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In-situ stress measurements and stress change monitoring to monitor overburden caving behaviour and hydraulic fracture pre-conditioning

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ABSTRACT

A coal mine in New South Wales is longwall mining 300 m wide panels at a depth of 160–180 m directly below a 16–20 m thick conglomerate strata. As part of a strategy to use hydraulic fracturing to manage potential windblast and periodic caving hazards associated with these conglomerate strata, the in-situ stresses in the conglomerate were measured using ANZI strain cells and the overcoring method of stress relief. Changes in stress associated with abutment loading and placement of hydraulic fractures were also measured using ANZI strain cells installed from the surface and from underground. Overcore stress measurements have indicated that the vertical stress is the lowest principal stress so that hydraulic fractures placed ahead of mining form horizontally and so provide effective pre-conditioning to promote caving of the conglomerate strata. Monitoring of stress changes in the overburden strata during longwall retreat was undertaken at two different locations at the mine. The monitoring indicated stress changes were evident 150 m ahead of the longwall face and abutment loading reached a maximum increase of about 7.5 MPa. The stresses ahead of mining change gradually with distance to the approaching longwall and in a direction consistent with the horizontal in-situ stresses. There was no evidence in the stress change monitoring results to indicate significant cyclical forward abutment loading ahead of the face. The forward abutment load determined from the stress change monitoring is consistent with the weight of overburden strata overhanging the goaf indicated by subsidence monitoring.

1. Introduction

SCT Operations Pty Ltd. (SCT) have been conducting overcore stress measurements and stress change monitoring using the ANZI strain cell for over 25 years in a range of surface and underground mining environments. The ANZI overcore and strain change monitoring instruments are essentially similar in construction with one measuring the 3-dimensional strain changes when the in-situ stresses on the rock are fully relieved and the other measuring 3-dimensional strain changes associated with mining induced ground disturbance [1]. The work described in this paper applied overcoring and stress change monitoring to investigate the in-situ stress state and stress changes in the overburden strata as part of a strategy to characterise the overburden behaviour and modify its behaviour using hydraulic fracturing.

The coal seam currently being extracted is overlain by the 16–20 m thick Digby Conglomerate. The conglomerate was assessed prior to mining as being capable of hanging up for 60 m during longwall start-up and producing an initial caving event capable of producing a windblast. The conglomerate strata were also assessed as having potential to cause periodic weighting on the longwall face during regular mining. As part of a strategy to manage the windblast and periodic caving hazards, SCT and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) were commissioned to undertake investigations to support a program of hydraulic fracturing pre-conditioning of the conglomerate strata. Stress measurements and stress change monitoring were undertaken as part of this program.

Fig. 1 presents a mine plan showing the location of stress measurements and stress change monitoring sites. Two measurements conducted at the Longwall 101 start-up area measured the in-situ stress regime in the conglomerate prior to the commencement of longwall mining. The stress measurements were used to predict the orientation and breakdown pressures of the hydraulic fractures. The results indicated stress conditions had potential to be favourable for emplacing horizontal fractures suitable to pre-condition the conglomerate. A full-scale trial conducted at the start of Longwall 101 confirmed that the hydraulic fractures were forming horizontally [2].

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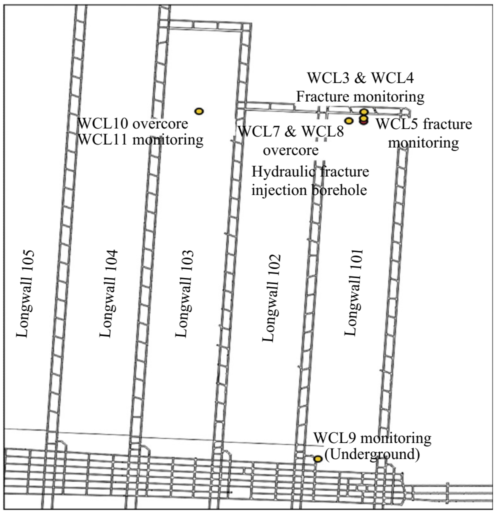

Fig. 1. Mine plan showing location of overcore stress measurement and stress change monitoring at mine site.

Several successive stress measurement and stress change monitoring campaigns were undertaken after the commencement of longwall operations to measure the changing stress regime in the conglomerate. Forward abutment loading and horizontal stress changes during final retreat of Longwall 101 were measured through periodic monitoring of a single ANZI strain change-monitoring cell installed into the coal barrier pillar behind the finish line.

