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A review on the development of rock slope stability assessment in Malaysia

A F Salmanfarsi[1], H Awang[2*], M I Ali[2]

[1] PhD Student, Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia.

[2] Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia.

*Email: haryatiawang@ump.edu.my .

Abstract. Rock mass classification systems are commonly used in the design and construction of rock engineering, and have seen widespread modifications and validations by various researchers over the last few decades. In Malaysia, several methods for large- and medium-scale slope assessment systems have been developed for prediction of landslide risk. Most of the methods however were found to be unsatisfactory in actual prediction of slope failures. The rock mass classification, in particular the slope mass rating (SMR), continues to be the preferred preliminary method in small-scale assessment of rock slope stability. Kinematic analysis is also widely used for predicting potential failure in structurally-controlled rock slope, and has been used independent or as compliment to rock mass classification systems. These methods are not entirely adequate in incorporating the local condition of rock mass: as a result, several works have modified the parameters of slope stability assessment methods to consider the condition of the rock mass such as the effect of heterogeneous rock units and weathering of rocks. In addition to these conventional methods, geophysical methods such as electrical resistivity, and remote sensing methods such as light detection and ranging (LiDAR), are increasingly being used in both preliminary and post-slope failure analysis. This paper reviews the development of rock slope stability assessment methods in Malaysia, as well as covering the viability of integrating geophysical and laser scanning methods with conventional methods to develop a more comprehensive rock slope assessment.

1. Introduction

Rock slopes are susceptible to instability problems due to various factors, both in the rock mass conditions and external factors from the environment. The material of the slopes, slope height, slope face angle, and discontinuities orientation all play important role in affecting the stability of rock slopes. Slope stability provides major concerns for researches working in various fields, and as such various techniques and methods for slope stability assessment have been proposed throughout the years. Although geological condition have been reported to account only a portion of the contributing factor to landslide in Malaysia, accounting for a total of 8% [1], the input of engineering geology to the process of excavation and treatment of cut slopes is still of great importance [2]. This is especially crucial in the case of highway, where large rock bodies of rock is excavated for the purpose of road's construction.

In addition to field investigation for slope stability analysis, geophysical method have increasingly being used both assessment of slope stability as well as post-slope failure investigations. The electrical resistivity method in particular is a popular method in landslide assessment. Also of interest in slope assessment are remote sensing methods, in particular laser scanning, which can extract slope parameters either in an automatic or semi-automatic way. Remote sensing method is particularly valuable for slope stability study due to the ability to extract data over large area in relatively short time.

2. Rock slope stability assessment methods

2.1. Kinematic analysis

Kinematic analysis represents one of the conventional methods of slope stability analysis, and is a purely geometric method which examines potential modes of failures in jointed rock mass through the usage of stereographic projection technique. The usage of this method is limited to structurally controlled slopes. The common method of kinematic analysis was originally proposed by [3], later redefined by [4-5]. In the test, the great circle of the slope face and circle of friction angle, φ, is plotted on stereographic projection. The zone between the great circle and the friction circle (sliding envelope) represent the condition for failure, where the plunge value of the joint is less than the slope angle and greater than the friction angle of the joint.

The method however only provides the potential for slope failure, ignoring the strength parameters of the discontinuities and of the rock mass as well as acting forces on the slope, hence not providing the slope stability condition in a quantified way [6]. Kinematic analysis is, however, essential in any evaluation of structurally controlled rock slopes, and is recommended as the first step before proceeding to other analytical techniques of slope stability [7].

2.2. Rock mass classifications

Rock mass classifications are one of the most widely known empirical classification for rock engineering. They represent the means for evaluating the performance of rock cut slopes based on important parameters, describing the rock mass condition quantitatively [8]. Summary of existing rock mass classification systems can be found in the work of [8-9].

