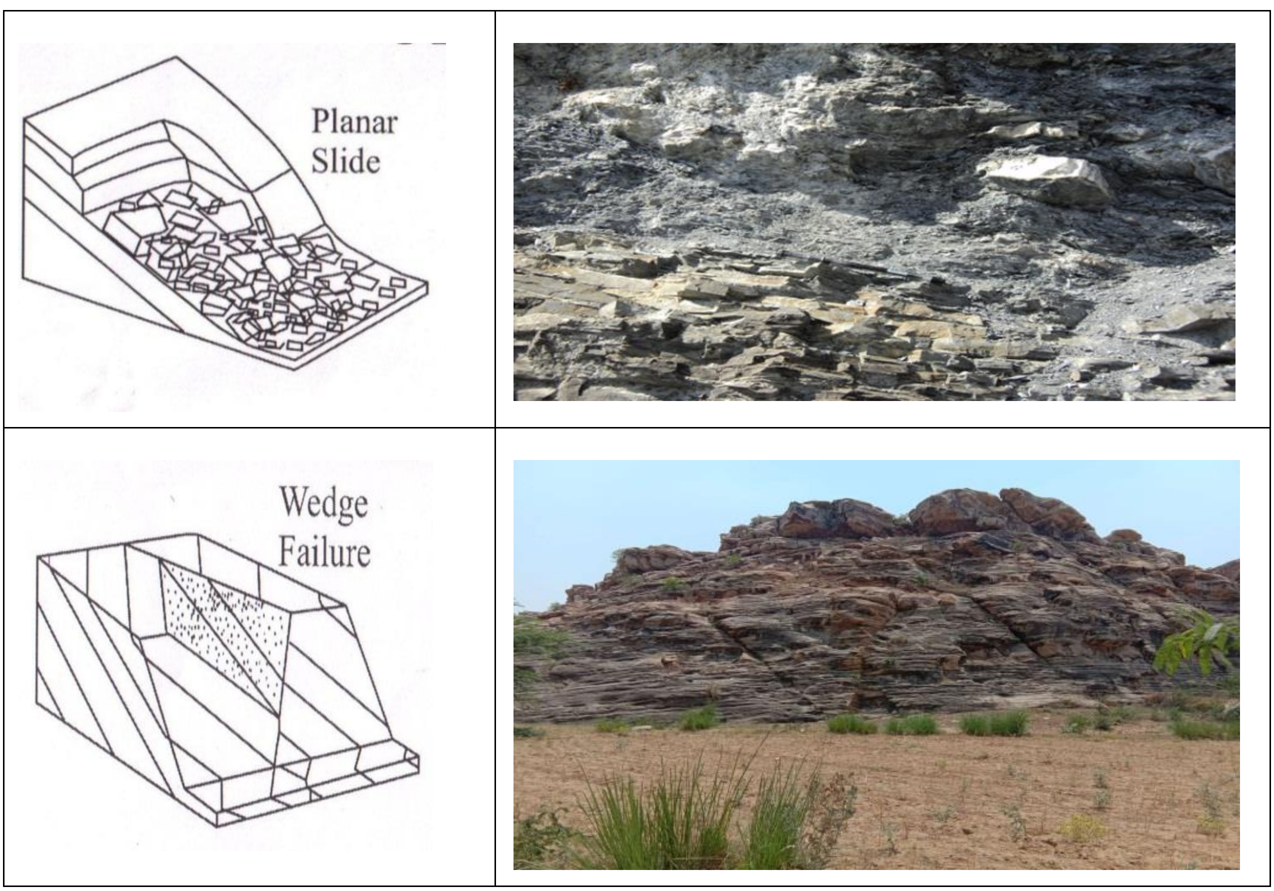

Figure 1: Figure showing different types of failure in graphic form and as real field sites. (a) Planar Failure, alternate Quartzite and Phyllite, Middle Himalaya, Nainital, Uttrakhand. (b) Wedge Failure, Sandstone Vindhyan Hills, Bindrauli, FatehpurSikri, UP. Toppling Failure, Charnockite, Western Ghats, Wayanad, Kerala.

