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Horizontal Pillar Extraction at Mt. Isa Mines Limited

—Some Rock Mechanics Aspects

By

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SUMMARY AND ABSTRACT.— Sublevel caving in rib pillars in the 650 Copper orebody allowed excessive dilution of ore. For horizontal pillar extraction after encouraging photoelastic analysis a series of cut and fill stopes 12 ft wide using ringblasting and cemented fill, and leaving temporary transverse pillars proved successful. Subsequently the temporary pillars up to 42 ft wide were extracted. Crown pillars 10 ft thick (and sometimes 20 ft) provided safety from filled stopes above. Stability measurements of levelling and convergence and with borehole extensometers indicated high stress values, but the deterioration which occurred did not lead to collapse.

In preparation for sublevel stoping of pillars above old cut and fill stopes in the 8, 9 and 10 lead orebodies, finite element and photoelastic two dimensional analyses were made, and indicated extremely high stress concentrations. To overcome limitations of two dimensional analyses a three dimensional physical model, highly instrumented, was tested and indicated less extreme conditions. Subsequent extraction bore out the practicability of sublevel stoping beneath the narrow wedge of ore forming the crown pillar. Fracturing was observed, but no serious instability resulted, but due to fill breakthroughs from above 30 percent of drawpoints were abandoned prematurely. Extensometers and stress meters monitored the initial slotcutting and subsequent stoping and showed greatest ground adjustments on shotfiring. Some correlation was found between these measurements and the prior finite element analyses, although both analytical methods indicated stress much higher than experienced in practice. Lack of detail in the physical model apparently gave higher strength and prevented some crown pillar failures which occurred in practice.

I.— INTRODUCTION

Remnant pillar extraction has always been one of the more interesting activities in mining due to the higher than normal stress levels encountered. Adequate planning involves ensuring that pillar extraction design must be part of the overall mining design in an area if recovery is to be optimised. Two examples of pillar extractions will be given which were not integrated into the initial planning stage but, which having proved successful, can now be used on a repetitive basis.

II.— HORIZONTAL PILLAR EXTRACTION 'A' 10 LEVEL COPPER STOPES, 650 OREBODY

(a) Extraction Method

Sublevel caving had been used to extract vertical rib pillars and a section of the 10 level floor pillar, but the degree of recovery of the broken ore was found to be severely dependent upon the distribution of copper slag in the dry fill used to fill the original void. This fine material filtered through very quickly after firing causing unacceptable dilution. Most of the remaining 10 level floor pillar had slag immediately overlying it, so another method of extraction was designed for this section.

Transverse stopes were extracted in the pillar leaving a thin shell of ore intact to prevent dilution, with filling of these stopes with cemented fill immediately after mining (Ref. 1). The remainder of

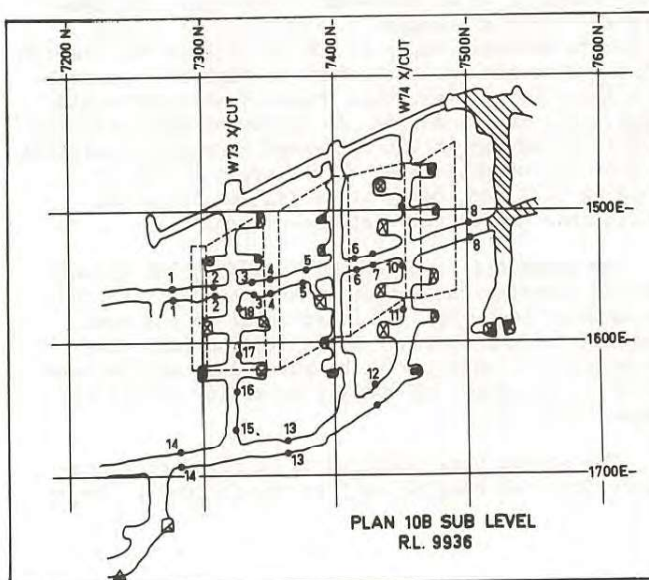


Fig. 1 Plan of 10B sublevel 650 copper orebody.

the pillar between the filled stopes could then be extracted by a method dependent upon the experience gained in the initial extraction.

