International Journal of Mining Science and Technology 26 (2016) 131–137

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Design of primary ground support during roadway development using empirical databases

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ARTICLE INFO

Article history:
Received 29 July 2015
Received in revised form 7 October 2015
Accepted 27 October 2015
Available online 12 December 2015

Keywords:
Roof support
Rib support
Empirical database
Coal mining
Geotechnical engineering

ABSTRACT

There have been many design practices utilised within the coal mining industry to arrive at the minimum densities of primary ground support required during roadway development. This paper demonstrates the practical use of empirical databases, and focuses on the main drivers for ground support as demonstrated in conceptual models. Golder Associates' empirical databases used for ground support include a primary roof support database and a primary rib support database. Both are based on successful ground support designs installed in mines in Australia, the US, the UK, South Africa, New Zealand, and Europe. The term "successful" refers to those designs that were used on a repeated basis for the purpose of roadway development. The primary roof support database indicates that the major factors influencing successful roof support designs are roof competency, expressed as the coal mine roof rating (CMRR), and in situ stress. In regard to the primary rib support database, it is evident from the current database that the primary factors affecting the capacity of rib support required for a successful design are roadway height and depth of cover. These databases have been used to help determine the minimum primary ground support designs required at many mine sites in Australasia, Europe, and the US. This paper will demonstrate the effectiveness and practicality of these databases at two selected mines in Australia and the US. In order to improve the primary rib support database, this paper will also propose a new rib deformation rating based on the addition of site specific coal strength data for the Australian mines. The proposed rating attempts to capture the main variables that define the behaviour of a buckling column.

1. Introduction

Roof and rib behaviour in rectangular excavations in coal mines begins with the redistribution of the in situ stress field, which prior to excavation, is in equilibrium. As stresses cannot travel though voids (or roadways in this case), they divert around the openings and concentrate in the roof, floor and ribs (Fig. 1). Ignoring geotechnical anomalies, the resulting impact of the stresses on the roof and rib conditions is in turn a function of the competency of the surrounding strata and the excavation dimensions. The modes of roof and rib behaviour proposed in this paper are outlined in the following conceptual models.

2. Conceptual models

2.1. Roof

The in situ stress in coal mines is defined by vertical and horizontal stresses. The vertical stress is generally related to the weight of the overlying rock, while the horizontal stress is primarily related to plate tectonics. Two horizontal stresses are evident; a major and a minor, which are by definition oriented at 90° to each other. Depending on the in situ stress environment, mine roof in sedimentary layered rock can fail in two modes. These modes are bending/block-type failures in low stress environments and buckling in moderate to high horizontal stress environments.

2.1.1. Bending/block failure

Bending or block-type failure typically occurs in low stress environments. The likelihood of roof failure is dependent on the thickness of the immediate roof units and the composition of the immediate roof [1]. In either case, the lack of any significant horizontal confinement in the immediate roof strata can result in bending or block failure due to gravitational loading and self-weight.

The failure initiates immediately following roadway development as the immediate roof gradually sags into the opening. As the beams in the lower roof sag and separate from the overlying units, the vertical load is laterally transferred to the ribs [1]. This, in turn, creates a de-stressed area above the opening typically referred to as arching [2]. The roof sag is aided by the low frictional forces along the bedding planes of most sedimentary rock types. If

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http://dx.doi.org/10.1016/j.ijmst.2015.11.021
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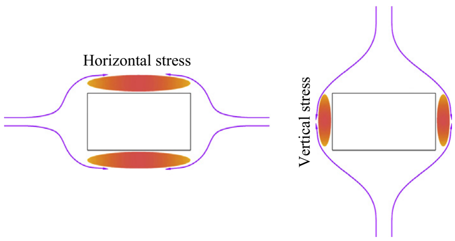

Fig. 1. Schematic showing redistribution of the in situ stress field following roadway development.

not controlled, the lower beam can collapse leaving cantilevers as abutments for the next beam so each layer above the roof has, in effect, a progressively smaller span. Continued failure of the beams eventually produces a stable, trapezoidal opening [3]. This process is illustrated in Fig. 2.

Bending failures are typically related to beams which are considered continuous structures that carry overlying weight. In most coal mine roofs, however, the strata is jointed and made up of individual blocks. When these blocks are subjected to low confinement, they are susceptible to sliding along joints planes, which are typically characterised by low frictional properties. This process is illustrated in Fig. 3.