Table 1.1: Rating values for different Slope Factors (Romana, 1985)

Case of Slope Failure		Very Favourable	Favour-able	Fair	Unfavour-able	Very Un-favourable
P T W	$\lvert \alpha_j - \alpha_s \rvert$ $\lvert \alpha_j - \alpha_s - 180^0 \rvert$ $\lvert \alpha_j - \alpha_s \rvert$	$> 30^0$	30^0 - 20^0	20^0- 10^0	10^0 - 5^0	$< 5^0$
P/W/T	**F_1**	**0.15**	**0.40**	**0.70**	**0.85**	**1.0**
P W	$\lvert \beta_j \rvert$ $\lvert \beta_j \rvert$	$< 20^0$	$30^0 - 20^0$	35^0 - 30^0	45^0 - 35^0	$>45^0$
P/W	**F_2**	**0.15**	**0.40**	**0.70**	**0.85**	**1.0**
T	**F_2**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
P W	$\lvert \beta_j - \beta_s \rvert$ $\lvert \beta_j - \beta_s \rvert$	$> 10^0$	10^0 - 0^0	0^0	$0^0 - (- 10^0)$	$< - 10^0$
T	$\lvert \beta_j + \beta_s \rvert$	$< 110^0$	110^0- 120^0	$> 120^0$	----	----
P/W/T	**F_3**	**0**	**- 6**	**- 25**	**- 50**	**- 60**

Table 1.2: Values of Adjustment Factor for Method of Excavation

Method of Excavation	F_4 Values	Method of Excavation	F_4 Values
Natural Slope	+ 15	Pre Splitting	+ 10
Smooth Blasting	+ 8	Normal Blasting	0
Mechanised Excavation	0	Poor blasting	- 8

Romana (1985) gave five slope stability classes as per SMR (table 1.3) which can be used in landslide zonation, cut slope design and deciding for slope of open cut mines.

Table 1.3 Slope Stability Classes Based on SMR Values.

Class No.	**V**	**VI**	**III**	**II**	**I**
SMR Values	**0 – 20**	**21 – 40**	**41 – 60**	**61 – 80**	**81 – 100**
Rock Mass Description	Very Bad	Bad	Normal	Good	Very Good
Stability	Completely Stable	Unstable	Partially stable	Stable	Completely stable
Failures	Big planar or soil like complex failure	Planar or big wedges	Planar along joints and wedge failure	Some block to toppling failure	No Failure
Failure Probability	**0.9**	**0.6**	**0.4**	**0.2**	**0**

Broad remedial measures can also be suggested by detailed study of the problem, analysis of SMR values and good engineering acumen as per the table 1.4

Table 1.4: SMR Classes and Suggested Remedial Measures.

SMR Classes	**SMR Values**	**Remedial Measures**
Ia	91 – 100	None
Ib	81 – 90	None to some scaling
IIa	71 – 80	Scaling, provision of toe ditch or fence net
IIb	61 – 70	Toe ditch or fence net, Spot to pattern bolting
IIIa	51 – 60	Toe ditch or fence net, Pattern bolting and Spot shotcreting
IIIb	41 – 50	Toe ditch and wall, Pattern bolting, Systematic shotcreting, Dental concrete
Iva	31 – 40	Anchors, Systematic shotcreting, Dental concrete, Drainage Improvement
IVb	21 – 30	Systematic reinforced shotcrete, Concrete wall, Re-excavation, Deep drainage
V	11 – 21	Re-excavation, Deep drainage, Gravity Wall, Anchored retaining wall with buttresses

In last three decades or more, SMR is being used very frequently to get:

1. Geomechanical classification system for rating of rocky slopes.
2. Preliminary investigations to find out the vulnerability of slope failure.
3. Served as base indicator for engineering solutions on failing slopes.

But, some natural issues of rock slopes could not be factored in SMR and resulted in to poor results. Many scientists tried to incorporate these parameters and have incorporated extra factors to get more realistic results.

2. Chinese Slope Mass Rating System (CSMR)

It was developed by Chen (1995) to adopt SMR system to rock slope conditions in China. It is used as a national standard for slope in design and construction of Dams and Hydroelectric power Stations. It adapts two additional factors in SMR:

1) Height of slope, ξ (if more than 80meter).

