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New risk assessment methodology for coal mine excavated slopes

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ABSTRACT

This paper presents a new risk assessment methodology for coal mine excavated slopes. This new empirical-statistical slope stability assessment methodology (SSAM) is intended for use by geotechnical engineers at both the design review and operational stages of a mine's life to categorise the risk of an excavated coal mine slope. A likelihood of failure is determined using a new slope stability classification system for excavated coal mine slopes developed using a database of 119 intact and failed case studies sourced from open cut coal mines in Australia. Consequence of failure is based on slope height and stand-off distance at the toe of the excavated slope. Results are presented in a new risk matrix, with slope risk being divided into low, medium and high categories. The SSAM is put forward as a new risk assessment methodology to assess the potential for, and consequence of, excavated coal mine slope failure. Unlike existing classification systems, assumptions about the likely failure mode or mechanism are not required. Instead, the SSAM applies an approach which compares the conditions present within the excavated slope face, with the known past performance of slopes with similar geotechnical and geometrical conditions, to estimate the slope's propensity for failure. The SSAM is novel in that it considers the depositional history of strata in an excavated slope and how this sequence affects slope stability. It is further novel in that it does not require explicit measurements of intact rock, rock mass and/or defect strength to rapidly calculate a slope's likelihood of failure and overall risk. Ratings can be determined entirely from visual observations of the excavated slope face. The new SSAM is designed to be used in conjunction with existing slope stability assessment tools.

1. Introduction

Strata failure is a principal hazard in open cut coal mining as it has the potential to cause multiple fatalities. Rigorous geotechnical design is critical to preventing and managing strata failure.

Several empirical classification methods are available to predict rock mass behavior and/or slope performance [1–21].

A review of the existing empirical classifications highlighted a gap in the industry for a classification system specific to excavated coal mine slopes.

Specifically, many classifications systems have been designed for application in tunnelling or other underground excavations [1,6,11,22]. These classification systems give little to no consideration of factors that would also impact stability in slopes, or contain a considerably limited number of slope case studies in their reference database [23,24].

Classification systems like RMR, SMR, SRMR, MRMR, M-RMR, IRMR and GSI and its modifications place more significance on structures than intact rock strength, or they do not adequately account for other extraneous parameters that also control slope stability in open cut coal mines [1,3,5–7,9,11,13,15,18].

Existing classification systems designed for slopes are either: (1) based on natural (non-excavated) slopes; (2) do not extend sufficiently to the rock mass conditions observed in open cut coal mines; or (3) do not cover the extent of slope geometries observed in Australian open cut coal mines [2,10,12,21,25]. For example, the SSPC is based on case studies with a maximum slope height of 45 m [10]. Excavated slopes can exceed 80 m in Australian coal mines.

Further, consideration of slope geometry is not included in existing classification systems which is often viewed as a critical factor in the slope stability analysis of mine slopes [2,3,7,13,15,17,24,26,27].

Or alternatively, existing classification systems do not consider factors that have historically contributed to excavated coal mine slope failure. Such factors include: (1) groundwater; and (2) complex (structural and rock mass) failure mechanisms

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[3,5,7,8,10,12,13,15,16,20,28]. For example, the RMQR rock mass classes are intended to serve only as an index to characterise the state of the rock mass in relation to intact rock and give no relation to stand-up time or stable slope angle [20].

Of the rock mass classification systems published to date, the OPCASSTA-COAL and the GSPI are considered most applicable to the predict the likely slope behavior of excavated coal mine slopes [18,19]. However, both classification systems provide a qualitative indication of slope behavior only, in terms of very low to very high slope hazard or stable to collapse slope performance classification [18,19]. The Q-slope system does provide a quantitative likelihood of failure but does not contain coal bearing rock formation case studies in its database (Bar 2018, personal COMMS) [21,29]. No overall slope risk rating can be provided by any of these three classification systems.

Fewer risk-based classification systems have been published that predict both slope performance (i.e. likelihood of failure) and potential consequence of slope failure. Of the risk-based classification systems available none account exclusively for excavated coal mine slopes [14,30,31]. They either combine dumped and excavated slopes into an overall strip risk assessment, include mining factors (e.g. blasting practices, spoil loading on highwalls) in the assessment process or do not account for bench-scale slope failure, only isolated rock fall failure [14,30,31].

