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Whole-mine subsidence over tabular deposits and related seismicity

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ABSTRACT

The challenge of estimating mine-wide subsidence and linkages to seismicity over tabular deposits is addressed by a special finite element technique (dual node–dual mesh). Subsidence and mine-induced seismicity begins near the face when caving occurs and propagates to the surface as extraction reaches a critical extent. Thus, the challenge is to obtain details at the face at the meter scale and also at the surface over the whole mine at the kilometer scale. Interactions between old and new sections of a mine are automatically taken into account with this technique. The finite element method is well established technology based on fundamentals of physical laws, kinematics and material laws. With this technique, no empirical "scaling" or fitting computer output by input data "adjustment" to mine measurements is necessary. Capability is demonstrated for doing practical whole-mine subsidence analysis from first principles. Mine-induced seismicity is shown to correlate well with face advance and element failure.

1. Introduction

Seismicity associated with coal mining has been under study for several years by a team at the University of Utah. Team members include mining faculty, research geophysicists and students from the Departments of Mining Engineering and Geology & Geophysics. Mines in central Utah that have been studied include the Trail Mountain Mine the Beehive Mine, also known as the Des-Bee-Dove, and the Crandall Canyon Mine [1–3]. These mines were developed from outcrops in the Wasatch Plateau coal field west of Price, Utah, where the topography is characterized by steeply incised canyon drainages and high plateaus with relief of a thousand meters or so.

Seismicity associated with coal mining in central Utah has been of interest for many years and includes studies in the Book Cliffs to the east of Price, Utah, where mining is still active and to the northwest [4–11]. Results of many micro-seismic studies are summarized perhaps best by Iannacchione et al. in stating, "Deviations from normal strata response can provide useful stability information" [12].

This study concerns a fourth underground coal mine in the southern portion of the Wasatch Plateau coalfield, hereafter referred to as the MINE. Focus is on mining from 2004 to 2008 with the objective of examining mining in relation to seismicity.

2. Problem statement

The problem is to relate strata mechanics to seismicity associated with mining. Seismic events observed as mining proceeds are associated with mining but may not be caused by mining. However, events in close proximity to an active longwall face may be reasonably assumed to be mining induced. Close proximity means within a zone of influence of the face, a distance equal to the face length for a single, isolated panel or to the cumulative face lengths in case of adjacent panels. Four panels, each with a face length of 300 m, would have a zone of influence of 1.2 km. This observation indicates interactions between panels, certainly, and between sections of a large underground coal mine should be expected. Subsidence should be maximum, although depth of overburden, strata properties and chain pillars need to be taken into account when estimating surface subsidence. Thus, the problem is to do a whole mine analysis, past and present, following the mining sequence and the evolution of stress, strain and displacement changes induced by mining.

3. Problem approach

Whole mine analysis of strata-bound tabular deposits (e.g., coal, salt, trona) is a challenge of scale, regardless of the numerical method. When stratigraphy is taken into account, the popular finite element method is the most practical. The reason is to account for all the different rock types present. However, the extent of a finite element model is limited by an element aspect

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ratio required for numerical reliability. In a coal seam with a mining height of 3 m, the lateral dimensions of elements should be no more than 9 m. At a mine scale of kilometers, the number of elements required is an impossibly large number, in the hundreds of millions. A graded mesh would reduce the number of elements required but not nearly enough for practical computation.

A dual node–dual mesh technique meets the challenge of scale where a large mesh at the kilometer scale allows for interactions amongst sections of a mine and a dual mesh allows for details at the meter scale of a working face. The program is a special version of UTAH3 that has been in use for many years. Dual nodes and dual meshes have been used in past studies, but were linked for the first time in our mine-induced seismicity studies [13,14]. Fig. 1 illustrates the relationship between meshes. Both meshes are finite element meshes for conventional continuous Galerkin finite element computations. The mining seam is replaced by node pairs in the big mesh. In the dual mesh, the mining seam is explicitly represented by elements. Boundary nodes of the dual mesh have prescribed displacements obtained from the large mesh through interpolation when necessary. Although the volume of the big mesh is much greater than the dual mesh, the number of elements and nodes in each is often nearly the same (12–16 million).

