A comparison of overcoring and AE stress profiles with depth in Western Australian Mines

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ABSTRACT: Reliable estimation of in situ stress is a major step in the analysis and design of underground excavations in rock, particularly for evaluating the stability of underground structures and influencing processes to prevent failure or collapse. A technique that allows the estimation of stresses using oriented core that can be drilled at depth has been studied over the last six years at the Western Australian School of Mines (WASM). The technique is based on acoustic emission (Kaiser effect) and has been used to estimate the in situ stresses from more than fifty mine sites in Western Australia. After introducing this method, two case histories are used to compare in situ stress profiles established by CSIRO HI Cell (overcoring) and AE methods.

1 INTRODUCTION

Generally, two main categories exist for in situ rock stress measurement methods: one category is associated with disturbing the in situ rock conditions by inducing strain and deformation changes or crack opening; the second category includes the methods based on the observation of rock behaviour without major influence from the measuring method (Ljunggren et al., 2003). The CSIRO Hollow Inclusion (HI) Cell stress measurement method is one of the overcoring methods and belongs to the category of disturbing the in situ rock conditions. The CSIRO HI Cell stress measurement method has been very popular in the Australian mining industry since its development in late 1970s.

The Acoustic Emission (AE) method relies on the concept of the Kaiser effect and falls in the rock behaviour observation category for the in situ rock stress determination. Even though the Kaiser effect concept was introduced in the 1950s (Kaiser, 1953 and Ljunggren et al., 2003), one of the first publications on its application to rock stress measurement was seen in 1989 (Seto et al., 1989). In last six years, the Western Australian School of Mines (WASM) has studied and developed an AE stress measurement technique using orientated core named the WASM AE method (Villaescusa et al., 2002a and 2002b). It allows the determination of a representative and detailed knowledge of the in situ stress field during the early stages of a project (such as mine feasibility studies), even in areas where development access is not yet available (such as below current open pits). The method has been used for in situ stress measurement at more than 50 mine sites in Western Australia and 30 more sites in other regions and countries. The measuring results match the geological conditions of the specific mines well and have been used as input to optimize extraction sequences (Villaescusa et al., 2002b and 2003a).

Two case histories are used to compare the CSIRO HI Cell and the WASM AE stress measurement results.

2 WASM ACOUSTIC EMISSION STRESS MEASUREMENT METHOD

The Acoustic Emission (AE) method is based upon the principle of the Kaiser effect (Kaiser, 1953). The analysis of this phenomenon supposes that a previously applied maximum stress can be detected by loading a rock specimen to a point where a substantial increase in acoustic emission (AE) activities is experienced (See Figure 1). The Kaiser effect is the recollection of the immediate maximum previous stress to which a particular rock mass has been subjected by its environment. The principle behind the technique is that changes in the rate of AE occur at the maximum stress level (along the axis of the sample) to which a sample had previously been subjected. The methodology has been developed over the last 15 years by several researchers with the aim of providing a practical technique for retrieving the Kaiser effect (Kurita and Fujii, 1979, Houghton and Crawford, 1987, Seto et al., 1989a, Seto et al.,
The stress tensor has six independent components, and therefore six independent normal stress measurements suffice to determine the full stress tensor. The principal stresses can then be obtained by a standard eigenvalue analysis. Six small cylindrical samples of rock are under-cored from conventional oriented drill core recovered from the site for which stress data is sought. Each sample is instrumented with a pair of acoustic emission (AE) transducers. The samples are then loaded uniaxially with the AE transducers providing a record of the number of AE ‘events’ with increasing load and hence stress. Finally, the AE information from the six samples is analysed to give six independent normal stresses from which the full stress tensors can be obtained.

The signal noise associated with crack closure during loading can obscure the Kaiser effect. It has been observed that this noise is substantially suppressed when the acoustic emission information is recovered from a second subsequent loading of the sample (Villaescusa et al., 2002b). Clearly, this is impossible if the first loading takes the sample to failure. In the present work two or three loading-unloading-reloading cycles are performed on each under-cored sample. The AE activity in the second loading cycle is usually used to determine the in situ stress. Figures 2 and 3 respectively show the undercoring orientations with respect to an oriented core axis and the AE sample ready to test (Villaescusa et al., 2002b, 2003a and 2003b).

