Experience with the Monitoring of Crown Pillar Performance in Two Australian Mines

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SUMMARY: The optimisation of crown pillar dimensions is of concern to the metalliferous mining industry throughout the world. Excessively large pillars may sterilize valuable ore reserves whilst undersized pillars may be prone to failure, leading to hazardous situations and/or loss of reserves through premature interruption to mining operations. The work described in this paper was carried out at the Mt. Isa Mine of Mount Isa Mines Pty. Ltd. and at the New Broken Hill Consolidated Mine of Australian Mining and Smelting Pty. Ltd. and was concerned with monitoring to assess the status of crown pillars in relation to cut and fill and open stoping operations respectively. The work was part of a wider program concerned with the rational design of crown pillars and was undertaken to provide *in situ* information on the performance of crown pillars for comparison with the results of predictive models.

Monitoring techniques employed included static measurements of deformation and point stress changes as well as geophysical measurements (microseismic noise, transmitted wave velocity). An automatic data acquisition system was also developed. This paper describes the instrumentation and methods of application, and summarises and discusses the results obtained.

1 INTRODUCTION

The use of crown pillars to limit stope wall movements and reduce the possibility of large scale failure affecting surrounding development is a well established mining practice. The pillars left must be large enough to remain stable, often for extended periods of time. However, since crown pillars are often formed within an orebody, large pillars could represent a substantial loss of reserve or involve the need for costly pillar recovery techniques. Crown pillar dimensioning has to date relied largely on experience of past pillar behaviour. Increase in depth of mining and new mining practices coupled with depletion of valuable reserves is, however, highlighting the need for a more quantitative approach to crown pillar design.

To achieve this it is essential to gain an understanding of the bulk strength (including reinforcement) of crown pillars, as well as the nature of loadings generated as a result of mining. This is particularly true in the case of crown pillars associated with large open stopes where stoping limits and pillar dimensions are often decided prior to commencement of mining with little if any scope for modification of final pillar size once mining has started. In this situation, failure of crown pillars arising as a result of inadequate initial dimensioning may lead to excessive dilution as well as possibly endangering the regional stability of the mine.

In overhead cut and fill stoping there is often scope for deciding on "pillar" thickness during the mining operation, based on progressive assessment of the stability of the material remaining above the stope back. "Pillars" left at any stage may subsequently be reduced by further cut and fill lifts, if and when conditions permit, provided this is done cautiously by taking small lift heights. Refinement of this approach requires the development of practical monitoring techniques that can describe the relative stability of a "pillar". Such techniques will make more objective decisions on when to stop mining, and when further mining is possible.

The work described in this paper forms part of an ongoing project concerned with crown pillar design, being conducted by CSIRO Division of Applied Geomechanics in collaboration with Australian mining companies, with financial sponsorship through AMIRA Ltd. The work is being undertaken with the dual aims of gaining a quantitative understanding of crown pillar performance in general as well as attempting to develop procedures for predicting the onset of pillar failures. Experience gained during the monitoring of crown pillars in cut and fill mining (8 Orebody, Racecourse Orebodies, Mt. Isa Mine) and open stoping (B Lode Orebody, New Broken Hill Consolidated) situations is presented.

2 8 OREBODY, RACECOURSE AREA, MT. ISA

The Racecourse Orebodies consist of an *en echelon* series of thin, tabular, steeply dipping silver-lead-zinc deposits mined by an overhead, mechanised, cut and fill technique (Goddard and Bridges, 1977). The plan of the orebodies at 11 level is shown in Figure 1. The locations of the two sites selected for study in 8 Orebody are marked. Number 8 Orebody is one of the major orebodies occurring in the series, and at the time of the monitoring program was being mined between 13 and 11 levels, having been previously mined from 12 m above 11 level to 9 level (Figure 2). At the commencement of the monitoring program the total height of the 11 level crown "pillar" of 8 Orebody was approximately 30 m.

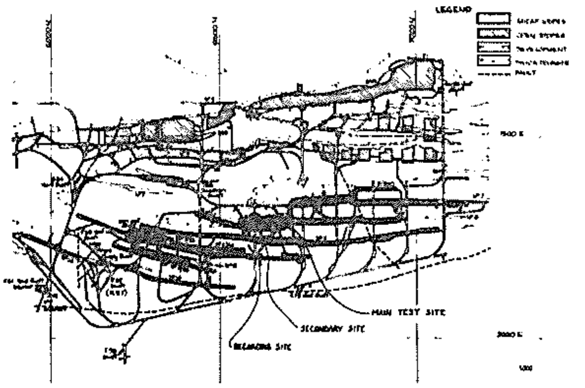

Fig. 1. Plan of 11 level Racecourse area Mount Isa Mine showing location of test sites in 8 Orebody.

