STRATA MECHANICS OF PILLAR MINING AT THE CRANDALL CANYON MINE

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BACKGROUND

The Crandall Canyon Mine (CCM) is located in the Wasatch coal field in central Utah. Extensive longwall mining at CCM preceded a decision to recover coal left in barrier pillars on each side of a set of main entries extending far into the mine. During mining in March, 2007, a major bump occurred that led to cessation of mining in the barrier pillar on the north side of the mains and to begin mining in the south barrier pillar. Subsequent loss of ground control in August, 2007, through coal pillar bursts had tragic consequences with loss of six miners and shortly afterwards three rescue team members. An MSHA report describes the events in detail (MSHA, 2008). An important lesson to be learned from CCM is the need to select a computer program suitable for pillar design. Computer programs are engineering tools; selecting the right tool for the job is essential. In this regard, a minimum program requirement is capability for computing stress distribution within a pillar and adjacent roof and floor strata. The reason is simple: strength of rock is stress dependent; both vary from point to point in pillars and adjacent strata. Preferably, one should follow the evolution of stress as the mining plan is executed from start to finish to assure safety or to warn of a potentially hazardous situation developing as mining progresses.

The approach to the problem posed by barrier pillar mining at CCM is conventional in the sense of applying well known finite element modeling techniques to analysis of a proposed mining plan. The engineering purpose is to evaluate the mining plan with respect to ground control questions including roof, floor and pillar safety. Results of previous two dimensional finite element analysis indicated pillar safety was by no means assured (1, 2, 3). Geometry of barrier pillar mining is limited in two-dimensions, for example, crosscuts are not seen in vertical cross sections. While three dimensional analyses are preferred, even moderately sized regions often lead to very large problem sizes that exceed computer capabilities. However, a recent development in finite element modeling of tabular deposits allows for whole mine analysis in three-dimensions. This technique involves a dual node – dual mesh concept. Both have been used separately in much earlier work, but are only now are used in combination. Estimation of subsidence at a kilometer scale and details of stress, strain and displacement about barrier pillars, main entries and pillars, and so on at a meter scale are possible (4). No compromise involving empirical formulas or similar guess work is required. Indeed, all calculations are based on first principles: physical laws, kinematics, and material laws. Effects of joints and in situ variability or uncertainty in strata properties, elastic moduli and strengths, may be included for greater realism. An important objective of the present study is to assess the role of three-dimensional pillar geometry in arriving at conclusions regarding barrier pillar mining versus two-dimensional results.

MINE MODEL

Important features of the mine model within the context of the popular finite element method are input data, the mesh geometry that represents the mine, and strata behavior. Input data are mainly strata properties including elastic moduli and strengths. Mesh geometry follows from surface topography, the geologic column including strata types and thicknesses, joint set geometry, and properties variability. Importantly, the mine layout at seam level is represented in the mesh. Strata behavior is described by material laws. Elastic behavior is a de facto model in most engineering analyses including rocks and soils. Strengths limit the range of purely elastic behavior. In three dimensions, the limit to elasticity is described by a failure criterion such as the well-known Mohr-Coulomb criterion. Beyond the elastic limit, some form of inelastic behavior occurs, perhaps brittle fracture or ductile straining or some combination. Strain hardening, strain softening, and peak-residual behavior are possibilities. The choice is mainly guided by site-specific conditions and laboratory test results on intact core and joint surfaces, but may also be constrained by program capability. Laboratory test results in sufficient numbers allow for determination of statistical variability in properties data and when mapped back to source locations in the mine, allow determination of spatial variability. The purpose is to provide quantitative accounting for uncertainty in strata properties as they vary from element to element.

Strata properties are summarized in Table 1 and are the same properties used in previous two-dimensional studies. Figure 1 is a histogram of coal modulus (Young's modulus, E). The mean value of over 370 laboratory tests is 3.4 GPa; the coefficient of variation is 21.4 percent. Mean unconfined compressive strength is 29.8 MPa; coefficient of variation I 49.4 percent. Similar variability measured by the coefficient of variation (ratio of standard deviation to mean as a percent) is observed in laboratory tests for strength of other formations in the geologic column (5).

The mesh begins with a digital terrain model from the Shuttle Radar Terrain Mission and shown in Figure 2. Figure 3 is a three-dimensional perspective.

Table 1. Strata elastic moduli and strengths.

	FMF	E/GPa	v	Co/MPa	To/MPa
1P	R2	2.07	0.26	81.384	.83
2N	H2	0.69	0.26	68.832	.62
3C	G2	1.38	0.22	66.142	.97
4S	&S	20.690	.249	3.10	8.21
5B	CC	2.97	0.12	28.481	.93
6R	&F	19.310	.238	4.00	8.90
7C	WC	2.97	0.12	28.481	.93
8R	S2	3.45	0.26	100.007	.52
9H	IC	2.97	0.12	28.481	.93
10	FS	23.450	.268	0.83	8.07
11	MS	15.170	.357	1.03	0.41

FMF=formationE =Young s modulus
v=Poissons ratioC o=unconfined compressive strength
To=unconfined tensile strength PR=Price River
NH=North Horn CG=Castlegate sandstone
S&S=sandstone and siltstoneB CC=Blind Canyon coal
R&F=roof and floor sandstoneC WC=Cottonwood coal
RS=roof sandstoneH IC=Hiawatha coal
FS=floor sandstoneM S=Masuk shale (Mancos)

The mine layout in the vicinity of barrier pillar mining is shown in Figure 4. Figure 5 illustrates at seam level, excavation of old main entries, old panels, barrier pillar development