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A combined 2D and 3D numerical modeling approach to provide adequate roof support in complex 3D excavations

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ABSTRACT

Traditional methods for assessing effective roof support can be difficult to apply to complex three-dimensional excavations. Through worked examples, the approach of combined two-dimensional and three-dimensional numerical modeling has been shown to be successful in understanding mechanisms of rock failure for unique excavation geometries and geotechnical properties and, in turn, provides adequate roof support recommendations for complex three-dimensional excavations in Australian coal mines. An interactive approach of monitoring and model review during the excavation process is an important part of model support recommendations to ensure rock failure and deformation in the model are representative of actual conditions, to provide effective and practical controls.

1. Introduction

Traditional methods for determining support requirements can be difficult to apply to complex three-dimensional excavations. A combination of two-dimensional and three-dimensional numerical modeling can be used to determine key drivers for failure about complex three-dimensional excavations in order to recommend adequate geometry design and roof support.

Excavations, such as gate roads and main headings, are commonly designed with two-dimensional modeling and empirical assessments, while large complex three-dimensional excavations, such as drifts, underground bins, acute roadway intersections, and high cut roadways, are more difficult to represent in simple two-dimensional models and are generally out of the range of empirical datasets.

Numerical modeling can be a valuable tool for assessing the key drivers of rock failure around complex excavations, which, in turn, feed into the design of the excavations and support recommendations. Numerical modeling is a tool often used to assess the stress redistribution about excavations in anisotropic stress environments and to assess the mechanics of the resultant rock failure [1,2]. The value of numerical modeling is that site-specific stratigraphy and rock properties can be incorporated into the model in order to assess a unique combination of excavation geometry and geotechnical properties.

A numerical model should not be used as a "black box" where rock inputs are entered and a unique outcome solves the problem at hand, without an understanding of the rock failure mechanisms. An interactive approach of continual validation through site monitoring is a key component in ensuring the models correctly represent the site-specific rock failure mechanisms.

This paper uses case studies as examples to show how a combination of two-dimensional and three-dimensional modeling can be used to understand the mechanisms for failure about complex excavations in Australian coal mines, with three examples from Austar Coal Mine and one from an unnamed mine.

2. Important design considerations

Important design considerations that need to be understood to achieve excavation stability are typically a combination of all, or some, of the following geotechnical parameters: (1) strain softening characteristics of strata for intact and residual strengths; (2) dynamic and permanent stress distribution around the excavation; (3) confinement and generation of confinement; (3) mode of failure (e.g., shear, bedding shear, and tensile); (4)excavation geometry; (5) support design and specification; and (6) structure or discontinuities.

Understanding how each of these parameters interacts with each other will provide for implementation of effective design and support to control stability of a complex excavation. The numerical modeling process allows for parametric modeling to assess the sensitivity of individual parameters.

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3. Methodology

A combination of two-dimensional and three-dimensional numerical modeling is typically used to assess the key drivers for deformation about complex excavations. Model time constraints often dictate a combination of two-dimensional and three-dimensional models to be used to gain detailed rock failure together with three-dimensional assessments.

Unless stated otherwise, the two-dimensional modeling using FLAC2D incorporates SCT's in-house rock failure code where the constitutive model is based on Mohr–Coulomb criteria relevant to confining conditions in the ground. The model is similar to FLAC's strain-softening ubiquitous joint model where the model includes pre-existing joints and exhibits both intact and post failure behavior. The code in FLAC2D uses a coupled mechanical and fluid flow system to simulate rock failure and pressure effects. A detailed description of the SCT rock failure routines used in FLAC can be found in a number of references, in particular Gale et al. and Gale and Tarrant [3,4].

The modeled stratum is based on geotechnical properties from a combination of site-specific rock test data, geophysical relationships, and prior experience. The unconfined compressive strength (UCS) is determined from borehole sonic velocity and laboratory UCS relationships empirically described by various researchers such as McNally and Hatherly et al. [5,6].