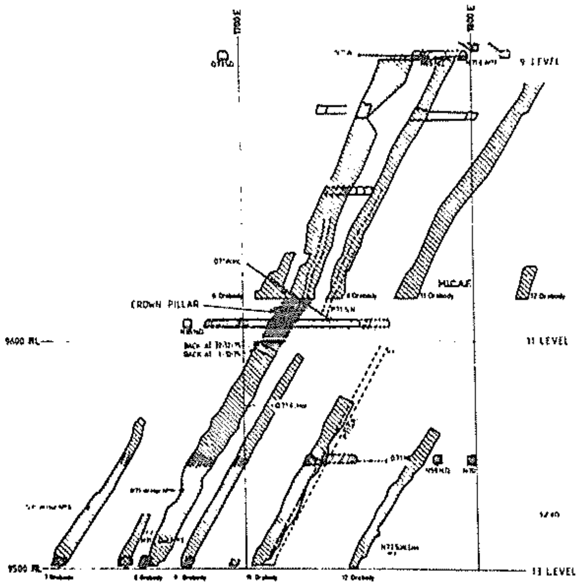

Fig. 2. Vertical cross section at northern test site (Fig. 1) showing mining development at the time of commencement of the monitoring program.

The monitoring period described extended from September 1975 to June 1976 during which a total of four lifts (each approximately 2.5 m high) were mined along the length of 8 Orebody, reducing the average thickness of the material remaining below 11 level from approximately 18 m to 8 m, at which time the pillar was noticeably cracking. Mining was discontinued shortly after. During the same period, the adjacent orebodies of the Racecourse series were being mined. Number 9 Orebody was of particular importance in this regard as it was in very close proximity to 8 Orebody and was being mined at approximately the same elevation. Mining was resumed in 8 Orebody approximately two years after completion of the monitoring program. During the intervening period, considerable mining activity had taken place in the parallel stopes of the Racecourse series. Upon resumption of mining, the remaining material in 8 Orebody up to 11 level was removed with little difficulty.

Absolute stress measurements were conducted at the approximate mid-height of the "pillar" using the stress relief overcoring technique, in conjunction with a USBM borehole deformation cell and the CSIRO hollow inclusion gauge (Worotnicki and Walton, 1976) in December 1975 (i.e. at the commencement of the monitoring program) and in December 1977 (i.e. well after its completion). The results for the northern most test site are given in Table No. 1. Severe core disking was encountered at both sites during the earlier measurements. This is consistent with the stress magnitude reported, in particular the very high cross-stope (approx. E-W) stress component which approached the measured uniaxial compressive strength of the rock forming the crown "pillar" (Miller, 1977). The reduced stress magnitude indicated by the latter measurements is consistent with the relative ease with which the "pillar" was mined subsequent to the monitoring program (see earlier). In fact it was partly on the basis of the latter stress measurements that mining was recommenced in 8 Orebody. The actual mechanism by which the stress relief took place is as yet uncertain, but a combination of bedding plane slip, stress shielding and cracking has been suggested. In this regard, significant subsidence and bedding plane movements have been observed by Mt. Isa personnel.

TABLE 1

RESULTS OF ABSOLUTE STRESS MEASUREMENT (STRESS COMPONENTS IN MPa), 8 OREBODY 11 LEVEL CROWN PILLAR

Date	σ_1 (approx) E-W	σ_2 (approx) N-S	σ_3 (approx) Vert.
Dec. 1975	95	46	27
Dec. 1977	19	13	7

Stress change monitoring was undertaken to provide a continuous record of the magnitude of cross-stope stress changes. A number of uniaxially sensitive rigid inclusion stress meters were installed at various locations between the stope back and 11 level at both sites. Although results were obtained from both sites, it was only from the northern-most site that a continuously reliable record resulted.

The National Coal Board (U.K.) instrument (Enever, 1977) was used for the monitoring. This device consists of a tapered steel plug (Fig. 3) fitted with electrical resistance strain gauges oriented to measure diametric strain changes. The device is forced into a matching tapered socket prepared at the bottom of a hole drilled to the required location. Increases in uniaxial compression occurring in the host rock, in the sensitive direction of the instrument, are transferred to the stressmeter and registered as strain changes. Calibration of the instrument/rock system enables electrical output to be related to changes in rock stress.

For the work in 8 Orebody, a number of holes were drilled from 11 level, parallel to dip, and one instrument inserted per hole, at the required depths, with the required orientation. Instrument cables emerging from the holes were terminated at secure locations on 11 level near to the respective test sites. Signals from the instruments were