An overcore stress measurement was conducted in the conglomerate over Longwall 103 after the extraction of the first two longwall panels. Stress change monitoring in the conglomerate at the same location provided a means to measure the cumulative stress change in the strata during longwall approach. The forward abutment loading and horizontal stress changes in the conglomerate were measured using this instrument.

2. ANZI strain cell

The ANZI strain cell comprises a soft, inflatable membrane supporting 18 electrical resistance strain gauges that can be pressure bonded directly to the rock surface of a borehole using epoxy cement. Several versions and configurations of the ANZI strain cell have been developed for different applications. Fig. 2 shows the 58 mm diameter strain cell and a smaller 48 mm version that is now commonly used for installations conducted in surface exploration holes through HQ drill rods using wireline technology to drill the pilot hole. The installation details and operation of the ANZI strain cell is described in Mills [1,3,4].

The overcoring method of stress relief involves removing the in-situ stresses acting in the ground by drilling over the strain cell to form a cylindrical annulus of rock into which the strain cell has been previously installed in a pilot hole. The strain cell measures the small deformations that occur in multiple directions as the stresses are removed by the overcoring process. By also measuring the mechanical properties of the rock, the magnitude and direction of the small deformations can be used to determine the complete 3-dimensional in-situ stress field. The confidence that may be placed in the final stress measurement result is indicated by the internal gauge correlation and expressed as the correlation coefficient. Six independent strain measurements are required to provide a 3-dimensional stress measurement result. With 18 gauges available, the statistical analysis has 12 degrees of freedom available to provide a strong indication of the confidence that can be placed in the instrument.

Fig. 2. Instrument assembly for the double 58 mm ANZI stress cell and the single 48 mm ANZI stress cell.

Strain change monitoring cells are essentially similar to overcoring strain cells except that, instead of measuring the change in stress when the in-situ stress is completely removed by overcoring, they measure the changes in stress that occur as a result of mining activity.

3. Overcore in-situ stress measurements

Overcore in-situ stress measurements were conducted at two locations at the subject mine from vertical boreholes drilled from the surface. The first measurements were undertaken at the hydraulic fracture trial site at Longwall 101 start-up prior to the commencement of longwall operations. The second site was located on the centreline of Longwall 103, 435 m from the start line. The measurements at Longwall 103 were conducted after the extraction of Longwall 101 and 102.

The point measurements discussed in this section have been normalised for variation in elastic modulus between measurement locations for direct comparison. The process of normalisation involves making allowance for the variations in horizontal in-situ stress that are observed in horizontally bedded rock with different elastic modulus. Fig. 3 presents a summary of the stress measurements results normalised to a rock with an elastic modulus of 16 GPa.

Two ANZI strain cells, WCL7 and WCL8, were overcored in the conglomerate at a depth of 145 m at Longwall 101. The two independent results show close agreement in both magnitude and orientation, and indicate essentially the same stress field. The major principal stress has a magnitude of 9.0 MPa and is effectively horizontal and oriented 15° grid north (GN). The intermediate principal stress has a magnitude of 5.5 MPa, dipping at about 20° and oriented at 285° GN. The minor principal stress is sub-vertical with a magnitude of 3.1 MPa.

A single ANZI strain cell, WCL10, was overcored in the conglomerate at a depth of 172 m over Longwall 103. The major principal stress indicated by WCL10 is horizontal with a magnitude of 14 MPa and oriented at 27° GN. The intermediate principal stress is sub-horizontal and has a magnitude of 5.1 MPa, dipping 24° at 117° GN. The minor principal stress is sub-vertical with a magnitude of 4.1 MPa.

Fig. 4 presents a plan of the stress measurement sites showing the overcore locations and the orientation and magnitudes of the measured horizontal stresses normalised to a rock with an elastic modulus of 16 GPa. A slight rotation in the horizontal stress field and a 5 MPa increase in the magnitude of the major stress at Longwall 103 is observed, possibly associated with some stress concentration around the corner of Longwall 102.

The dip of horizontal stress commonly parallels the dip of the strata in horizontally bedded rocks where units of varying stiffness overlie each other. The major principal stress is effectively horizontal at both measurement sites and roughly consistent with the dip