The pillar to be extracted was approximately 200 ft in strike length and between two vertical pillars. Stope No. 1 (Figs. 1 and 2) had its southern wall at the northern limit of the 7250N vertical pillar and stope No. 8 had its northern wall at the southern limit of the 7550N vertical pillar. The eight transverse stopes were 12 ft wide with a pillar of approximately 15 ft between each stope in the initial design but this was subsequently modified (see later).

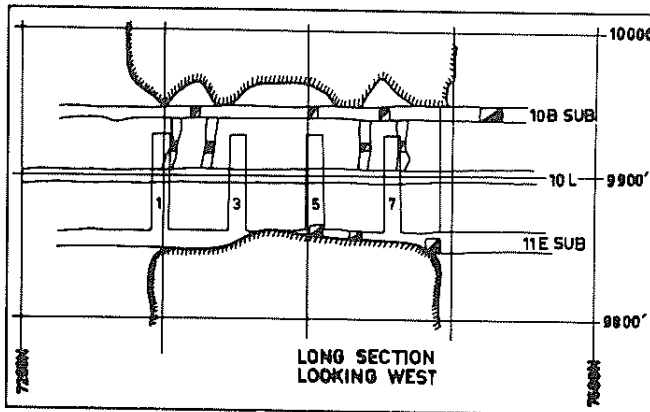


Fig. 2 Long section, looking west, of pillar extraction area.

A 10 ft thick (minimum) crown pillar was left below 10B sublevel as a support to prevent dilution to fill from the grizzlies of the stopes above. It was realized that at some stage of the extraction this crown pillar would be stressed well above the rock strength in an East-West direction. The laboratory uniaxial compressive strength of silica dolomite averaged about 21,000 psi and it was through that due to the massive nature of this rock comprising the floor pillar, this order of strength would be applicable in the field. It was hoped that cracking due to stressing in the East-West direction would not reduce the effectiveness of the crown pillar in holding fill vertically above it, and the crown would span effectively between stopes.

Cemented fill requirements included the potential of carrying the weight of the crown pillar and an arch of loose fill at least equal to the span between initial stopes. Stope heights (and thus cemented fill unsupported heights) were approximately 80 ft to in excess of 100 ft, depending on cut off grade (Fig. 3).

The stopes were designed to be fired progressively from the hanging wall to the footwall. Rings

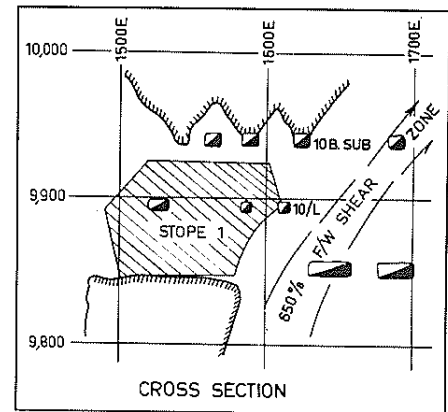


Fig. 3 Cross section on stope 1, 650 orebody.

drilled in north-south vertical planes were fired back until slashing rings drilled in east-west vertical planes could be fired. Slushers and LHD units were used to extract the fired ore on 11E sub.

(b) Model Work

A photoelastic examination was made of the area in an attempt to arrive at an optimum stoping sequence from the viewpoint of ground stresses. Two photoelastic models of various stope extraction sequences in plan were tested. The average east-west stress on the pillar was estimated to be 6500 psi, and the 'in situ' uniaxial compressive strength was taken to be 15000 psi with the tensile strength at 2500 psi. The models were cut from $\frac{1}{2}$ in. thick sheets of Columbia Resin No. 39, being $11\frac{1}{2}$ in. square and loaded uniaxially in a direction at about 20° to the long axis of the stopes.

Analysis of the first model was carried out in two stages.

First stage - stopes 1, 3, 5 and 7 out (Fig. 4)
Second stage - all stopes out.

In the second model, analysis was carried out in four stages.

First stage - stopes 4 and 5 out.
Second stage - stopes 3, 4, 5 and 6 out.
Third stage - stopes 2, 3, 4, 5, 6 and 7 out.
Fourth stage - all stopes out.