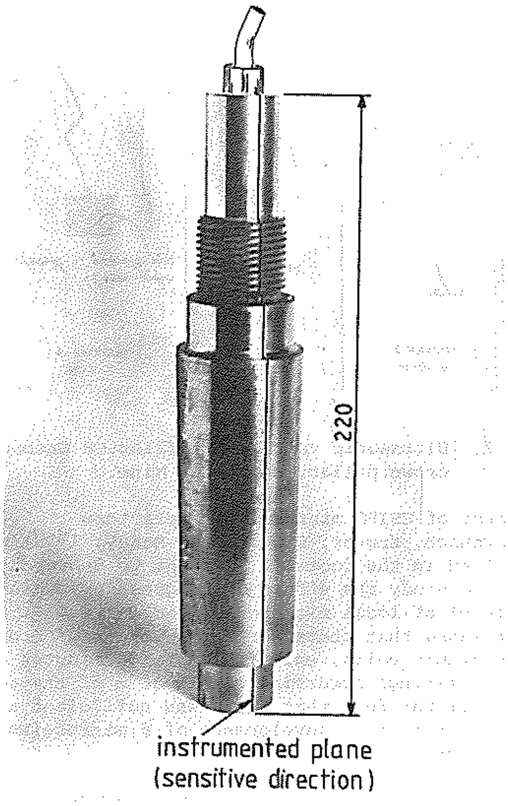

Fig. 3. National Coal Board (U.K.) Rigid Inclusion STressmeter.

transmitted up to 500 m to a central recording site (Fig. 1) where they were registered on a data logging system providing the capability for continuous monitoring. Results were provided both in hard copy format (for immediate inspection and manual reduction) and in the form of magnetic tape records permitting automatic data reduction. This system proved effective in providing essential data at critical times, but did present maintenance problems. These were largely overcome by providing strict environmental control for the logger (Spathis, 1978).

Figure 4 shows the results of monitoring of cross-stope stress in 8 Orebody at the northern site, for a period during which three lifts were mined in both 8 and 9 Orebodies. Incremental stress changes associated with specific events in the mining history for the period concerned are shown in respect to their relative location in the pillar as it existed at that particular time. A significant increase in cross-stope compression occurred up to approximately 5 metres above the new stope back formed by removing a lift in 8 Orebody. The peak stress change occured approximately 2 to 3 metres above the back. The displacement of the peak stress change away from the back can be explained in terms of the superpositioning of induced increments of compressive stress from previous lifts on the already high cross-stope stress (see above) leading to failure of the rock near the stope back. This condition would be aggravated by blast damage. This region is therefore unable to accept further stress increase.

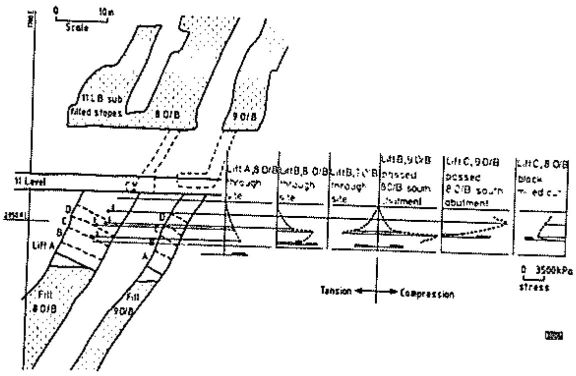

Fig. 4. Incremental cross-stope stress changes for various stages of mining sequence, 11 level crown pillar, 8 Orebody, Mount Isa Mine.

A number of interesting observations regarding the interactive effect of parallel mining in 8 and 9 Orebodies on the 8 Orebody crown pillar can be deduced from Figure 4. On one occasion, a reduction in cross-stope stress was measured when mining of lift B in 9 Orebody passed the test site. At this stage, the height of development of 9 Orebody, measured in the dip plane, exceeded that of 8 orebody at the test site. This partial destressing effect was attributed to stress "shielding" of the 8 Orebody crown pillar by 9 Orebody. On two separate occasions a large increase in compression was noticed at the test site when no mining was being conducted in the immediate vicinity. In both instances a "pendant" block had been left in 8 Orebody close to the test site, from the preceding lift, and mining of 9 Orebody was proceeding past the vicinity of the south "abutment" of 8 Orebody. The postulated explanation is shown diagramatically in Fig. 5. It was noticeable that when the "pendant" block was subsequently mined, a stress decrease was recorded at the test site. The effects observed demonstrate the need for attention to mine scheduling to avoid potentially troublesome situations and/or to take advantage of the benefits offered by the concept of "shielding".

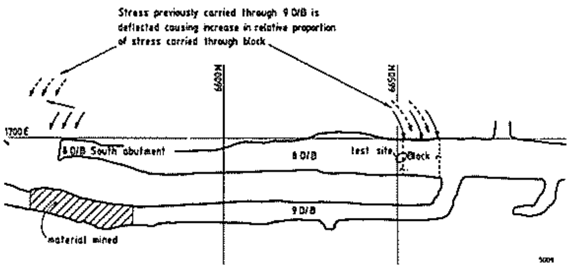

Fig. 5. Representation of proposed interaction in longtitudinal direction between 9 Orebody and 8 Orebody.