2.1.2. Buckling failure

In classical beam/column theory, buckling can be defined as a mode of failure generally resulting from structural instability due to compressive action on the beam. As most coal mine roof is comprised of sedimentary layered rock, the individual layers of the strata can be susceptible to buckling along bedding planes under the action of horizontal stress. When considering Euler's buckling beam theory, the likelihood of buckling occurring during roadway development in coal mines is a function of unit thickness, horizontal stress magnitude, competency of the strata, and the elastic modulus of the rock.

During buckling of the roof strata, the increased levels of displacement will cause the units in the lower roof to shear and thus shorten. As a result of the stiff nature of the loading system, the horizontal stress and associated confinement reduces during this shortening process. The horizontal stress will then transfer to the overlying units which have not broken down and as such, are still confined by the in situ horizontal stress. If not controlled, this process can repeat itself up to a maximum height determined by the roadway's failure arch (Fig. 4). The maximum height typically assumed for failure arches in coal measure strata is 0.8–1 times the roadway width. The resulting breakdown or "softening" of the roof and associated loss of confinement increases the likelihood that the roof will fall if not controlled.

2.2. Ribs

Most researchers agree that the failure mechanism for coal ribs is related to buckling columns [4–6]. When considering Euler's buckling column theory, the main factors to consider are depth of cover, the height of the rib, the thickness of the column, and the strength of the coal.

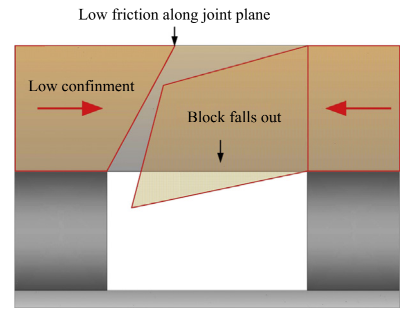

Fig. 3. Schematic showing block type failure in coal mine roadways.

Additional factors to consider are cleat orientation, cleat density, and prominent banding in the coal. It is a common occurrence in coal ribs that buckling will initiate at the interface between the stone bands and coal due to slipping along low friction layers. An example of this failure mechanism is shown in Fig. 5, where buckling consistently occurred along a prominent tuffaceous clayband at several mines in the Hunter Valley Coalfield in Australia.

As cleat density increases, it is generally accepted that the overall competency of the coal decreases. With everything else being equal, it is reasonable to assume that the likelihood of buckling will increase as cleat spacing decreases as this would directly impact the thickness of the column in Euler's buckling theory. It is however of note that a statistical analysis carried out by Colwell concluded that cleat spacing and cleat density did not have a significant impact on rib behaviour [5]. The author indicated that the reason behind this conclusion was probably related to the strength of the coal, which appeared to be driven by cleat density. This, therefore, suggests that the average strength of a coal seam and cleat density are related.

3. Industry databases

In order to arrive at the minimum density of ground support required for roadway development, Golder Associates utilises empirical databases which have been compiled from mines in various coal producing regions around the world. These databases are based on successful ground support designs installed on a repeated basis during roadway development.

3.1. Primary roof support

Golder's primary roof support database is based on successful primary roof support designs installed in over 60 mines in Australia, New Zealand, the UK, South Africa, and Norway (Fig. 6). The mines included in the world database employ similar ground control methodologies, where systematic roof bolting is employed.

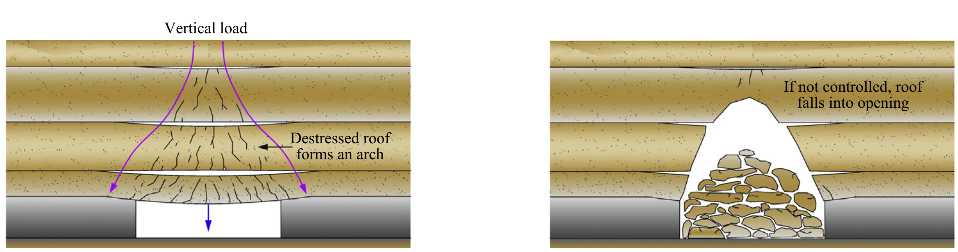

Fig. 2. Schematic showing roof failure in low stress environments.