2) Conditions of discontinuity, λ.

ξ and λ and modified slope mass rating (SMR) formula as follows.

CSMR = (ξx RMR) + [λ x(F_1 x F_2 x F_3) + F4]

Where, $\xi$and λ represents the slope height factor and discontinuity factor respectively. ξ and λ are significant factors and included in the framework of SMR in light of the fact that there are a few slope failures for which SMR indicates stable slopes. Therefore, these two factors are included to improve the classification system, while other parameters remained the same. The factor ξ is applicable only for heights greater than 40 m. However, this is an accepted system of classification in China and for application other than China it requires a number of corrections and modifications before using at any other place.

$$\xi = 0.57+0.43\text{x}\frac{80}{H}$$

Where, H is the height of slope in meters and, λ=0.7 for closed joints and tightly interlocked bedding planes. λ = 1 for faults, λ = 0.8 to 0.9 for long weak seams filled with clay and large scale joints.

3. Graphical Slope Mass Rating (Tomas et al 2012):

This classification system is based on graphical approach to find the correction factors in basic SMR by using stereo plots. Correction factors were determined, which were applicable in various failure like toppling, wedge and planar failure. Tomas et al (2012) gave single correction for **(F1, F2)** ψ, with the help of stereo plots position of discontinuity pole found out or from intersection of the planes. Whereas, F_3 depends on the type of failure mode. Hence, modified equation is as follows

SMR=RMR +$\psi F_3 + F_4$

It is suitable for various engineering and practical application like linear slope open pit mining, the biggest advantage of this approach is that it brings ease in calculation of correction parameters of slope mass rating (SMR).

Where the strikes are different and dips are same this method has added advantage of being applicable in the case of field measurements of various discontinuities in order to find the values of correction parameters. One of the benefits of the graphical method is the simple and effective calculation of SMR correction factors for various slope directions influenced by a similar set of discontinuities. It is generally depicted in roads, railways, channels, linear infrastructures, and in case of open pit mining where the slopes excavated over rock masses depicting same dip but different strikes.

4. Continuous Slope Mass Rating (Co SMR)

Romana (1985 suggested), for $\mathbf{F_1, F_2, F_3}$ **and** $\mathbf{F_4}$in SMR **=** $\mathbf{RMR_B + (F_1 \times F_2 \times F_3) + F_4}$**,** are discrete and relies more on judgment of the explorer and investigator Since it requires a lot of experience in assigning the rating based on one's experience. Tomas et al., (2007) [16] proposed a continuous function for $\mathbf{F_1, F_2, F_3}$ **and** $\mathbf{F_4}$ which best suits the discrete values. Following are the equations for the continuous functions:

$$F1 = (\frac{16}{25}) - (\frac{3}{500}) \tan^{-1}(\frac{1}{10}|A| - 17)$$

$$F2 = \frac{9}{16} + \frac{1}{195} \tan^{-1}(\frac{17}{100} B - 5)$$

For planar and wedge failure,

$$F3 = -30 + (\frac{1}{3} \tan^{-1} C)$$

And for topple failure,

$$F3 = -13 - (\frac{1}{7}) \tan^{-1}(C - 120)$$

Where, ***A*** is difference between slope strike and plunge direction of angle of intersection for wedge failure and parallelism between slope strike and joint strike for planar and toppling failures. ***B*** is plunge of angle of intersection in wedge failure and dip of joint in planar failure. ***C*** is difference between angle of slope and dip of joint for planar failure, in case of toppling failure, difference between angle of slope and plunge of line of intersection, for wedge failure, addition of slope angle and dip of joint.

5. Landslide Hazard Zonation(IS:14496 Part II)

The Bureau of Indian Standard has given this code IS 14496 Part II, 1985, [5] for landslide hazard mapping based on ten causative factors with each factor given landslide hazard evaluation factor (LHEF) as 1 or 2, totaling 10 maximum points. (table 5.1). The area to be mapped for landslide hazard zonation is to be divided into different smaller regions using maps of 1: 50,000 to 1: 25,000 for macro zonation.