Incremental ultrasonic wave velocity and attenuation measurements were made along the centreline of the crown pillar, in the dip direction. A piezoelectric crystal detector was lowered down a water-filled hole drilled from 11 level, at the northern site. Ultrasonic pulses were generated near the collar of the hole by means of a magnetostrictive transducer attached to a large pad of concrete. This system was arranged to produce pulses travelling nearly parallel to the direction of the hole (Fig. 6). The fastest travel path for the pulses was through the rock in the hole wall and then, via the water, directly to the detector. By recording the arrival time and the amplitude of the first peak of repeated pulses, at a series of survey points down the hole, it was possible to determine incremental transmission velocities and signal attenuations for waves travelling in the rock (McKavanagh and Lee, 1979). Periodic surveys of this type were made of the 8 Orebody crown pillar at various stages during the monitoring period and continuous profiles of velocity and attenuation produced, as shown in Fig. 7.

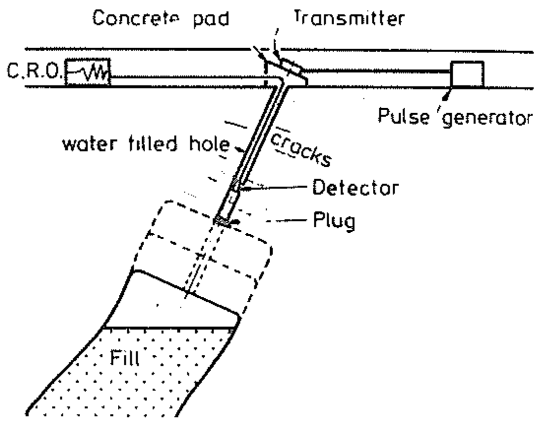

Fig. 6. Photo of ultrasonic set-up Mt. Isa.

The first survey (6/12/75) shows a marked decrease in incremental velocity from approximately 5 metres above the stope back to the back. This can be readily attributed to increasingly severe development of cracks approximately parallel to the stope back, causing increase in travel path length with commensurate apparent decrease in incremental velocity. This observation is generally consistent with the results of the stress change monitoring. The marked change in velocity approximately 7 metres above the back was attributed to a large single crack thought to exist at the location. Smaller scale variations in velocity were observed to be due to different rock types. The latter surveys (10/1/76 and 7/2/76) yielded substantially similar results, both indicating a tendency for reduction of incremental velocity in the region approximately 5 metres above the new stope back. The other interesting facet of the latter surveys was the relative reduction of velocity for the higher region of the pillar, which may be indicative of the development of ubiquitous cracking in the pillar.

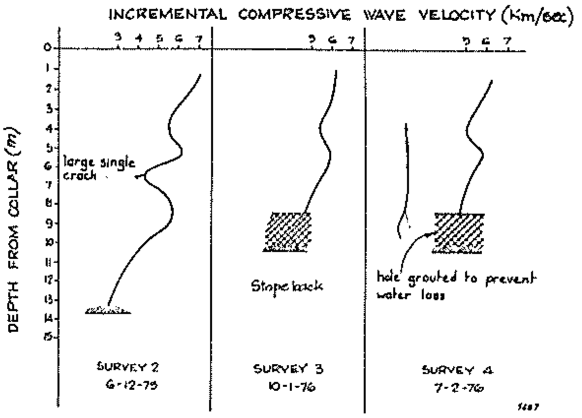

Fig. 7. Ultrasonic velocity profiles, 8 Orebody crown pillar, Mount Isa Mine.

A number of CSIRO microseismic detectors (McKavanagh, Enever, Siggins and McKay, 1978) were installed in the footwall adjacent to 8 Orebody, in order to study the effect of progressive mining on the level of local microseismic activity. It was established that there were high levels of broadband microseismic noise, existing up to 30 minutes after orebody firings occurring within 30 m of the test site. It was felt that there was sufficient activity to warrant further development of a microseismic warning system.

A number of rod and resistance wire extensometers (Enever, McKavanagh and Carson, 1977) were installed in holes drilled parallel to the dip of 8 Orebody to monitor "pillar" dilation. These instruments were connected to the automatic data acquisition system described previously. As a general comment it was found that dilation was of a negligible magnitude during the monitoring period.

3 PANEL 10, B LODE OREBODY, BROKEN HILL

Panel 10 is one of the series of large open stopes developed to extract the lower, northern, portions of the zinc rich B Lode Orebody. Figure 8 is a generalized longitudinal section through the major orebodies in the region, showing the location of

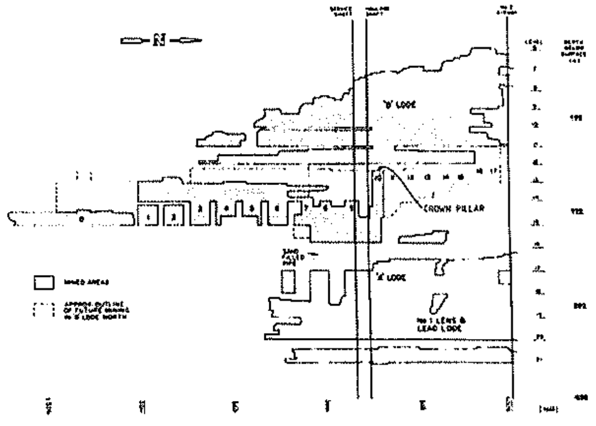

Fig. 8. Longtitudinal section of New Broken Hill Consolidated mine showing position of Panel 10 in "B" Lode sequence.