3 CASE STUDIES

Over the last six years, the WASM AE stress measurement method has been applied to in situ stress measurements at more than 50 mine sites in Western Australia. Among the 50 mine sites, a number of sites carried out the CSIRO HI Cell stress measurements prior to WASM AE stress measurements. Therefore, it provides an opportunity to compare the AE results with existing CSIRO HI Cell data.

3.1 Case study 1 – Kanowna Belle gold mine

The Kanowna Belle gold mine is located about 25km east of Kalgoorlie and operated by Placerdome. By 2003 a total of nine stress measurements had been carried out using the CSIRO HI Cell method, at depths of above 1000m. In 2005, a stress
measurement using the WASM AE method was carried out for a depth of 1600m below ground surface. Figure 4 shows the locations of HI Cell stress measurements. The depth ranged from 263m to 980m below the ground surface (i.e. at the bottom of Block D). Figure 5 shows the principal stress orientations and dispersions from the CSIRO HI Cell measurements. It can be seen from Figure 5 that the orientations are highly scattered. Figure 6 illustrates the orientations of principal stresses measured using the WASM AE method. These orientations for principal stresses reconcile with the breakout failures observed in raise-bored holes at this mine.

Figure 4. Long section of Kanowna Belle orebody and HI Cell stress measurement locations.

Figure 5. Principal stress orientations and dispersions from CSIRO HI Cell measurements at Kanowna Belle mine.

In addition, comparative magnitudes for the principal stresses at 1600m deep with the HI Cell results are shown in Figure 7. Another stress measurement using the WASM AE method (at about 1200m deep) is scheduled for 2006. Figure 7 suggests that the principal stress magnitudes from the CSIRO HI Cell are also scattered.

Figure 6. Principal stress orientations from the WASM AE measurement at 1600m deep – Kanowna Belle mine.

Figure 7. In situ stresses magnitudes and profiles at Kanowna Belle mine derived from HI and AE methods.
3.2 Case study 2 – Perseverance nickel mine

Perseverance is a nickel mine owned and operated by BHP Billiton Nickel West. It is located 500km north from Kalgoorlie in Western Australia. By 1992, a total of 6 stress measurements above 800m deep had been conducted using the CSIRO HI Cell method. By 2002, a number of stress measurements using HI Cell and hydraulic fracturing (HFRAC) methods were completed at depth from 770m to 1120m. In 2004 and 2005, 4 stress measurements using the WASM AE method were conducted at depths ranging from 1175 to 1330m.

Figures 8 and 9 illustrate the orientations and magnitudes of principal stresses, respectively, measured using the CSIRO HI Cell and HFRAC methods. It can be seen that both orientations and magnitudes for the in situ stresses vary significantly with the depth. The plunge for all three principal stress components ranged from horizontal to vertical as shown in Figure 8. No strong clusters for azimuths and dips of the principal stresses can be found.

However, the orientation and magnitude results obtained using the AE method are more consistent. Figure 10 shows that the orientations for every principal stress component of all four AE measurements can be grouped. In addition, Figure 11 shows the magnitudes of the principal stresses fit in situ stress profiles required for numerical modeling.
Recently, a total of 12 boreholes situated within the same region experienced severe breakout failures. A substantial analysis on borehole surveying data was carried out and revealed that 10 of the 12 borehole surveys yielded reasonably similar patterns of ovularity. The ovularity ratio is defined as the ratio of major to minor diametric dimensions of a borehole. The observations collectively indicate that the stress magnitudes below 1100m are sufficient to cause rock failure around all boreholes at all depths in all rock types over a range of rock strengths. In addition, the data suggest that between 1100m and 1400m deep the preferred orientations of the major principal stress are $230° \pm 30°$, which are similar to the AE results within this depth range shown in Figure 12.

4 CONCLUSIONS

The methodology of Acoustic Emission (AE) to measure rock stress has been developed and implemented at the Western Australian School of Mines over the last six years. The rock stress results measured using the WASM AE method are comparable to the results using the CSIRO HI Cell method. In both case histories, the major principal stress azimuths determined by the AE method were verified by breakout failures of raise-bored holes and diamond drill holes. Consequently, the WASM AE method is considered an alternative technique for rock stress measurement, with advantages of low cost and no requirement for underground access.

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6 PREFERENCES


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