Rock Mass Rating (RMR) is one of the most widely used empirical method for rock mass classification. Originally designed by Bieniawski [10] to evaluate the quality of rock mass while working in underground projects, the system contain five parameters representing different conditions of rock and discontinuities: strength of intact rock material (uniaxial compressive test or point load strength) (R_{δ}), rock quality designation (R_{RQD}), spacing between discontinuities (R_{SD}), condition of discontinuities (R_{CD}), and groundwater condition (R_{CG}) (Eq. 1):

$$RMR = R_{\delta} + R_{RQD} + R_{SD} + R_{CD} + R_{CG} \quad (1)$$

Bieniawski [11] later proposed slope adjustment factor to the original system to take into account whether the discontinuities strike and dip are favourable or not to slope failure. The rock mass could be sorted into five classes according to the basis of RMR values: very good (RMR 100–81), good (80–61), fair (60–41), poor (40–21), and very poor (<20). For any given classes of RMR, [12] provided guidelines for supports to tunnel excavated through conventional drilling and blasting.

The Slope Mass Rating (SMR), devised by Romana [13] modifies the RMR of [10] The SMR system aims to remove ambiguities in RMR, and has become one of the most commonly used classification for rock slopes. The SMR index adds four adjustment factors, with parameters that reflect joint-slope relationship (F1-F3), as well as method of excavation (F4) (Eq. 2):

$$SMR = RMR + F1\ F2\ F3 + F4 \qquad (2)$$

As with RMR, the slope stability is divided five classes according to the basis of SMR values: completely stable (SMR 100–81), stable (80–61), partially stable (60–41), unstable (40–21), and completely unstable (20-0). Of the various rock mass classification systems, SMR is one of the most widely used classification system used for the purpose of slope stability analysis, with subsequent modifications by workers commonly derived from the system. Bieniawski [11] recommends the usage of Romana's SMR [13] for rock slope stability analysis.

Due to its relative simplicity of usage, the rock mass classification systems are not applicable to complex cases involving variable slope geometric, coupled problems, and/or complex conditions of discontinuities [6]. It however continues to enjoy wide usage due to their simplicity, reliability, and been time-tested for more than three decades [14]. The system is a powerful system in the initial stage of slope stability analysis, and continues to act as a common language for both engineering geologist and geotechnical engineers.

3. Modification of rock mass classification systems for Malaysia

As Malaysia is particularly vulnerable to landslides occurrence, several empirical methods for slope assessment and management have been developed over the years for in large-scale and medium-scale assessment of slope. [15] reviewed the accuracy of five slope assessment systems (SAS) developed in Malaysia, where it was found that none were satisfactory in predicting landslides in rock cut slopes. The various reasons for the unsatisfactory prediction of landslide were cited to be the result of usage of hazard score developed from other country, insufficient database, the use of an oversimplified approach, and the use of database derived from a different rock/soil formation.

A review for case studies of engineering geology in Malaysia by [2] specifically outline the usage of kinematic analysis for assessment of rock slope stability, reflecting the common practice of adoption of this method amongst geologist and engineer geologist. Various local slope stability analyses employed kinematic analysis, either in conjunction or independent of rock mass classification systems. The SMR in particular has seen frequent usage among local practitioners: for example, recent case study on slope stability analysis of limestone cliff at Gunung Kandu, Gopeng by [16] highlight how the usage of SMR is significant for its quantification of rock slope stability in a practical method for large area of rock slope assessment.