The models were each loaded to two 'fringes' and stress concentration factors calculated at the

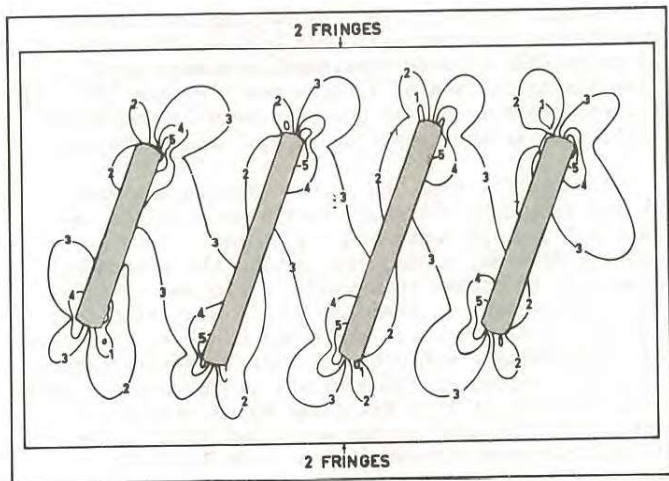


Fig. 4 Photoelastic fringe pattern, first stage of first model.

mid span of the pillars together with the maximum and minimum stress concentration factors. The maximum values were usually at the NW-SE corners and the minimum values on the opposite diagonal.

Conclusions drawn from the photoelastic work were:-

- (i) The extraction sequence in the first model produced lower stress concentrations for a greater part of the extraction sequence than that in the second model.
 - (ii) The north west and south east corners of the stopes would exhibit scaling effects and audible microseismic activity would take place at an early stage with each sequence. This was not noticeable in practice.
 - (iii) The rock tensile strength would be exceeded at the north east and south west corners of the stopes. This would cause vertical cracking roughly perpendicular to the bedding. Again this was not immediately apparent in practice but could have been hidden by cracking due to blasting.
- (c) Movement Monitoring

It was recommended that no delay took place between emptying a stope and filling it with cemented fill. It was not anticipated that the wide zone of shearing to the footwall of the orebody would have much effect on the operation. Development cross sections were to be kept to a minimum and bolted in an attempt to reduce ground failure effects. In practice, some trouble was found in development on 11E sub in that the ground of the back of Z74-75 stope was very broken with flat dipping cracks at right angles to the general bedding plane dip predominating. As the crosscut development for 1, 2 and 3 stopes neared the hanging wall one of these partings was followed and used as the back of the crosscut. This increased the height of the drive but provided a more stable excavation. The lower parts of the pillars between the extraction crosscuts of Nos. 1 to 4 stopes were very broken near the hanging wall, while between 3 and 4 stopes an opening appear-

ed in the wall due to development firings. There was no difficulty rockbolting the backs, but the broken walls could not be completely bolted. Further north the development was in more competent ground.

Movement measuring stations were set up on 10B sub in the crown pillar above the stopes (Fig. 1) and in the vertical pillars to the north and south on 10 level in order to monitor ground behavior. Extensometers and a self adjusting parallel plate level giving measuring accuracies of ± 0.01 inch were used.

Extraction of 1,3,5 and 7 stopes produced unusual levelling rises possibly due to tilting of blocks in the two crosscuts (Figs. 5a and 6a). Measurements in the crosscuts were not possible after these initial stope extractions due to difficulty of access. Generally east-west compressions were measured with the extensometer due to this extraction the order of movement being quite low (Figs. 5b and 6b) but in excess of what would be expected from a purely elastic situation. Stress increases of approximately 40,000 psi could be calculated using a rock modulus of 10^7 psi.