Panel 10. The designed height of the opening was 120 m and the maximum length at mid-height, 44 m. The stope was mined by developing a vertical cut-off slot at the southern end, progressing from east to west, followed by larger ring firings, extending to the full width of the stope, progressing towards the north. The crown pillar above the stope (below 12 level) was planned to be 12 metres thick. Due to overbreak, however, the actual height of the pillar was reduced over part of its length to approximately 6 metres. During extraction of the stope, the crown pillar began to "bump" and drives contained within the pillar suffered spalling and timber damage. The pillar was reinforced by installation of fully grouted cables at this time (approximately half way through the lift of the stope). It was concurrently decided to commence monitoring of the pillar. The detailed geometry of the crown pillar and the arrangement of instrumentation is shown in Figures 9(a & b). Between October 1976 (when mining was completed) and February 1977, sporadic signs of increased activity (large audible bumps) were reported from the crown pillar, one event being large enough to be recorded on a nearby seismic station (21/1/77). From shortly after this latter event, however, the pillar appeared to become stable with no further signs of significant activity.

Absolute stress measurements were made, using the stress relief overcoring method in conjunction with the CSIRO hollow inclusion gauge (see earlier) at three stages during the monitoring program; at the commencement of monitoring (August 1976), at the completion of excavation of the stope (October 1976) and after a further period of approximately four months (February, 1977).

The results of the absolute stress measurements conducted during the course of the monitoring program are given in Table No. 2. The first two measurements show essentially uniaxial E-W loading of the pillar with an increase in E-W stress between August and October that can be attributed to the mining that took place during that period. The difference between the results of October 1976 and February 1977 is particularly interesting. In general terms the stress field in the pillar during this period tended to become more isotropic, with an increase in the intermediate and minor stress component magnitudes without any substantial change in the E-W stress. It was during this period that the significant seismic activity mentioned earlier occurred, even though the size of the stope was not increased (the stope was in fact being filled with dry fill during this period). It may be postulated that during this period the pillar, which had been effectively overloaded due to mining, suffered an extended phase of instability. This was due, possibly to a combination of the effects of time dependent material and/or discontinuity behaviour and continuing stress readjustments resulting from sequential small scale failures near the stope back In this region the highly concentrated stress may have exceeded the uniaxial strength of the rock (McKavanagh, Tillman, Alexander and Enever, 1978). This could eventually lead to major failure of the pillar under the action of the predominant E-W stress. Yielding of the pillar in the E-W direction under approximately constant stress can be imagined to have caused a sympathetic increase in the vertical and N-S stress components, due to a "mutual confinement" effect. As such a process continued, a point was presumably reached when the net stress condition in the pillar resulted in the pillar becoming stable, due to the strength enhancing effect of the confinement provided by the vertical and N-S stress components.

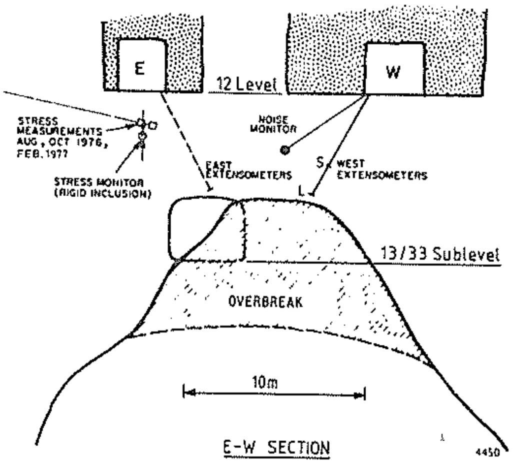

Fig. 9a. E-W section of Panel 10 crown pillar showing overbreak and monitoring installations.

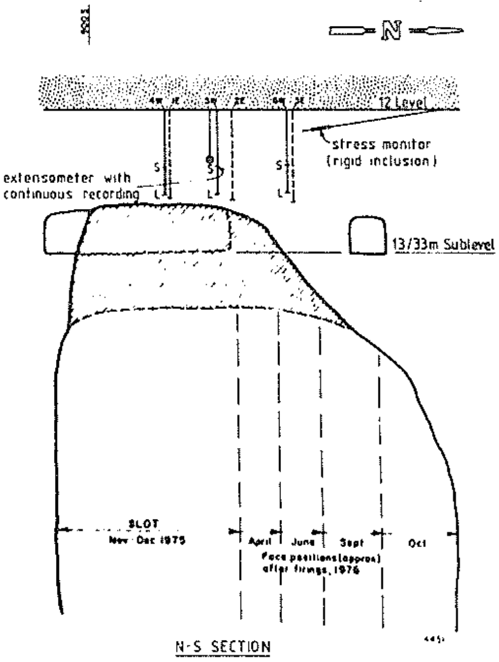

Fig. 9b. N-S section of Panel 10 crown pillar showing overbreak and monitoring installations.

