International Journal of Rock Mechanics & Mining Sciences 70 (2014) 240–251

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

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

Horizontal stress under supercritical longwall panels

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ARTICLE INFO

Article history:
Received 8 March 2013
Received in revised form
27 March 2014
Accepted 29 March 2014
Available online 4 June 2014

Keywords:
Horizontal stress
Multi-seam mining
Supercritical longwall panels

ABSTRACT

This study identifies the relative magnitude of horizontal stress change below a series of parallel longwall panels as a consequence of multi-seam mining. The investigation method yields an upper bound to the horizontal stress change by assuming that the fractured and caved overburden above the supercritical longwall panels is not able to support any lateral load. Finite element modelling was conducted to consider the effects of the following variables on the horizontal stress redistribution: the ratio of the equivalent width of the extracted area to the overburden depth, the ratio of the original horizontal to vertical in situ stress components, and anisotropy in the rock mass behaviour.

The key findings of this research are that the maximum horizontal stress induced as a consequence of extracting multiple supercritical longwall panels will be within approximately 10% of the original in situ horizontal stress for the case of isotropic rock strata. The magnitude of this horizontal stress may be larger in a stiff stratum if the overall sequence of strata consists predominantly of softer rocks. Anisotropy in the strata underlying the extracted longwall panels also causes an increase in the maximum horizontal stress induced into the immediate floor of the first extracted seam, and an increase in the rate of dissipation of horizontal stress change with depth. These findings indicate that a significant increase in horizontal stress relative to the original in situ horizontal stress should not be expected in multi-seam mining situations. The results from this study need to be considered in conjunction with predicted vertical stress distributions in order to accurately predict the overall stress environment likely to be encountered when conducting multi-seam mining.

1. Introduction

The number of multi-seam longwall coal mines in Australia and around the world is likely to grow in the near future [1,2]. Untouched areas of coal reserves are dwindling and so there is a need to extract coal from below or above previously mined seams. Advances in technology over the last two decades have enabled longwall mining to supersede room and pillar mining in terms of both safety and production levels. There has been little research conducted into multi-seam mining where both seams are mined using the longwall method. Furthermore, the literature is sparse on the topic of the redistribution of horizontal stresses when multi-seam mining.

High magnitudes of horizontal stress have been a major concern for ground control coal mining engineers involved in single seam mining, and yet the origin of the horizontal stress and how it is redistributed in a stratum after mining are poorly understood. Many major coalfields around the world report high in situ horizontal stresses [3–5], and often the maximum horizontal stress exceeds the corresponding vertical stress component and is the major principal stress. High horizontal stresses have been reported as the cause of instabilities in longwall mine roadways, such as compressive roof failures (often referred to as cutter roof or guttering), directionality of roof falls, and maingate failures [6].

One of the consequences of the redistribution of horizontal stresses has been significant horizontal movements of the ground surface, sometimes observed several kilometres away from extracted longwall panels, and this is often referred to as far field movements [7]. A second consequence of the redistribution of horizontal stresses is the 'skew roof deformation mechanism' which was proposed to explain how the strata deform in the horizontal direction on either side of the longwall panel [8,9]. However, these large scale effects of horizontal stress on coal mining activity have only come to our attention from observations in the field, and not through any rigorous theoretical attempt to understand how horizontal stresses redistribute around longwall panels. In order to predict with sufficient accuracy the stress environment applicable in multi-seam mines, it is imperative that we gain an understanding of how horizontal stresses redistribute

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http://dx.doi.org/10.1016/j.ijrmms.2014.03.009
1365-1609/

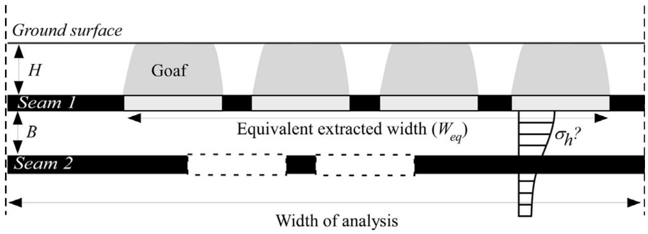

Fig. 1. Schematic representation of the structure of the strata before multi-seam mining commences.

around extracted longwall panels. A rigourous understanding will enable planning for safe multi-seam mines and allow the prediction of potentially undesirable long-term effects (e.g., upsidence, disturbing groundwater aquifers).