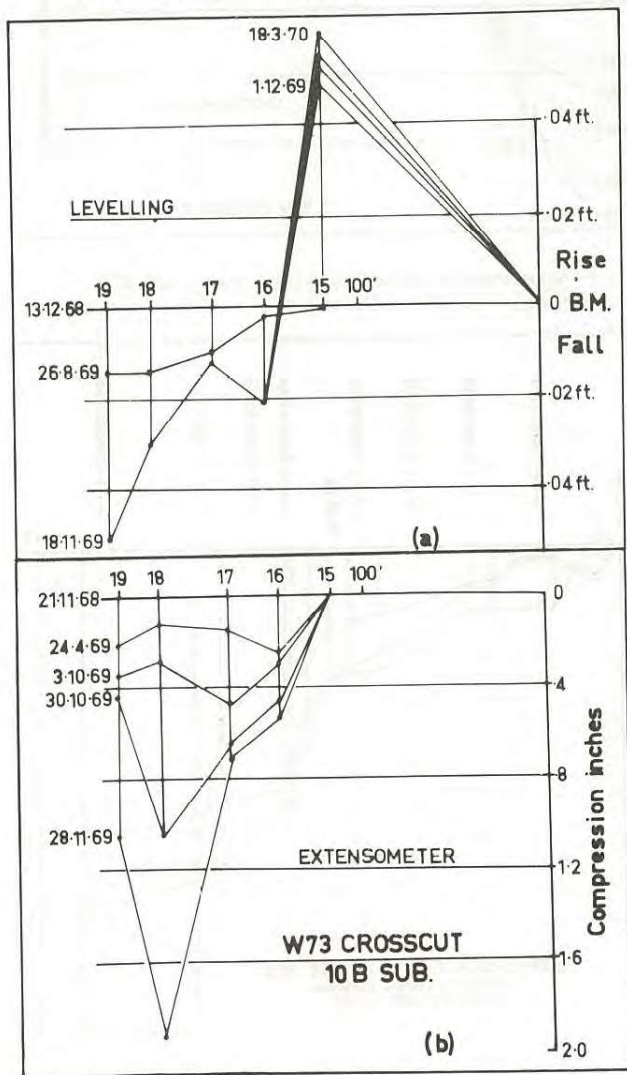


Fig. 5 Extensometer and levelling results, W73 crosscut, 10B sublevel.

Visible cracking occurred between stations 17 and 18 after the extraction of stope 3 but not after the extraction of stope 1. This cracking was comparable to that described previously as being in the back of the stopes below 10 level, that is, flatly dipping to the east and roughly perpendicular to the general bedding direction. Thus the capacity of the crown pillar to span north-south was not affected.

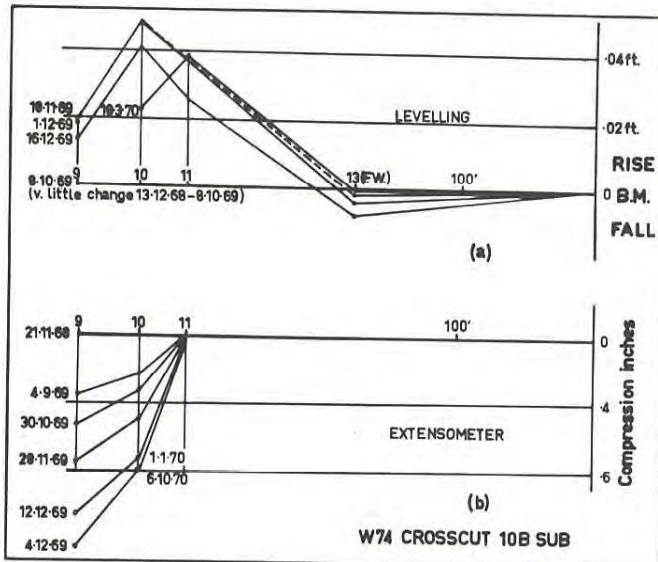


Fig. 6 Extensometer and levelling results, W74 crosscut, 10B sublevel.