It has direct similarity with SMR in terms of its parameter B which is equivalent to F1, F2 and F3 of SMR (table 5.2).

Table 5.1: Causative Factors and Landslide Hazard Evaluation Factor

Sr. No.	Causative Factors	LHEF	Category	Rating	Remarks
A	Lithology	2	Type 1 – 3 & Soil (Old – Young)	0.2 – 2.0 0.8 – 2.0	C1 HW(4 1.5) C2 MW(3/1.25) C3 SW(2/1.0)
B	Structure	2	I to III Relationship of Slope **VS** Discont. Orientation and inclination	0.2 – 0.5 0.3 – 1.0 0.2 – 1.2	**I** Very Favourable **to** **V** Very Unfavourable
C	Slope Morphology	2	Escarpment>45^0 Very Gentle < 15^0	2.0 0.5	**No. of Contour lines of 20m interval in 10m line**
D	Relative Relief	1	Low <100m, Med. 100 – 300 High >300	0.3 0.6 1.0	**Seismic Zone 1,2,3 *half Severe Hyd Cond. x 1.5***
E	Land Use & Land Cover	2	Agriculture Thickly Vegetated Mod.Vegetated Sparse Vegetated Barren	0.6 0.8 1.2 1.5 2.0	
F	Hydrological Conditions	1	Flowing Dripping Wet Damp Dry	1.0 0.8 0.5 0.2 00	
Other Factors		Up to 200m strip on either sides of the Fault, Thrust 7 intra Thrust Zones will be awarded extra 1.0 ratings.			
Total		10			

The similarity with SMR in terms of its parameter B which is equivalent to F1, F2 and F3 of SMR but with different rating values (table 5.2) are as follows:

a) The extent of parallelism of discontinuity plane or the line of intersection of two discontinuity planes *w r t* slope orientation (STRIKE) i.e. F1 of SMR.

b) The difference in the dip or inclination of discontinuity plane or the line of intersection of two discontinuity planes *w r t* slope inclination (DIP) i.e. F3 of SMR.

c) Steepness or dip of the discontinuity or plunge of line of intersection of two discontinuity planes i.e. F2 of SMR

Table 5.2: Showing angular relationship relation between (a) - orientation of slope and joint, (b) –between inclination of slope and dip of joint and (c) –dip of the joint.

(a) -The extent of parallelism of discontinuity plane or the line of intersection of two discontinuity planes *w r t* orientation of slope (STRIKE $\alpha_j - \alpha_s$ for Planar Failure, $\alpha_i - \alpha_s$ for Wedge Failure), Where α_j - Orientation of Discontinuity (Joint), α_i - Orientation of Discontinuity (Joint), α_s- Orientation of Slope				
Case I	**II**	**III**	**IV**	**V**
Angle $>30^0$	$30^0 - 21^0$	$20^0 - 11^0$	$10^0 - 5^0$	$< 5^0$
Rating 0.20	0.25	0.30	0.40	0.50

(b)- The difference in the inclination of discontinuity plane or the line of intersection of two discontinuity planes *w r t* slope inclination (DIP, $\beta_j - \beta_s$ for Planar Failure, $\beta_i - \beta_s$ for Wedge Failure), Where β_j = Dip of Discontinuity (Joint), β_s= Inclination of Slope, β_i= Plunge of Intersection line of two joints				
Case I	**II**	**III**	**IV**	**V**
Angle $> 10^0$	$10^0 - 0^0$	0^0	$0^0 - (-10)^0$	$> - 10^0$
Rating 0.20	0.30	0.50	0.70	1.00

(c)- The inclination or Dip of discontinuity plane (DIP of Planar Joint or Discontinuity β_j or Intersection line of two sets of joints β_i				
Case I	**II**	**III**	**IV**	**V**
Angle $<15^0$	$16^0 - 25^0$	$26^0 - 35^0$	$36^0 - 45^0$	$>45^0$
Rating 0.20	0.25	0.30	0.40	0.50

Depending upon the estimated value of each region the entire area can be identified in to five hazard zones as per the table 5.3.

