International Journal of Coal Geology 106 (2013) 39–47

Contents lists available at SciVerse ScienceDirect

International Journal of Coal Geology

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

A numerical study of stress changes in barrier pillars and a border area in a longwall coal mine

Mahdi Shabanimashcool *, Charlie C. Li

Department of Geology and Mineral Resource Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

ARTICLE INFO

Article history:
Received 3 September 2012
Received in revised form 20 December 2012
Accepted 21 December 2012
Available online 30 December 2012

Keywords:
Longwall mining
Numerical modelling
Barrier pillars
Large-scale numerical modelling
Stress changes

ABSTRACT

In longwall mining, stope voids are filled by caved-in rock materials. Cave-in and fracturing of roof strata cause severe disturbance to and stress changes in the host rocks. The study site is the Svea Nord coal mine. Longwall mining method was implemented to extract coal at the study site. It is intended that the coal in the border area on one side of the longwall panels will be mined after completion of the longwall mining. There is a concern about how the longwall mining affects the stress state in the border area and how the stress changes would affect future mining in the border area. 3D numerical modelling was conducted to consider the above concerns. Two models were constructed in the study. The first one is a local model that includes only two panels to study how the stresses in the barrier pillars are changed during panel mining. The second one is a mine-scale global model that includes all the panels with the aim of studying the disturbance to the border area by the longwall mining. The simulations show that the stresses in the barrier pillars fluctuate up and down during mining because of periodic cave-in events behind the longwall face. A failure zone of about 12 m exists in the wall of the barrier pillar. A large portion of the barrier pillar is still intact and is thus capable of protecting the border area. A disturbed zone of about 20 m is found to have developed in the wall of the main tunnels on the side of the border area after all the longwall panels have been mined out. The stress state in the remaining portion of the border area remains unchanged. Therefore, by considering a pillar with width of 25–35 m into the border area along the access tunnels, it will be possible to mine the rest of the border area with room-and-pillar method in the future.

1. Introduction

In longwall mining, stope voids are filled by caved-in rock materials. Cave-in of the roof strata results in stress changes in the rock mass surrounding the longwall panels. The stress redistribution is mainly associated with the in-situ stress state, the layout of the panels, and the mining sequence. The vertical stress in panel walls would increase with an enlargement of the mined-out region. The horizontal stresses in the roof and floor are also changed by the advance of the longwall face as well as the enlargement of the mined-out voids.

Whittaker (1974) developed an empirical approach to calculate the vertical stress ahead of the longwall face for rock conditions prevailing in the UK. In his approach, a yield zone exists ahead of the face. The vertical stress is zero both at the face and at the rib side. It increases quickly with the distance from the face. Wilson (1983) developed an analytical–empirical method for the same purpose, whose results agree with those of Whittaker (1974). Numerical analyses conducted by, such as, Park and Gall (1989) agree well with the results of Whittaker and Wilson. All of these studies showed that the maximum abutment stress of four to six times the original vertical stress happens at a close distance from the stope face.

Recently, however, numerical studies and field measurements in Australia showed that the maximum abutment stress of about twice the original one occurs at a great distance from the stope face. Kelly et al. (1996, 2002) argued that those diversities are owed to the high horizontal stress acting along the panel. High horizontal stress causes shearing of the intact rock and bedding planes which results in abutment stress concentration far ahead of the stope.

The horizontal stress redistribution as a result of longwall mining has been studied through field measurements and numerical modelling as well. Such cases are, however, limited and there is no internationally accepted approach to assess the horizontal stress redistribution due to longwall mining. Gale and Blackwood (1987) carried out a numerical investigation on the influences of the horizontal stress orientation on the stability of the gates at an Australian colliery. They devised a graph, depicting the stability of the gate roof in relation to the orientation of the principal in-situ stress with alignment of the gates. Recently Coggen et al. (2012) carried out two and three dimensional numerical simulations in order to study influences of the magnitude and orientation of the in-situ horizontal stresses on the stability of the gates. They

* Corresponding author at: Sem Sælands veg 1, N-7491, Trondheim, Norway. Tel.: +47 73594831; fax: +47 73594814.
E-mail address: mahdi.shabanimashcool@ntnu.no (M. Shabanimashcool).

0166-5162/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.coal.2012.12.008

concluded that gates driven at an angle to the in-situ stress field suffer asymmetric deformation with pronounced stress effect.

Mark et al. (2007) investigated horizontal stress changes in the tailgate of a coal mine in the USA using detailed field measurements. They showed that horizontal stress in the direction of the perpendicular to the longwall panels dramatically increases owing to mining and the principal stresses reorient owing to roof strata deformation and yielding. They also claimed that the required length of the rock bolt for reinforcing of the roof strata is dependent on the magnitude of the horizontal stress perpendicular to the gates.

The stress redistribution is associated with the geological conditions, the mechanical properties of the rocks, the state of the in-situ stresses, the layout of the panels, the mining sequence, and so on. Neither analytical nor empirical approaches can take into account too many factors in their estimations, so their applications have limitations (Brady and Brown, 2002). Oversimplifications would bring about uncertainties in the results. Numerical modelling, however, provides us with an opportunity to include a good number of relevant factors in the analysis so that the results may be more realistic than those of analytical and empirical approaches. Furthermore, the effects of single factors can be easily studied numerically, which is helpful to identify the most important factors for use in practice. Numerical modelling together with field measurements is an appropriate way of studying stress redistributions in longwall coal mines. Previous studies of this kind have proven the validity of the method, e.g. Gale and Blackwood (1987), Singh et al. (2001), Mark et al. (2007) and Jiang et al. (2012).