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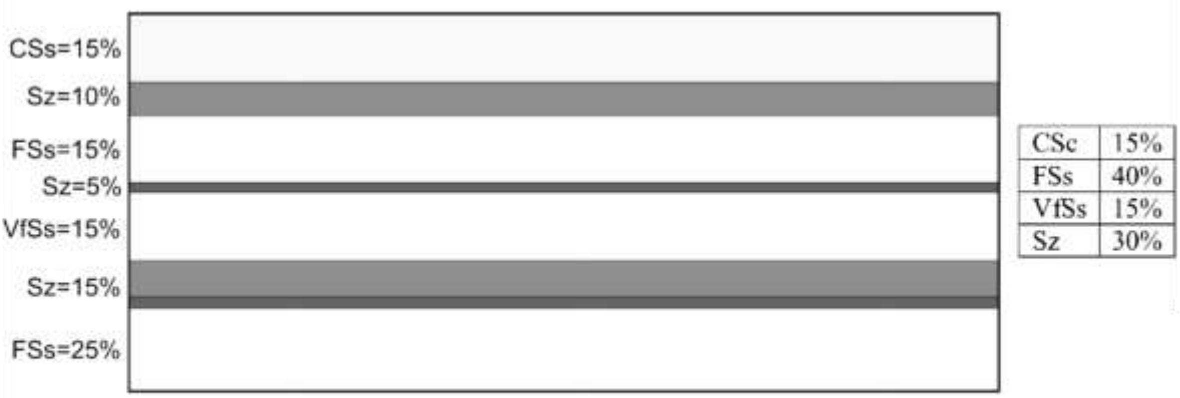
Presently, only a few works have attempted to modify the rock mass classification system in the context of local slope stability studies. The most notable example is the Modified Slope Mass Rating (M-SMR) [17-19] resulting from the works on the Crocker Formation in Kota Kinabalu. The system modifies the original RMR [12] and SMR [14] to consider the effect of alternating lithologies in heterogeneous rock formation, where the concept of 'lithological unit thickness' is used in place of a single value for strength of intact rock material (UCS) of the whole lithology unit (Fig. 1). The system divides rock mass into six classes: very good (M-SMR 100–81), good (80–61), moderate (60–41), poor (40–21), very poor (20-1) and extremely poor (<1).



Lithology	Thickness (m)	Thickness %	Strength (UCS) MPa	Strength by lithology (MPa)	Strength of the SFRM (Mpa)
MSs	k	15.00	100.00	15.00	107.85
FSs	l	40.00	165.00	66.00	
VfSs	m	15.00	105.00	15.75	
Sz	n	30.00	37.00	11.10	
	Total	100.00			Very strong

Figure 1. Lithological unit thickness model. Final intact rock strength of slope forming rock material (SFRM) is represented by the sum of strength of all lithological in any particular slope. [17]

Another notable modification is the development of systematic cut slope stability evaluation by [20-21], where the dip angle of the discontinuity (βi) and the peak friction angle, αp of discontinuity surfaces from laboratory tests were compared with the RMR and SMR values for slope stability. The system is based on the derived polynomial equations by [22] that correlates the αp of discontinuity planes from schist bedrocks with Joint Roughness Coefficient (JRC), where the parameter of discontinuity surface roughness is then included for cut slope stability evaluation. The systematic approach propose four classifications for potential for failure: very high failure potential, intermediate failure potential, low failure potential, and stable (Fig. 2).

Due to the tropical condition of Malaysia, exposed rock mass are subjected to various degrees of weathering. From this, [23] developed a typical mass weathering profile of tropically weathered granite, characterized by both geological and structural parameters (joint characteristics, corestone occurrence, rock/soil ratio, mass homogeneity, colour of rock, and discoloration at joint' surfaces). The weathering profile provides useful parameters for the preliminary stage of any civil engineering design, which potentially will save cost and time during site investigations for development of engineering work design parameters.

In most rock classification systems, the role of water movement has not been given significant proportion in the parameters. This is especially significant in the case of Malaysia, with water movement being the largest contribution factors for landslide, making up to 58% [1]. This offers the potential for the development of a more comprehensive rock mass classification system that include precipitation as triggering factor, in order to develop a rock quality index with hazard for failure in rock slopes as per the recommendation by [8].