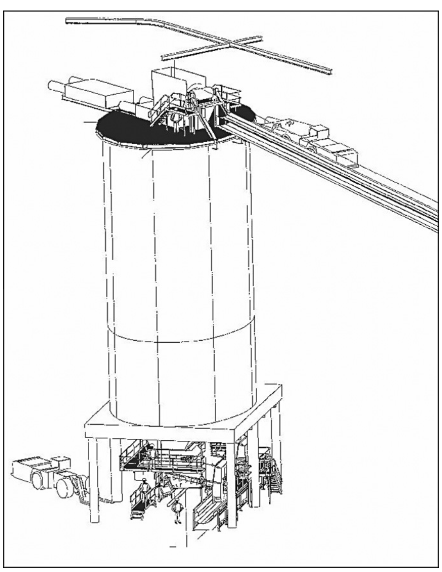


Fig. 1. 3D diagram of underground coal storage bin arrangement (courtesy of Arkhill Engineers).

The three-dimensional modeling used the constitutive model of the bilinear strain-softening ubiquitous joint model in FLAC3D. Rock properties were again based on site-specific rock test data, geophysical relationships, and prior experience. The three-dimensional models were generally used to assess the stress distribution around the excavations, the extent of failed strata, and support loading.

4. Austar Coal Mine example

4.1. Background

Austar Coal Mine (Austar) is located approximately 10 km southwest of Cessnock in the Newcastle coal fields, New South Wales, Australia. Austar is owned by Yancoal Pty Ltd. and mines premium coking coal from the Greta Seam of the Greta Coal Measures at current overburden depths of approximately 500–550 m. Austar constructed an underground coal storage bin where design input was required for various geotechnical scenarios related to the bin construction. This example outlines the modeling approach used to understand the key drivers for rock failure and deformation about specific features of the bin construction.

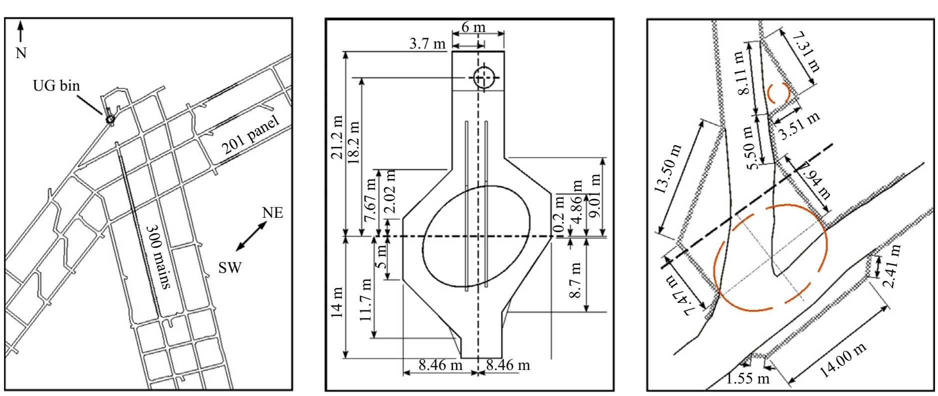
The underground coal storage bin design consists of the bin, bin top area, bin base area, and drift. The bin design is presented in Fig. 1. The sequence of bin excavation consisted of the drift, followed by the widening and floor excavation of the bin top area, then the benching down of the bin, followed by the seam level widening of an existing intersection at the bin base area.

The bin location, maximum horizontal stress orientation, and bin top and bin base area designs are presented in Fig. 2. The bin is an elliptical design with its long axis oriented in line with the maximum horizontal stress. The bin top area is an irregular shape of approximately 14 m by 20 m, with the drift entering approximately from the south. The bin base area is an irregular area with an approximate roof span of 14 m by 8 m adjacent to the bin.

The modeled stratum is based on geotechnical properties from a combination of Austar's rock test data, geophysical relationships, and prior experience. The model UCS is based on geophysics and rock test data from Austar, for both the drift separation models and the updated bin models and, in the area of extraction, generally ranges from 20 to 80 MPa for the original models and 40–100 MPa for the updated models.

4.2. Drift and roadway vertical separation assessment

Numerical modeling using FLAC2D was conducted by SCT to assess the deformation between the Greta Seam roadway and the above drift to determine a minimum vertical separation to prevent



(a) Bin location (b) Bin top area (c) Bin base area

Fig. 2. Bin location with bin top and bin base area dimensions.