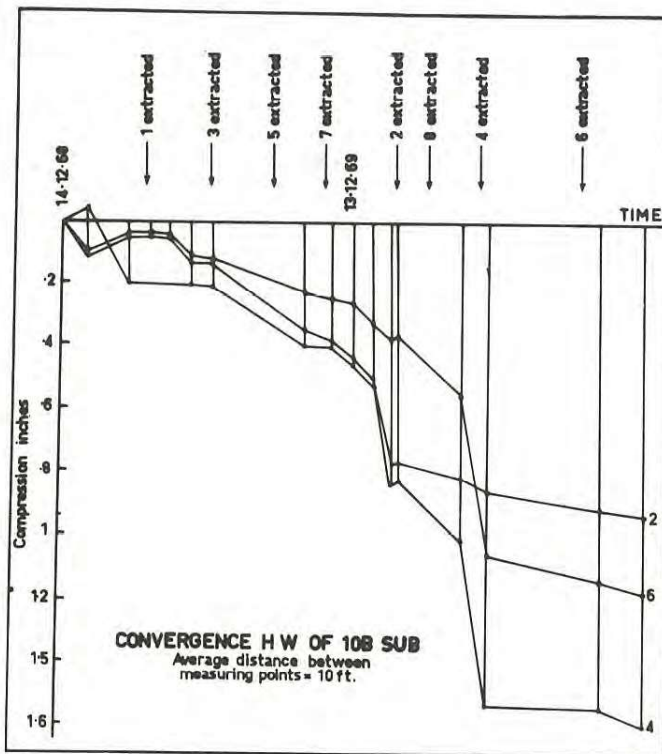


Fig. 7 Extensometer convergence measurements - hanging wall drive 10B sublevel.

It will be noted that the hanging wall drive convergence, measured east-west between the sides of the drive did not show considerable change until after the extraction of 1, 3, 5 and 7 stopes (Fig. 7). This was probably due to the considerably increased strike span of the remaining 2, 4, 6 and 8 stopes.

A variation from the initial design was made for the secondary stopes in that a proposal to extract all the ore between 1 and 3 stopes leaving cemented fill walls was made, giving the subsequent stope a 42 ft north-south width. This was successfully carried out in practice but it was noted that when the east-west stope width was 80-90 ft considerable microseismic activity and visible deterioration suddenly occurred on 10B sublevel in the hanging wall area. Because of this No. 4 and No. 6 stopes, although of the same strike width had their crown pillar thickness increased from 10 ft to 20 ft minimum dimension. These were also successfully extracted but again with signs of increased deterioration at stope widths of 80-90 ft. No. 8 stope design was not altered and gave little trouble since it was abutting onto a vertical pillar.

The increase in east-west stress necessary to produce the observed deformation in the hanging wall drive was estimated to be about 40,000 psi assuming a field elastic modulus of 10⁶ psi. Some spalling of the roof occurred in this drive to a depth of about 1 ft but no cracking of the sides was observed.

(d) Conclusions

Although fractured near its hanging wall side after the primary stope extractions the crown pillar successfully prevented fine fill from entering subsequent open stopes spanning 42 ft by 100 ft area. Monitoring of ground movements indicated that most deterioration occurred during the extraction of the secondary stopes. Stress increases in the crown pillar were equivalent to 30,000-40,000 psi if a rock modulus of 10⁶ was assumed.

III.- HORIZONTAL PILLAR EXTRACTION 'B' 8, 9 AND 10 LEAD OREBODIES, 9 LEVEL

(a) Extraction Method

Upper limits for cut and fill mining were reached in Nos. 8 and 9 hanging wall lead orebodies at about 75 ft below 9 level due to localised ground falls resulting from high stressing. This occurred earlier than anticipated probably because of an under-estimation of the stress level which was based on the weight of superincumbent rock. Calculation showed that a 50% recovery of pillar ore in all orebodies would be equivalent to a new orebody.

The sublevel stoping method proposed to recover the horizontal pillar is shown in Fig. 8.

Transverse cut off slots were to be developed at about 80 ft intervals along strike. The remaining ore would be fired to expand into the slots. A vital requirement was that a narrow wedge of ore immediately below the hydraulic fill in the stopes above 9 level remained intact and prevented dilution from this fill. Due to the attractive economics of the method, in that all metal above that extracted for cut off slots was clear profit, and the potential repeatability of the operation in other orebodies, additional investigation programmes were pursued.

