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Application of rock mass classification systems to rock slope stability assessment: A case study

Hassan Basahel*, Hani Mitri

Department of Mining and Materials Engineering, McGill University, Montreal, H3A 0E8, Canada

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ABSTRACT

The stability of rock slopes is considered crucial to public safety in highways passing through rock cuts, as well as to personnel and equipment safety in open pit mines. Slope instability and failures occur due to many factors such as adverse slope geometries, geological discontinuities, weak or weathered slope materials as well as severe weather conditions. External loads like heavy precipitation and seismicity could play a significant role in slope failure. In this paper, several rock mass classification systems developed for rock slope stability assessment are evaluated against known rock slope conditions in a region of Saudi Arabia, where slopes located in rugged terrains with complex geometry serve as highway road cuts. Selected empirical methods have been applied to 22 rock cuts that are selected based on their failure mechanisms and slope materials. The stability conditions are identified, and the results of each rock slope classification system are compared. The paper also highlights the limitations of the empirical classification methods used in the study and proposes future research directions.

1. Introduction

Rock slopes in most road cuts, especially in mountainous areas, are prone to instability problems due to variation in the rock mass conditions and external factors induced by the environments such as seismic activities and water in the slope (Pantelidis, 2009). The material characteristics of a rock slope, the height, the face angle, and the rock joint orientations play a significant role in the instability problem of road cuts and slopes. In addition, the stability of rock slopes may also be influenced by the road curvature, particularly in rugged terrains (Hoek and Bray, 1981).

Slope stability problems attract major concerns from researchers, and consequently, several techniques and methods for slope stability evaluation have been proposed. These methods can be basically grouped into four categories, i.e. kinematic analysis, limit equilibrium, numerical modelling, and empirical methods. Kinematic analysis is commonly used to predict potential structural failure mechanisms (planar, wedge, and toppling) using stereonet projection technique. This technique is used to project the orientation of discontinuities by pole, containing information about the dip and dip direction of a joint on a two-dimensional (2D) stereonet (Price and Cosgrove, 1990). Limit equilibrium method compares the magnitudes of the driving and resisting forces that act along the sliding planes to estimate the factor of safety (Coggan et al., 1998), and it is also widely used to examine slope structural stability. Numerical modelling is used in more complex slope geometries and failure mechanisms. It is particularly useful when the above-mentioned methods cannot represent the behaviours of the slope. Numerical modelling provides insight into the effect of stress distribution in the slope and displacements on its behaviour (Wyllie and Mah, 2004). Rock mass classification systems or empirical methods represent an important tool that is often used for preliminary assessment of the engineering behaviours of the rock mass (Duran and Douglas, 2000). In this paper, the focus is put on empirical methods, and the goal is to assess their efficiency for determination of the rock slope stability.

Rock mass classification systems have been commonly utilised in the field of geotechnical engineering, especially for design purpose. They are widely used due to their simplicity and the limited need for detailed information (Duran and Douglas, 2000). However, these classification systems are initially established for

* Corresponding author.
E-mail address: Hassan.basahel@mail.mcgill.ca (H. Basahel).

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underground excavations (Hoek, 2007). They are developed based on the importance of parameters; each is assigned with a numerical value and a weighting factor. By substituting these weighting values into an empirical formula, one can obtain the final rating for a rock mass (Hack et al., 2003). Such rating is of value in the sense that it can help the engineering judgment of underground projects for design purpose (Bieniawski, 1993).

Even though empirical rock mass systems are established for underground stability assessment, some of classification systems have been applied to the evaluation of rock slopes by calibrating some parameters to make it applicable to surface excavations in rock (Pantelidis, 2009). Rock mass characterisation and discontinuity conditions represent the backbone of most empirical methods. These conditions can be summarised into five categories, i.e. unconfined compressive strength (UCS) of intact rock, rock quality designation (RQD), spacing between discontinuities, discontinuity condition, and groundwater condition. These five factors also refer to as the well-known Bieniawski's rock mass rating (RMR) (Bieniawski, 1973, 1976, 1979, 1989).

In this paper, five rock mass classification methods are chosen. The selected methods are original slope mass rating (SMR) (Romana, 1985), Chinese SMR (Chen, 1995), continuous SMR (Tomás et al., 2007), graphical SMR (Tomás et al., 2012) and an alternative for rock slopes (Pantelidis, 2010). The stability assessment for rock cuts using the selected five empirical methods has been conducted and their validity was examined. All results for rock slope description and stability categories have also been compared.