The problem considered in this paper is schematically shown in Fig. 1. It is assumed that the first seam has been extracted using a series of parallel longwall panels and that these longwall panels are located at a relatively shallow depth such that they give rise to supercritical failure of the overburden. Since no information is available on the lateral capacity of the goaf material, it is assumed that all the goaf material above each longwall has no stiffness in the horizontal direction. This assumption would predict the largest possible horizontal stress that could be induced into the strata below the first mined seam. The analysis is conducted by assuming that effectively the block of strata above all of the longwall panels extracted from the first seam does not support any lateral load. The width of this block of strata is defined by an equivalent extracted width (W_{eq}). The equivalent extracted width (W_{eq}) can correspond to either the total width of the series of longwall panels when the analysis plane is parallel to the longwall face (as shown in Fig. 1), or to the length of an individual longwall panel (L) when the analysis plane is aligned perpendicular to the longwall face. The ratio of the original horizontal to vertical in situ stress components (K), together with the an-isotropic and inhomogeneity typically present in coal measure strata are considered.

2. Background

A thorough understanding of the in situ stress environment is essential for effective ground control during all underground mining. In particular, understanding the stress field around a longwall panel and its gate-roads is one of the key components that enable mining engineers to predict potential failures. Correct prediction of potential failures enables effective mitigation to be implemented (i.e., ground control in the form of rock bolts, mesh and shotcrete), that in turn should ensure that both worker safety and coal productivity is maintained.

The in situ stresses encountered when second and subsequent seams are to be extracted in a multi-seam mining operation are not the same as for virgin conditions, prior to any mining at all in the strata [10]. In the case of the first seam to be mined, the vertical and horizontal stress components at any given depth are usually considered to be relatively uniform across the mining area. In the case of multi-seam mining, previous mining in seams above or below the current seam will have altered the original in situ stress field. This situation is referred to as multi-seam interaction. Although multi-seam interactions have been studied by many researchers [11–16], there is still a limited understanding of the stress fields in which multiple seam longwall mining is conducted.

2.1. Virgin in situ stress

The in situ stresses arise from the weight of overburden strata as well as stresses of tectonic origin. The magnitude of in situ vertical stress correlates well with the product of the depth below the surface and the unit weight of overlying rock mass [17]. However, the origin of horizontal in situ stress is not completely understood. Horizontal stresses in coal measure strata have been reported to vary significantly among coalfields around the world [3,4,6].

It is generally recognised that the in situ horizontal stress depends on the depth below ground surface, stratum stiffness, current tectonic state of stress, or a combination of all three. Originally, it was expected that the magnitude of horizontal stress would correspond with depth below the ground surface only. This gave rise to horizontal stress typically being reported according to a parameter K, as defined by

$$\sigma_h = K\sigma_v = K\gamma z \tag{1}$$

Terzaghi and Richart [18] initially suggested that the value of K was independent of depth and depended on Poisson's ratio of the rock mass, according to $K = \nu/(1-\nu)$. However, stress measurements revealed that the magnitude of K is typically higher at shallow depths and decreases with depth [19]. When the horizontal stress results from North America and Australia were analysed, they typically showed a correlation with both stratum stiffness and depth [4,5]. In contrast, stress measurements in the United Kingdom coal measure strata did not correlate with depth but with stratum stiffness [20]. Therefore, there appears to be inconclusive evidence from experimental measurements on the key parameters that affect horizontal stress magnitudes.

There have been several postulates for why the horizontal stresses would exceed the value determined by the Poisson effect. The commonly accepted reason is that stresses have been locked into the stratum from a time and environment of high compression, which could have arisen from either the strata having experienced deep burial or high tectonic compression. However, current-day deep-seated continental crust stresses have also been suggested as generators of high in situ horizontal stresses at shallower depths [21,22]. A second proposed reason for the generation of significant in situ horizontal stress arose from analysis of the World Stress Map [23]. The World Stress Map shows that the orientation and relative magnitude of horizontal stress is quite uniform over large areas of the plate interiors. A third proposal is that the magnitude of horizontal stress is governed by the earth's curvature, the stratum stiffness and the temperature gradient in the crust and mantle [24]. The analytically derived elasto-static thermal stress model of the earth estimated crustal stresses that agreed with field measurements of horizontal stresses.

Although vertical in situ stress is generally well understood, there are many disputed theories as to what generates in situ horizontal stress. The main purpose of understanding how in situ stresses arise is to be able to better predict the stability of underground openings. However, if there is a further disruption to these in situ stresses, such as due to mining activity, it is important to be able to quantify how the in situ stresses will be redistributed.

2.2. Horizontal stress redistribution around an extracted longwall panel

Extraction of a longwall panel of coal and the formation of a subsequent goaf cause the in situ stresses to redistribute, which they will generally do as a function of the local geology, the original in situ stress field and the mining extraction method [25]. Adverse mining conditions experienced while mining under residual pillars of overlying seams have led to many comprehensive studies on vertical stress redistribution around mining structures and multi-seam interactions [e.g., 2, 15, 26, 27]. However,