TABLE 2

RESULTS OF ABSOLUTE STRESS MEASUREMENT (STRESS COMPONENTS IN MPa), PANEL 10 CROWN PILLAR.

Date	σ_1 (approx E-W)	σ_2 (approx VERT)	σ_3 (approx N-S)
30 August '76	33	5	3
21 October '76	58	6	-5
18 February '77	56	26	25

A number of rod extensometers were installed, in August 1976, to monitor dilation of the pillar. Most of these were read manually on a periodic basis by mine personnel. As such they provided a means of keeping track of the magnitude of deformations, but not necessarily of being able to locate precisely, in time, the point at which sudden movements occurred. For this specific purpose, one extensometer was fitted with a continuous deflection transducing and recording system (DC-LVDT attached to analogue chart recorder).

The overall history of pillar stability can be observed from the extensometer results (Fig. 10). For the period of active mining up until the end of October all extensometers revealed an approximately linear pillar dilation of modest mganitude, that can be attributed to the quasi-elastic response of the pillar to the increase in E-W compression generated in the pillar by mining. The period between the end of October 1976 and February 1977 is typified by two pronounced jumps in dilation, corresponding to episodes of violent pillar failure, with an intermediate phase of steadily increasing dilation occurring at an accelerated rate relative to the movements prior to October 1976. This mode of behaviour is consistent with the mechanism postulated previously, with two distinct large scale pillar failures occurring about the end of October 1976 and approximately mid January 1977. Soon after the event of January 1977, the pillar reached a stable condition with negligible further dilation. This implies that the event in January eventually resulted in the pillar reaching a stable condition.

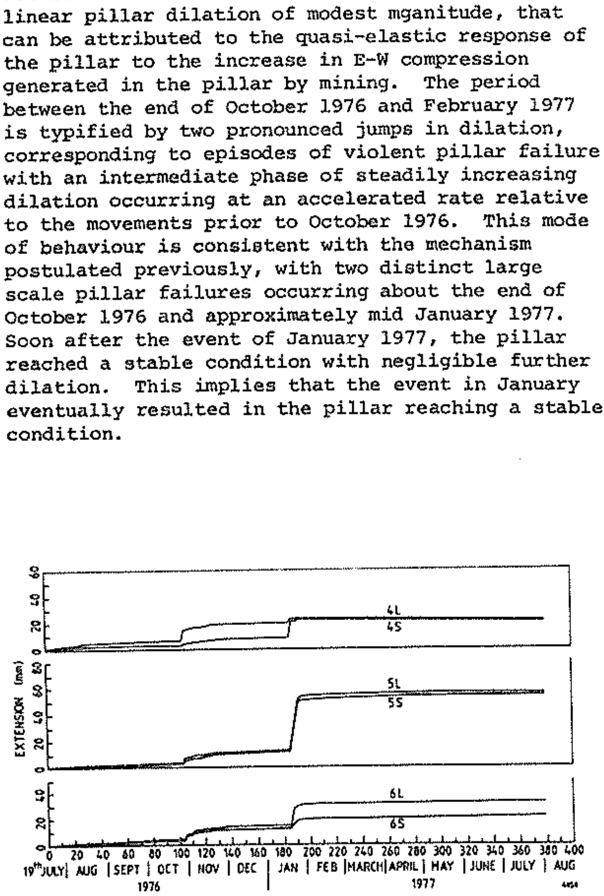

Fig. 10. Pillar dilation measured on the west side of the Panel 10 crown pillar. Two extensometers per hole S:shorter, L:longer.

In order to identify precisely when the pillar was displaying seismic activity, a CSIRO microseismic detector was installed in the pillar near to the anchor location of the extensometer fitted with the continuous recording system. Microseismic noises detected by the device were transmitted to a recording station located on 12 level, where a CSIRO "count rate converter" was used to filter out background noise below a frequency of 10 kHz and then to convert each remaining analogue signal to a digital count representative of the intensity of the signal. The principle of operation is illustrated in Fig. 11 for a microseismic noise recorded from the 10 Panel crown pillar. The total cumulative count for repeated noises detected in the crown pillar was displayed in analogue format on the same chart recorder that was used for the continuous record of deformation, on the same time base. This meant that periods of high activity in the pillars, which appeared as high count levels, could be directly compared with the occurrence of deformations.