Table 5.3: Landslide zones for total estimated hazard as per IS:14496 Part II

Total Estimated Hazard as per IS 14496 Part II	Zone Category	Zone Description
<3.5	I	Very Low Hazard
3.5 to 5.0	II	Low Hazard
5.1 to 6.0	III	Moderate Hazard
6.1 to 7.5	IV	High Hazard
> 7.51	V	Very High Hazard

Conclusion:

In this paper five classification systems thoroughly examined particularly those systems which are established for the assessment of stability of rock slope. The worth mentioning inferences drawn from the comparative study of the five methods, Slope Mass Rating (Romana, 1985**),** Chinese Slope Mass Rating System (CSMR), Graphical Slope Mass Rating (GSMR), Continuous Slope Mass Rating (Cont. SMR) and Landslide Hazard Evaluation Factor are as follows:

SMR methods are found to be most suited for the rock slope that undergoes failure mechanism which is structurally controlled .it includes the combine effect of dip direction and dip, which includes F_4as the effect of method of excavation which is correlated with parameters (**F_1, F_2, F_3**).SMR is slightly conservative. The extreme values of **F_3** (-60 and -30) proposed by Romana (1985) are something difficult to cope with, SMR does not take into account the effect of height.

The major drawback for Chinese SMR is that it is not applicable for height of slope below 80 m hence it is not suitable for rock cuts however it includes height and discontinuity condition. In case of favorable conditions to discontinuity this methods gives higher ratings in comparison to the original SMR. It needs to be equipped with considerable modifications as per requirements and number of corrections before applying at any other place.

Anthropogenic causes of landslides, very important aspect is not considered in detail in any of the method except incorporating excavation method in SMR and land use in LHEF, hence need additional examination as anthropogenic interventions are posing challenge by the day.

In Continuous SMR system rating functions were replaced by Continuous functions, its rating scores are higher in comparison to discrete system like SMR, CSMR and Graphical SMR.Continuous SMR can be categorized as relatively less perception based classification system as it gives particular outcome for each input value of a parameter. The influence of water and seismic effect not considered in the methods but Continuous SMR could be suitable method for rock cuts and it does not exaggerate or belittle the result of assessment of stability of slope

Due to the similarity in the methodology of evaluation of correction factor **(F_1 ,F_2, F_3)** there's quite resemblances in the result from graphical SMR and SMR and rock evaluation classes are quite similar, it allows a quantitative evaluation of the impact of discontinuities on the behavior of the rock mass and offers the required data for determination of rock mass classification values and failure mechanisms.

It is concluded that all empirical methods compared in this study are applicable to controlled failure mechanism and not consider the triggering factors like water presence. None of the above methods considers convexity or concavity of the slope, which generally encountered in the rock cuts hence suitable for linear structure. These methods can further improved by incorporation slope factor for height less than 80 m, effect of pore water and adjustment factors can further be improved analytically. Shape factors must be included which could add the effect of shape and curvature of the slope .the above mentioned limitations need to be addressed in the future study

It can be concluded on the basis of various case studies that need to employ parameters given by different authors in SMR. LHEF can be used for reconnaissance study though it is exhaustive but has lesser number of classes and wide range of values. Also it gives hydrology lesser importance with rating value of 1 only. The LHEF is silent on remedial measures to be provided if prone to instability. All above methods need proper technical expertise especially in measuring orientations, inclinations, and identification of most problematic joint. If LHEF and SMR with addition of parameters related to height, used as combined method can give better insight to slope.

Finally, all these methods are heavily relying on discontinuities (joint) and their orientation with respect to slope. But, do not factor the dip of the rocks. It is concluded that the horizontality, inclinity and verticality of rock mass, especially in layered rocks and their orientation with slope should also be taken into consideration. Also presence of “Shear Zones” which are very common in rock masses and are venues of severe mass wasting have not been considered where the discontinuity related parameters are overwhelmed.