Svea Nord is a coal mine in the archipelago of Svalbard in the North Sea. The longwall mining method is used at present, but it is intended that the coal in the border area of the longwall panels will be mined by room-and-pillar method in the future. There are concerns about how the longwall mining affects the stress state in the mining region, particularly in the border area, and how the stress changes would affect future mining in the border area. This study aims to investigate the above concerns through 3D numerical modelling. An algorithm developed by Shabanimashcool and Li (2011, 2012) was used for simulations. Two types of modelling were conducted in this study. The first one is a local model that includes only two panels to study how the stresses in the barrier pillars are changed during mining in a panel. The second one is a mine-scale global model which includes all the panels. The aim of the global model is to study the disturbance to the border area caused by the longwall mining. The significance of the study is that it proves that the failure zone in the country rock surrounding an underground void of large volume is limited to a relatively small extent as long as the void is backfilled by either caved-in materials or other types of loose materials.

2. Study site

The Svea Nord mine produces about 3 million tonnes of coal annually. The longwall panels are approximately 250 m wide and 2500 m long. The overburden varies from 50 to 400 m, and most of the ground surface above the panels is covered by glaciers of up to 250 m in thickness. Fig. 1 is a map showing the layout of the longwall panels.

In-situ rock stresses were measured in six locations in the mine by the overcoring relief method. The principal stresses in the mine area are vertical and horizontal. The vertical stress σ_v is equal to the weight of the overburden and the horizontal stresses in the central mining area are $\sigma_H = 10$ MPa and $\sigma_h = 8$ MPa. The horizontal stresses σ_H and σ_h are approximately parallel with and perpendicular to the panel length (a deviation of 15 to 20°), respectively. The ratios of the horizontal principal stresses to the vertical stress are approximately $k_{max} = \sigma_H/\sigma_v = 2$ and $k_{min} = \sigma_h/\sigma_v = 1.7$ in the mining region with the lowest overburden.

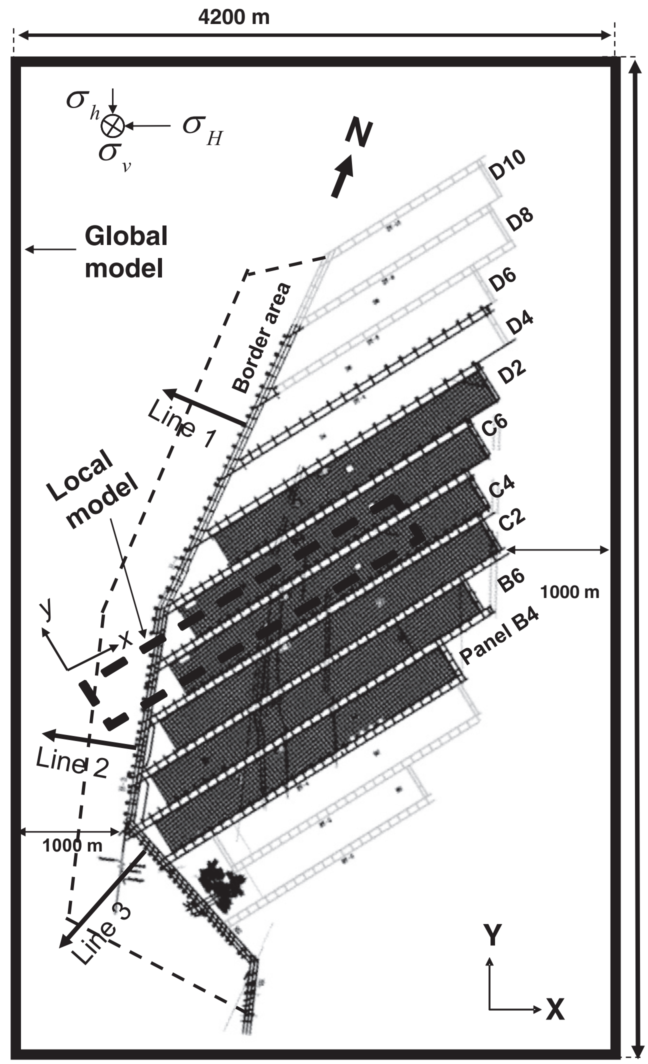

Fig. 1. Mine map and regions chosen for numerical modelling.

There are a number of thrust faults in the mining region, which strike approximately perpendicularly to the panels and have limited persistence.

Fig. 2 is a column map showing the sequence of the laminated sedimentary coal/rock layers below and above the coal seam being mined. The panel roof is marked by 0 on the scale ruler. The roof strata are composed of siltstone and finely grained sandstone interblended with thin coal and bentonite layers. A bentonite layer lies about 2–3 m above the coal seam. The roof strata may be divided into three units: unit 1 ranges from 0 to 2.5 m above the coal seam and is composed of siltstone with thin coal interlayers; unit 2 is from 2.5 to 10 m and is composed of sandstone and siltstone with coal interlayers; and unit 3 refers to the rock strata from 10 m upward and is mainly composed of relatively massive sandstone and siltstone. Unit 1 is the immediate roof of the panels. A bentonite layer marks the upper border of this unit.

The rock mass is in general dry in the mining region but wet in the cave-in area. The water comes from the glacier above the cave-in area. Water is not a big issue in the mine.

3. Numerical simulation

3.1. Simulation logarithm

In longwall mining, roof cave-in is a complex dynamic process involving rock fracturing, disintegration, movement, stress redistribution,