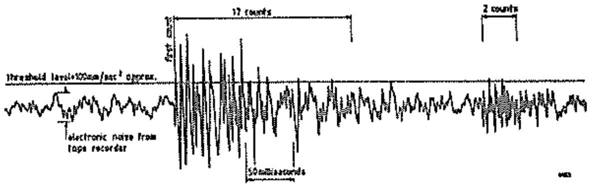

Fig. 11. Typical microseismic noise, recorded in Panel 10 crown pillar at 23.05 h 29 October, 1976 showing principle of noise counting.

A single National Coal Board rigid inclusion stressmeter was installed, in early November 1976, to monitor changes in the vertical stress component in the upper portion of the pillar. The aim of this was not so much to gain a complete understanding of the changes occurring in the total state of stress, but to be able to record, in time, for purposes of correlation, the occurrence of sudden changes in stress.

Figure 12 shows the combined results of the continuous monitoring for the period, November 1976 to February 1977, with displacement, change in vertical stress and cumulative noise count displayed on the same time scale. The pronounced changes in all quantities recorded early in the period of monitoring may be attributable to the after-effects of the activity known to have occurred around the end of October. The equipment had not been operating long enough, however, to get a reliable record of the complete behaviour. There was certainly some evidence of a specific event of pillar failure occurring on 15 November. This event was not nearly as significant, however, as the major event that occurred on 21 January, 1977 for which a complete record was obtained.

At this time all quantities showed a dramatic increase. Pillar dilation increased by approximately 50 mm, and at the same time a very large increase in vertical stress was observed. The interpreted magnitude of this latter change was considerably greater than the net change in the approximately corresponding stress component indicated by the absolute stress measurements. This discrepency was most likely the result of the application of an incorrect calibration factor for the interpretation of stress changes from the stressmeter strain changes. This discrepency in the magnitude of the stress change has not been satisfactorily resolved. The important aspect is, however, that an increase in vertical stress of significant magnitude was noted to occur contemporaneously with the pillar failure, after which, for the relatively short period of monitoring remaining, the stress appeared reasonably constant (as did displacement and noise count). This behaviour is consistent with the mechanism postulated previously in which it was the event of January 1977 which eventually marked the advent of pillar stability.

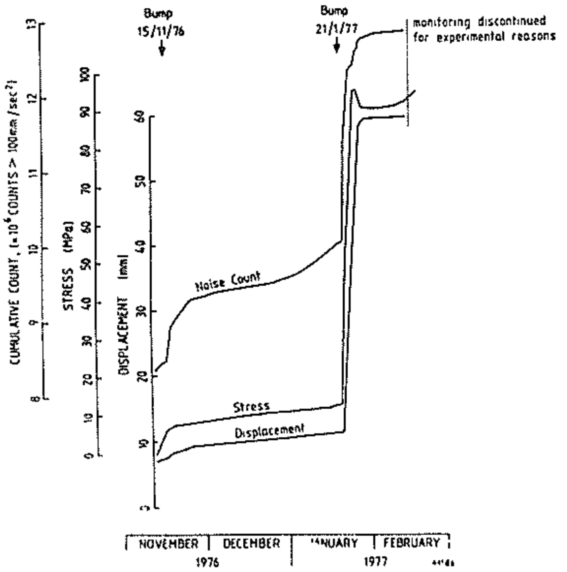

Fig. 12. Extensometer movement, vertical stress and noise measured in Panel 10 crown pillar.

Figure 12 shows clearly that the sudden jump in noise count that occurred as a result of the event of January 1977 was preceded by a significant period in which the background noise count rate noticeably increased (at least one week) without corresponding acceleration of stress and displacement. For approximately half an hour immediately prior to the event, the noise count was observed to drop to a negligible level. This form of behaviour has been previously observed in relation to microseismic monitoring overseas (Leighton and Steblay, 1975) and is currently being used as one of the bases for microseismic warning systems.

4 CONCLUSIONS

From the results of the two monitoring programs described, a number of specific observations were made in relation to the performance of crown pillars in the particular mining situations concerned. Such conclusions are, by their nature, of greatest significance in the context of the relevant mining situations and have already been discussed. There were, however, some aspects of general interest. In the broadest possible sense, the following points can be made:

(a) High compressive stresses, close to the relevant uniaxial compressive strength of the rocks involved, appeared to be the primary cause of instability at both mines. The situation was influenced in each case by local factors such as geology and mining practice.

(b) The major stress in both cases was the east-west component. Both in the Mt. Isa and Broken Hill areas the major tectonic stress is in the E-W direction (Worotnicki and Denham, 1976) and the orientation of the orebodies and/or stopes was such as to cause a further concentration of the E-W stresses in the pillars.

(c) Pillar stability appeared to be affected by pillar geometry. The squat pillar (normal to predominant loading) at Mt. Isa showed evidence of being relatively more stable (small dilation) than the approximately equidimensional pillar produced in Panel 10 (relatively large dilation).