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Figures

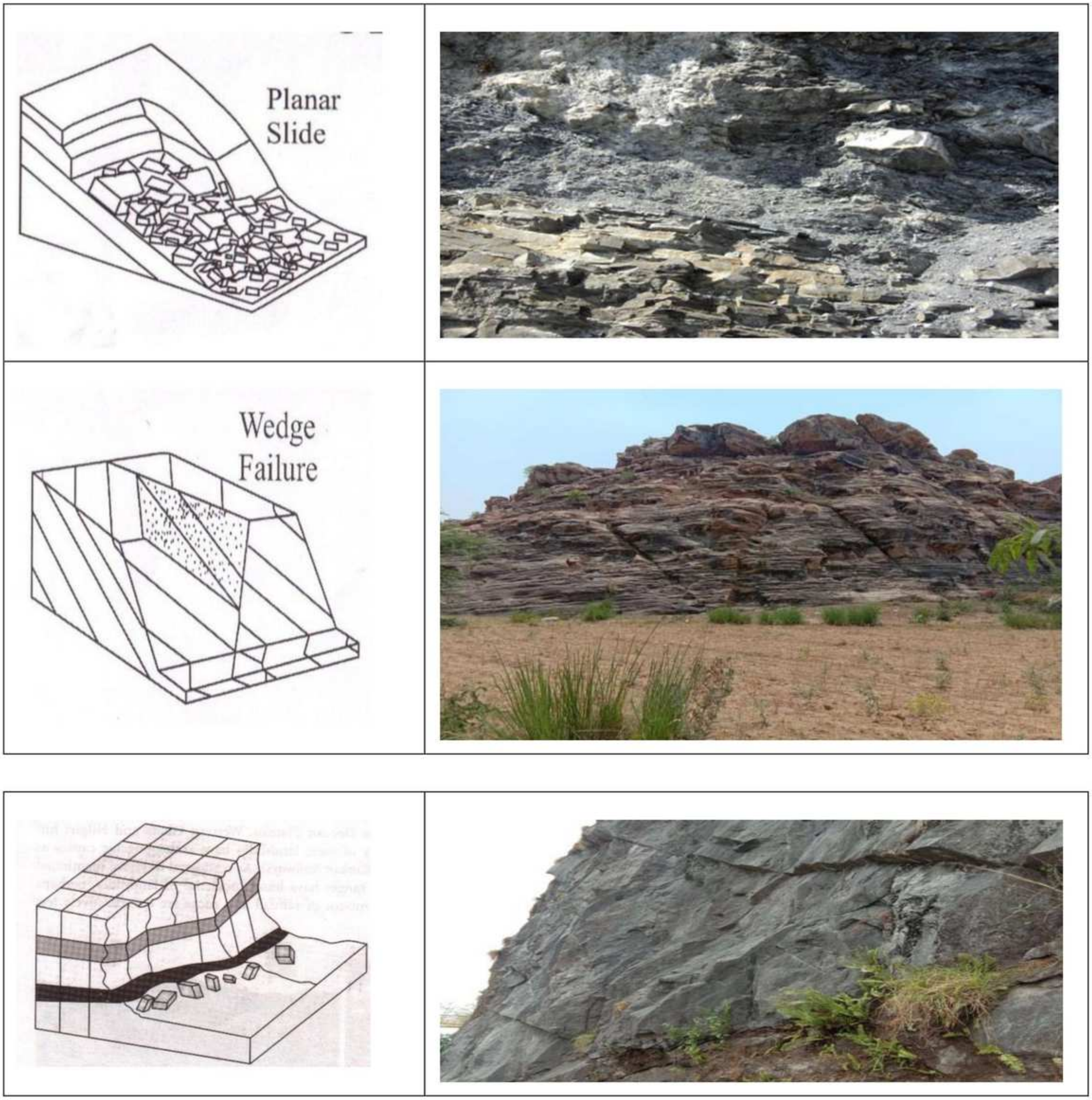

Figure 1

Figure showing different types of failure in graphic form and as real field sites. (a) Planar Failure, alternate Quartzite and Phyllite, Middle Himalaya, Nainital, Uttrakhand. (b) Wedge Failure, Sandstone Vindhyan Hills, Bindrauli, FatehpurSikri, UP. Toppling Failure, Charnockite, Western Ghats, Wayanad, Kerala.