Field Investigation of Sandstone Escarpment Stability at East Mountain, Utah, USA

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Abstract. During the last three decades, a significant amount of research has been directed to developing predictive tools for assessing the stability of the Castlegate Sandstone escarpment, travel distances for the debris and the need for any control measures in Central Utah. The cliff-forming Castlegate Sandstone is 60 m thick at the study mine in Utah and lies approximately 250 m above multiple-seam coal reserves. To assess escarpment stability, the authors used multiple regression analysis and extensive data on geology, mining, and escarpment stability collected over many years. The volume of failed rocks was used as the response variable. Mine layout options were developed to minimize cliff instability and frequency of mining-induced surface fractures. Geologic and geometric variables were obtained along 3.7 km of escarpment exposure at 180 study locations. A regression analysis of data from 29 study locations showed that surface topography plays a critical role in influencing escarpment stability. With additional data collected over the next longwall block, important variables were identified including canyon slope, thickness of Castlegate Sandstone and mining influence angle. Finally, the model was used for prediction of escarpment stability in area 3. In remote mining areas of Utah, warning signs were posted at the study areas.

1. Introduction

There are two methods routinely used by engineers and researchers to help predict what conditions will be in the future: statistical and computational. Starfield and Cundall\(^1\) identify rock mechanics problems as data-limited, that is, one seldom knows enough about a rock mass to use computational methods unambiguously. These methods, however, are extremely useful for studying failure mechanisms and testing different hypotheses on the cause of the failure. Statistical methods, on the other hand, are uniquely capable of being applied where there are good data, but a limited understanding of certain phenomena, such as the mechanism of escarpment failure (toppling, pure translation, or a combination of these and other mechanisms).

Various investigators from both the U.S. government and universities have used computational techniques for analyzing surface subsidence and escarpment failure mechanisms. The results are in general agreement with studies in the Sydney Basin of Australia\(^2\). U.S. studies used a combination of two-dimensional, boundary-element\(^3\), finite-element\(^4\), and discrete-element formulations. To overcome the limitations of using small-strain, continuum, elastic-plastic code, finite-element deformation was imposed on a detailed discrete-element model of the escarpment and the mudstone foundation and incorporated both horizontal slip planes and vertical joints\(^5\). The USBM\(^6\) also completed a few preliminary three-dimensional, finite-element modeling studies. While successful in analyzing failure patterns and mechanisms, these studies have clearly identified the limitations of numerical modeling techniques in matching measured surface deformation because of data-limited nature of these modeling efforts among other factors.
2. Characterization of geologic, mining and response variables

- Joint sets 1 and 2
- Angle between joint sets and an escarpment
- Excavation width-to-depth ratio
- Escarpment shape
- Influence angle
According to correlation among parameters between any pair of variables, the correlation coefficient (r) indicates the strength of linear relationship. The correlation matrix includes correlation coefficient, geologic, mining, and response variables. The bivariate correlation matrix was constructed to measure the linear relationships, a procedure that takes into account the interrelationships in the data and uses statistical tests. The correlation is then selected and tested for entering into the equation. This procedure is very good when there are hidden relationships among the variables. If the first variable meets the entry requirements, it is included in the equation. If a variable fails to meet entry requirements, it is not included in the equation. The failure index variable and the escarpment shape and index variable are hidden relationships among the variables. The failure index was selected from among other independent variables one at a time.

3. Results

Results Based on an examination of standardized regression coefficients for the first 29 cells (which are hidden relationships among the variables), it was shown that surface topography plays a critical role in the stability of the escarpment and can be estimated for the area above the mining limit and over 90 degree where the escarpment is directly eroded or not. The failure index equals values of 0, 1, and 2, depending on the estimated volume of failed material within the cell of interest. The failure index was selected from among other dependent variables in regression analyses. The failure index is used as a measure of goodness of fit, for the last step is 0.68. The following examples illustrate the application of the escarpment stability model.

- **Joint set i and escarpment erosion**
- **Joint set i and face erosion**
- **Joint set i and face erosion**
- **Joint set i and face erosion**
- **Erosion under escarpment**
- **Escarpment shape**
- **Failure**

In remote areas, Rock Fall Simulation Program (330) was used to predict the failure zones shown in red. Additional analysis is planned to improve on predictive capabilities of the Colorado model. Results of the Colorado model were in good agreement with initial projections using the Colorado model. The extraction of both seams. Predicted unstable areas, fair correlation as well as hidden relationships among the variables.
Fig. 1. Mining and escarpment geometry, Study area 1.

Fig. 2. Escarpment and mining geometry.

Fig. 3. Escarpment geometry and geological discontinuities.

Fig. 4. Study area 3, subsidence contours, cell locations and escarpment failure zones shown in red (top), observed failure pattern (bottom).
References


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