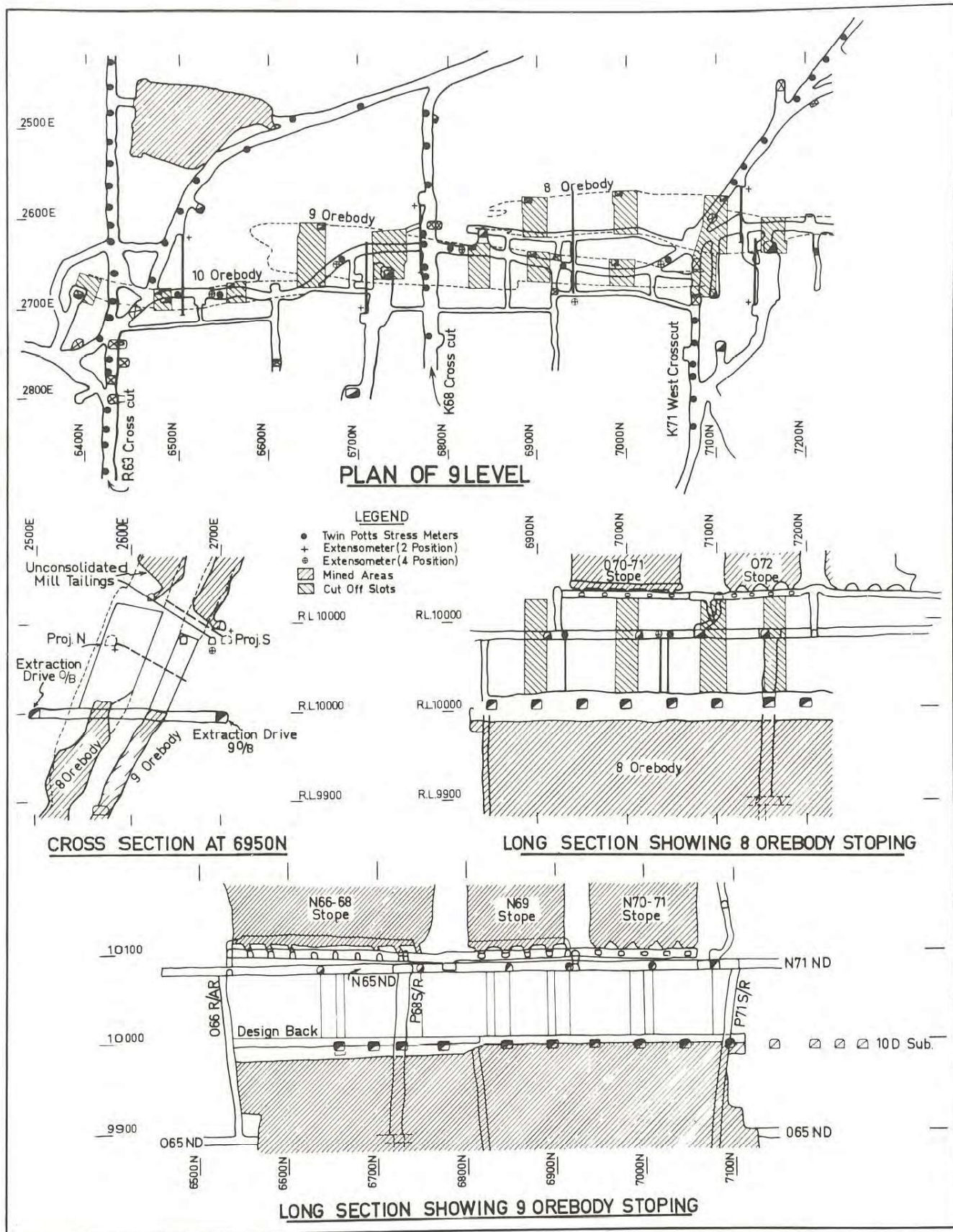


Fig. 8.

(b) Model Tests

Three models of the area were made of the extraction to investigate stability. Firstly, a two dimensional finite element model was constructed with loading perpendicular to the bedding about 1.4 times that down the bedding. The effect of extracting the pillar upon stresses and displacements in an isotropic elastic medium defined by a modulus of 10^7 psi and Poissons ratio 0.25 was determined. Compressive stresses of over 40,000 psi for an applied stress perpendicular to the bedding of 2500 psi were found on the immediate underside of the wedge so that plastic flow or failure was expected here. It was realised however that this two dimensional model did not take into account the finite strike length of the orebodies or the effects of vertical pillars in 8 and 9 orebody stopes above 9 level (see also comparison between actual and calculated displacements on 9 level in section on monitoring). A photoelastic model, also in two dimensions, was made to investigate stresses due to pillar extraction with comparable results but even higher stress concentrations on the wedge.