(d) In both situations, the investigations helped to gain a more quantitative understanding of pillar behaviour and to judge their relative state of stability. For the range of instrumentation employed, the following comments can be made:

  (i) Absolute stress measurements (particularly employing the CSIRO hollow inclusion cell) proved universally effective.

  (ii) Stress change monitoring proved useful, but refined and more reliable instruments are required before the technique could be used on a routine basis.

  (iii) Deformation monitoring techniques are well established and relatively reliable. As demonstrated, however, dilation cannot always be relied on as a precursor of failure. Pillars with squat geometries (e.g. Mt. Isa) may not exhibit significant dilation prior to reaching critical stress levels.

  (iv) Microseismic monitoring showed positive indication of potential value as a practical tool for giving warnings of imminent violent failure (marked count rate decrease) and possibly as a means of giving long range forecasts (increase in count rate) enabling remedial action to be attempted (reinforcing, destressing). Considerably more work is required to develop the full potential of the technique. Variations including local and regional systems employing various frequency ranges are possible. The promise shown by this technique has led Mt. Isa Mines to install a comprehensive rock noise location system in the area of the Racecourse Orebodies (Godson, Bridges and McKavanagh, 1978) as the most cost-effective way of monitoring an extensive area.

  (v) The ultrasonic wave propagation technique gave some evidence of being able to monitor pillar cracking, and may be able to be developed to a stage of becoming a practical tool. Operational complexity and the localised nature of the technique, however, means that even if developed it will probably only ever be useful for application in specific areas of great importance and would not be able to compete with the wider application possible with the microseismic technique.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

ENEVER, J.R. (1977). Stress change monitoring in the crown pillar beneath 11 Level, 8 Orebody cut-and-fill stope Racecourse area, Mount Isa. CSIRO Div. Appl. Geomech. Support and Stabilization of Stopes Project Report No. 17.

ENEVER, J.R, McKAVANAGH, B.M. and CARSON, G.H. (1977). Some applications of instrumentation in the Australian mining industry. Proc., Int. Symp. on Field Meas. in Rock Mechanics, Zurich, April, pp. 47 - 60.

GODDARD, I.A. and BRIDGES, M.C. (1977). Development in lead-zinc mining methods at Mount Isa, Australia. Proc., SME Conf. on lead-zinc Update, St. Louis, USA.

GODSON, R.A., BRIDGES, M.C. and McKAVANAGH, B.M (1978). A 32 channel rock noise location system. Proc., 2nd Conf. on Acoustic Emission/Microseismic Activity in Geological Structures and Materials, Univ. Pennsylvania, Nov.

LEIGHTON, F. and STEBLAY, B.J. (1975). Coal mine bounce and roof fall research. Proc., 1st Int. Conf. on Acoustic Emission/Microseismic Activity in Geological Structures and Materials, Univ. Pennyslvania, Nov. pp. 104 - 119.

McKAVANAGH, B.M., ENEVER, J.R., SIGGINS, A.F. and McKAY, J. (1978). Evaluation of the microseismic technique applied to outburst prediction at Westcliff Colliery, CSIRO Div. Appl. Geomech Geomechanics of Coal Mining Report No. 4.

McKAVANAGH, B.M. and LEE, M.F. (1979). Ultrasonic velocity measurements in the 8 Orebody crown pillar, 11 Level, Mount Isa Mine. CSIRO Div. Appl. Geomech. Technical Report No. 81.

McKAVANAGH, B.M., TILLMAN, V.H., ALEXANDER, L.G., and ENEVER, J.R. (1979). Stress, noise and displacement monitoring of Panel 10, Crown Pillar, NBHC. CSIRO Div. Appl. Geomech. Technical Report No. 101.

MILLER, D.R. (1977). Strength and deformability of rock materials from the crown pillar 11 Level, 8 Orebody, Mt. Isa Mine, Qld in triaxial compression. CSIRO Div. Appl. Geomech. Support and Stabilization of Stopes Project Report No. 24.

SPATHIS, A. (1978). Experience with a fast automatic data acquisition system in the 8 Orebody crown pillar on 11 Level, Mount Isa Mine. CSIRO Div. Appl. Geomech. Support and Stabilization of Stopes Project Report No. 36.

WOROTNICKI, G. and WALTON, R. (1976). Triaxial hollow inclusion gauges for determination of rock stresses *in situ*. Proc. ISRM Conference on Advance In Rock Stress Measurements, August, Sydney.

WOROTNICKI, G. and DENHAM, D. (1976). The state of stress in the upper part of the earth's crust in Australia according to measurements in mines and tunnels and from seismic observations. Proc. ISRM Symposium on Advances in Rock Stress Measurement, Sydney, August pp. 71 - 82.

WOROTNICKI, G. and WALTON, R.J. (1977). Rock stress measurements in a crown pillar - 11 level, 8 Orebody Racecourse area, Mt. Isa Mine. CSIRO Div. Appl. Geomech. Support and Stabilization of Stopes Project Report No. 19.