The rock slopes of the selected case study are in rugged mountainous terrain with complex geological features. They have steep slope face angles and sharp curvatures along the road. They are subjected to rain storms in different periods of the year, mostly in summer and winter seasons. The average annual precipitation of rainfalls is 500 mm (see Fig. 1). Due to heavy rainfall, most rock cuts, even slightly and moderately weathered, suffer from the stability problems, thus different failure mechanisms may be encountered. In addition, the excavation method used to create the rock cuts could play a role in the deterioration of the rock slopes. Poor blasting methods were used prevalently in most road cuts, without indispensable rock support.

2. Location of the study area

The study area is located in the far south-western part of Saudi Arabia known as Jazan region, between latitudes 16° and 18° north, and longitudes 42° and 44° east as shown in Fig. 2a. 22 road cuts are selected as case studies along five main roads, which are distributed as follows: five sites along road No. 12, seven sites along road No. 8, four sites along Al-Hasher road, five sites along Ar-Raith road, and one site along Al-Aydabi road (see Fig. 2a). The selected case studies are in an area with rugged terrains (Fig. 2b) and are selected based on the type of failure mechanism.

(1) Structurally controlled failures: different discontinuity orientations play a significant role in the instability condition of a structurally controlled slope (Fig. 3). The selected sites are: 1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 14, 16, 7, 18, 19 and 22.

(2) Non-structurally controlled failure (stress-controlled): the stability condition of the rock slope is influenced mainly by external forces, e.g. groundwater. Also, the degree of weathering is high. In non-structurally controlled slopes, the traces of rock joints are not obvious and have no or little effect on the stability behaviour of the slope (Fig. 4). The selected sites are: 8, 9, 15, 20 and 21.

3. Classification systems for rock slopes

As previously mentioned, five methods are used and discussed in this paper. Since all SMR methods are based on the scores of the basic RMR system, all the case studies are first analysed with the basic RMR value.

3.1. Rock mass rating (RMR)

RMR was established by Bieniawski (1973–1989) to evaluate the quality of rock masses for underground projects. The RMR system consists of five basic parameters that represent different conditions of the rock and the discontinuities. These parameters are: (1) UCS of intact rock, (2) RQD, (3) spacing between discontinuities, (4)

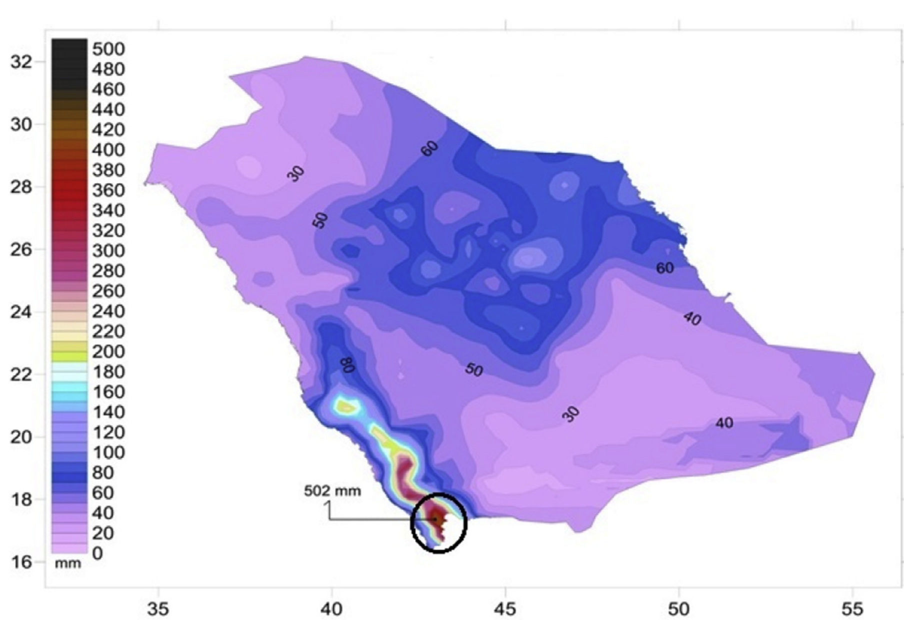

Fig. 1. Annual precipitation map of Saudi Arabian from 1960 to 2014, showing an average of 500 mm.

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