A physical model was also constructed by the Australian Coal Industry Research Laboratories (ACIRL) to determine the feasibility of design and the stress distributions as the respective orebodies were mined. The model scale was 1 in 148 with stresses applied being 2500 psi normal to bedding, 1400 psi down bedding and 1900 psi horizontally along bedding. A full report of the model test is given in Ref. 2. The main conclusions drawn were:-

- (i) The formation of expansion slots for the mass firing was a feasible procedure. The stability of the openings and the pillars surrounding them was excellent and no troubles were likely to occur at this stage. This was borne out in practice.
- (ii) Longitudinal separation parallel to the bedding coupled with a transverse break on the 8 orebody side occurred in the footwall of 9 orebody at 7200N in the model. Some fracturing of the diaphragm between 8 and 9 was noted in practice but little damage occurred at 7200N.
- (iii) Most of the 50 strain gauges incorporated in the model indicated stresses well below 20,000 psi which was the maximum recorded. The general impression gained from the model was that high stressing would not occur and this was borne out in practice except that the northern abutment of the area gave some audible microseismic effects for one week after the firing.
- (iv) The planned wedge dimensions seemed more than adequate in the model but possibly fill arching took place in the model which did not occur in practice since a fill breakthrough actually occurred immediately after firing in the widest part of the extraction at 6600N. Seven of the twenty three drawpoints had to be abandoned prematurely. In the model, fill was exposed in places but did not run.
- (v) An important factor in wedge stability would be jointing but this unfortunately could not be

incorporated in the model.

Overall, the model gave a reasonable assessment of the situation as found but probably over-estimated wedge stability by omitting the finer structural features.

(c) Monitoring of Ground Movements and Stresses

Devices installed to detect strain changes as a result of slot cutting were as follows:-

- (i) Two position extensometer installations to monitor change in strain across the pillar.
- (ii) Four position extensometer to monitor changes in strain down dip in the pillar.
- (iii) Twin 'Potts' stressmeter installations between each slot with blades located on strike and at 90° .

The latter showed little change and the majority were damaged before and during slot cutting. The extensometers showed movements of $\frac{1}{2}$ in. compression across the pillar due to slot cutting and are thought to be of little significance and so are not reported here.

Of more interest were the levelling and extensometer measurements taken in R63, K68 and K71 on 9 level (see Figs. 9 and 10).

The results in R63 and K71 crosscuts are shown in Fig. 9 and give the difference between immediately before the firing and immediately after the firing. These crosscuts were in the south and north abutments respectively and appear to indicate different behavior vertically as R63 hanging wall area rises but K71 falls while R63 footwall rises close to the extraction area while K71 has a pronounced fall. Horizontal movement trends are similar however with the larger extraction width at K71 possibly causing the larger order of movement at this location.

K68 crosscut, being approximately on the centre line of the extraction might allow a comparison with the movements calculated from the finite element model. Such a comparison is made in Fig. 10. Some correlation was achieved in that the same directional trends of movement were observed on the hanging and footwalls as were indicated by the model.

(d) Conclusions

The stresses estimated by finite element and photoelastic models seemed to be too high, possibly because of the three dimensional nature of the problem involving incorporation of vertical pillars. The lower deformations than obtained in practice of the finite element model may be due to too high a modulus being assumed.

The physical model could be deemed a fair assessment of reality but by not incorporating the finer structures in the shale the wedge stability was over-estimated.