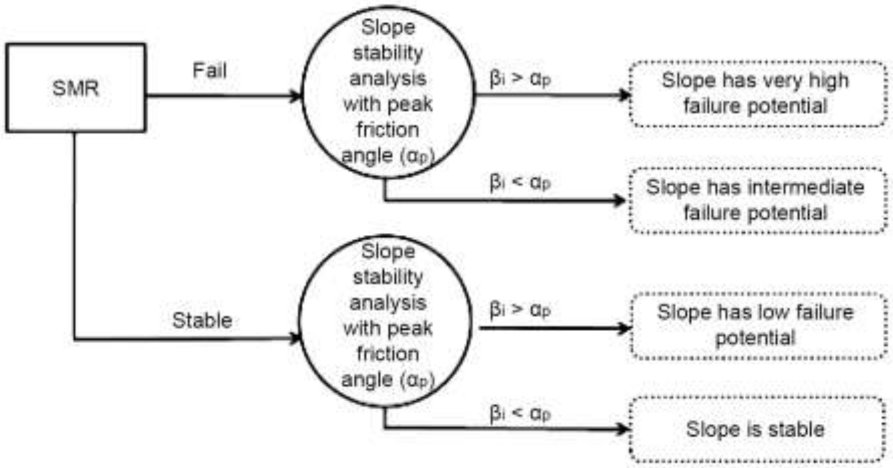


Fig. 2. Diagram for systematic cut slope stability evaluation [20]

4. Geophysical and remote sensing methods in rock slope assessment

4.1. Electrical resistivity

Electrical resistivity method is increasingly becoming popular as viable geophysical method to be used in conjunction with geological and geotechnical method in the study of slope failure in Malaysia. Usage of electrical resistivity methods in rock materials have shown some promising results for slope stability assessment. [24] conducted electrical resistivity method over granitic bedrock in Penang as complimentary to borehole log and engineering mapping, where the method was found to be correlated with weathering of bedrock and presence of fractures in granite. Several other usage of the methods include identification of different geological structures and lithological contacts [25], detection of loose rock boulders in weathered soil [26], and zones of groundwater accumulation [27-28].

Although electrical resistivity tests do not produce parameters immediately related to rock mass classification (i.e. discontinuities, rock properties), its strength over other available geophysical method is the ability to identify subsurface zone of low resistivity – which more often than not indicates the presence of water in the rock mass [25] [27-28]. Identification of subsurface water in rock mass is crucial for early indicator of potential failure zones, on account of the role of water movement in landslide. It is however strongly recommended for the integration of electrical resistivity with other direct tests such as geotechnical classification test in order to reduce the ambiguity of slope stability assessment interpretation [29].

4.2. Light Detection and Ranging

The usage of Light Detection and Ranging (LiDAR) in Malaysia in for landslide studies mostly focuses on mapping a 3D view of slope to monitor potential slope instability, as well as inventory mapping of landslides [30-32]. The method consists of the usage of either Terrestrial Laser Scanning (TLS) or Airborne Laser Scanning (ALS) to generate digital terrain models (DTM). The use of TLS for remote mapping of limestone hills [33-34] shows its capability in determining potential rockfall and slope hazard. Other case study involves a stability assessment of limestone rock cave using TLS [35], where kinematic analysis is carried out from extracted discontinuities from cave faces.

Although LiDAR has seen increased used in recent years in assessing potential landslide zones, the usage for the extraction of parameters related to slope stability analysis (i.e. discontinuities) still appears to be a relatively unexplored area. In their review of the development of SMR, [36] pointed how LiDAR allow the generation of precise 3D point clouds from slopes which can be utilized to obtain parameters that are relevant for SMR or other rock mass classification. The usage of LiDAR also offers the possibility of characterizing complex landslides along the transportation route in mountainous region [34].

5. Conclusion

Both kinematic analysis and rock mass classification have been established as valid and reliable methods for assessment of rock slope stability over the years, and have continued to be widely used in Malaysia. Factors such as alternating lithologies in rock unit, discontinuities conditions, and weathering of rock mass led to revisions of established rock mass classifications. Due to the tropical climate of the country, any subsequent modifications to the system should consider the role of weathering and water movement in rock mass. Electrical resistivity proves to be a viable method in detection of subsurface geological structures, lithological contact, and water bodies, leading to further identification of potential zones of slope failure. Laser scanning is a recent development in assessment of slope stability, and due to its wide area coverage and fast extraction of data, appears to be the next step forward in rock mass classification. The integration of geophysical and remote sensing methods offers the potential of a more comprehensive method of rock slope stability assessment.

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