4. Whole-mine finite element analysis

As with all finite element models, preprocessing input data (mainly mesh generation) and post-processing output data (mainly presentation of results) are major components of model effort. Mesh generation must be consistent with topography, stratigraphy, jointing and strata properties. An equilibrium and consistent premining stress field is essential. Results include surface subsidence, extent of yielding indicated in element safety factor distributions, and correlations with observed seismicity. Computational effort is nearly automatic once input data are prepared.

4.1. Mesh generation

Mesh generation begins with a download of the surface topography from the Shuttle Radar Topography Mission. The file used in our work has a point spacing of 10 m. Coordinates are state plane coordinates.

Fig. 2 shows the topography in color at the MINE from the download; redlines define mined areas. Of some interest is the depth of cover over much of the mined area near the figure center. As the color scale indicates much of the surface is "table top" and indicates a depth of cover of about 300 m. In this regard, seam elevation is taken to be 2300 m and the MINE is developed from outcrop. Overburden elevation above the panels of interest is about 2621 m, as the elevation scale indicates near the figure center. Topographic relief indicated in Fig. 2 is over 1219 m. Portal elevation is 2304 m.

As shown in Fig. 2, map width is about 21.6 km, and north is in the *y* direction.

Mesh construction begins with the topographic map and is extended above and below the surface terrain according to the geologic column for the MINE. Fig. 3 is a plot of topography and mined areas of interest during the period between 2004 and 2008 and is a plan view of a finite element mesh for this study. There are more than 124,000 elements in Fig. 3. Individual elements are 70 m × 70 m in lateral extent and are not discernable because of the scale and the use of the same color for element boundaries as for the elements proper. Fig. 3 is approximately 21.64 km wide (east-west) and 23.46 km in the north-south direction.

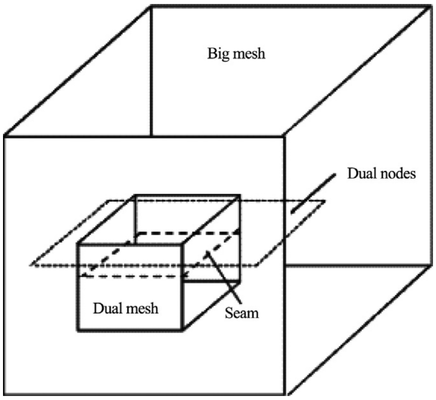

Fig. 1. Schematic of the dual node-dual mesh technique [1].

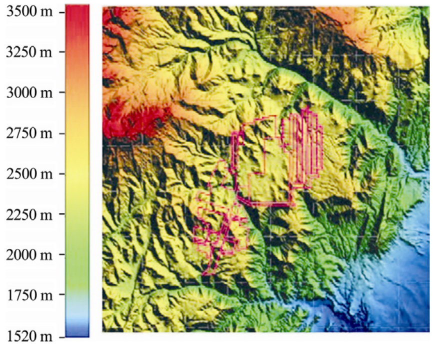

Fig. 2. Elevation map of the MINE.

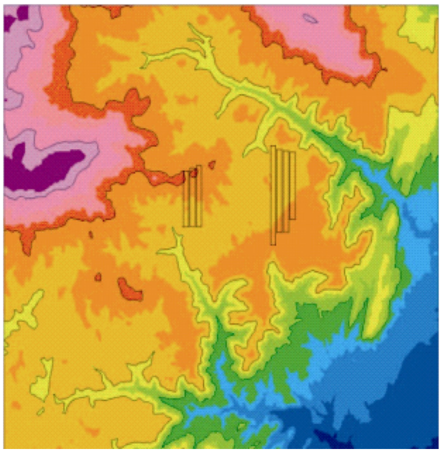

Fig. 3. Mined areas at the MINE.

Mesh generation includes representation of mining geometry and stratigraphy. In this regard, the seven longwall panels mined between 2004 and 2008 are outlined in Fig. 3. Seismicity associated with mining these panels may be correlated with production, as is generally the case and demonstrated in the case of mining P13 at the Trail Mountain mine. Anomalous seismicity was observed during barrier pillar mining at the Crandall Canyon mine, but also associated with production. Panels on the right hand side of Fig. 3 were mined first; panels on the left hand side were mined later.

Panel face width is approximately 280 m; length varies, as shown in Fig. 3. A three-entry system was used to develop the panels. Entries were assumed to be 6.1 m wide; pillars were assumed to be 18.3 m wide and 24.4 m long.