This paper presents a new risk assessment methodology for coal mine excavated slopes that overcomes the limitations of existing rock mass and risk-based classification systems for application in excavated coal mine slopes. The slope stability assessment methodology (SSAM) has been developed for Australian coal mines. The methodology has been designed so that it can be readily implemented at both the mine design and/or operational stage of a mine's life. Required inputs can be estimated from visual observations (or predictions) of slope conditions. Ratings should be refined if additional measurements become available from subsequent geotechnical investigation programs.

SSAM inputs are based on the back analysis of 119 intact and failed case studies sourced from open cut coal mines in Australia. Statistical analysis was completed to: (1) determine which slope conditions have the highest impact on slope performance; and (2) classify each case study as intact or failed. Statistical analysis was also used to determine a new impact ratio, to predict the potential consequence of slope failure based on: (1) slope height; (2) stand-off distance at the toe of the excavated slope; and (3) precedent failed slope material run out distances. The output of SSAM is a risk rating defined as a factor of likelihood of slope failure and impact ratio.

The SSAM is applicable for single-bench failures in competent coal measure rock masses. Rarely do coal mine excavated slope failures exceed multiple benches. Of the case studies used to generate the SSAM, only one out of the 63 failed case studies spanned multiple benches. In this instance, the slope contained persistent sub-vertical to vertical structure that spanned the vertical length of the multi-bench failure (Fig. 1). The 63 failed case studies are considered representative of the types and magnitudes of excavated slope failures experienced in Australian open cut coal mines.

Fig. 1. Example of case study in which slope failure spanned multiple benches.

The new risk assessment methodology is intended to be used as part of a holistic risk-based approach to identify sections of slope pre-conditioned to failure which can then be the focus of: (1) further stability assessment by numerical modelling; and/or (2) hazard management (e.g. targeted monitoring) at the operational stage.

The advantages of the SSAM include:

(1) It can be readily applied in the field at operational stage, or during the design assessment process using information that should be readily available at greenfields level of site investigation;
(2) It is simple and rapid enough to be completed at regular (e.g. daily or weekly) intervals to compare slope performance and risk category over time (e.g. from design through to implementation); and
(3) System inputs have been designed so that risk ratings can be calculated by geotechnical professionals through to mine operations personnel trained with a basic knowledge of mine geology (e.g. supervisors and open cut examiners).

2. Slope stability assessment methodology (SSAM)

The following sections describe the process used to develop the new slope stability assessment methodology (SSAM) (Fig. 2). The following sections will then detail each of the steps outlined in Fig. 2.

Step 1: review of typical failures in excavated coal mine slopes

The SSAM is based on 63 failed and 56 intact slope cases, collected from 25 open cut coal mines across coalfields in Queensland and New South Wales (from the Bowen, Hunter, Tarong and Callide basins). All reviewed slope cases were excavated between 2010 and 2017.

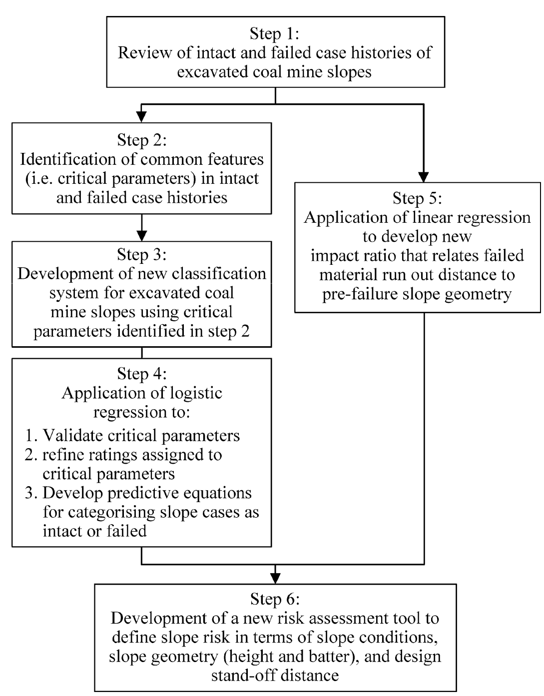

Fig. 2. SSAM development process.

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