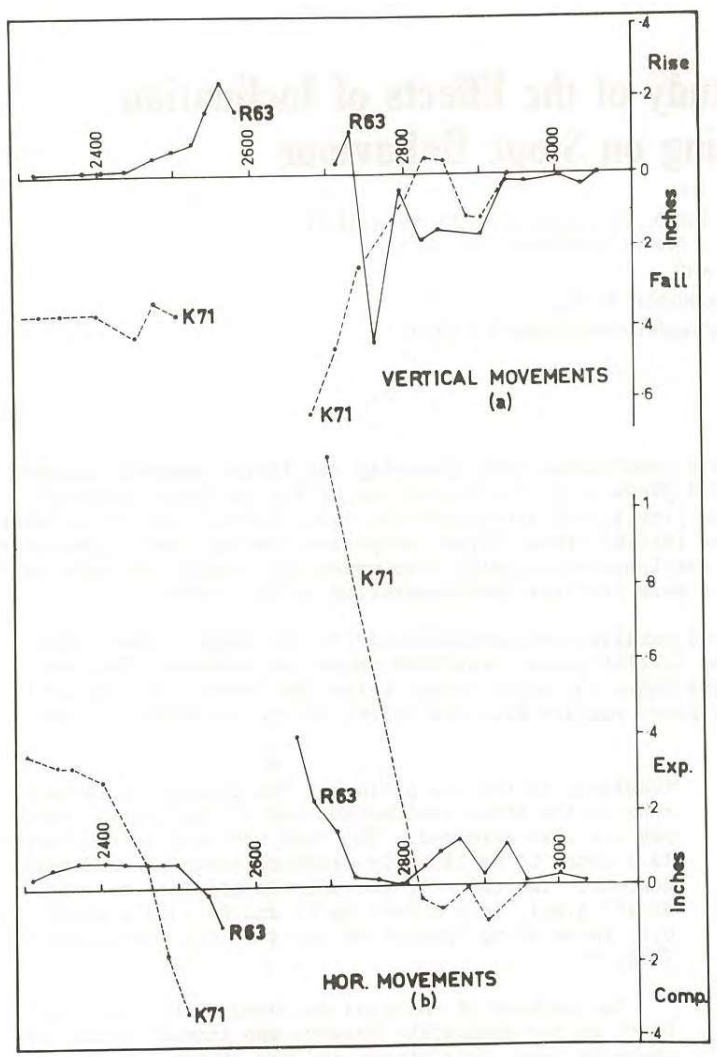


Fig. 9 Levelling and extensometer results, R63 and K71 crosscuts, 9 level.

IV.- ACKNOWLEDGMENTS

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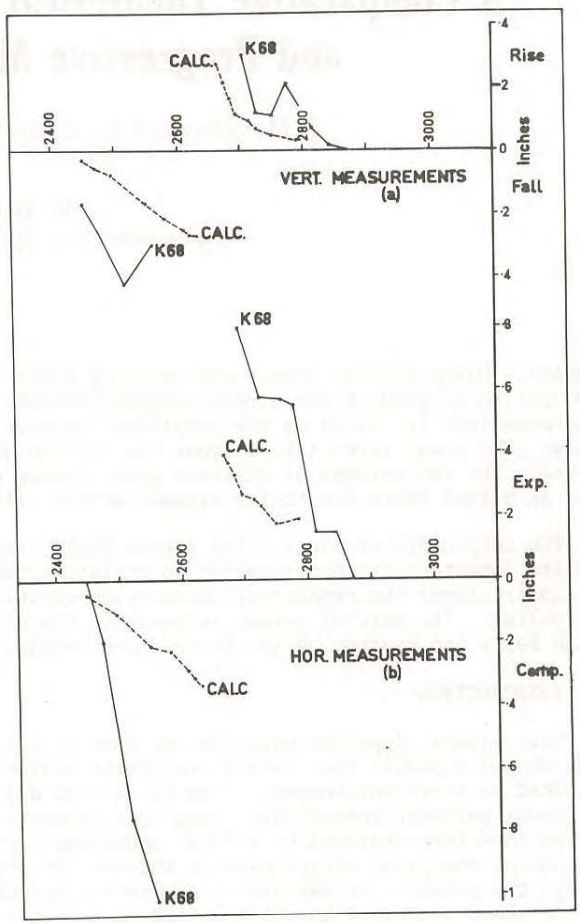


Fig. 10 Extensometer and levelling results K68 crosscut and comparison with finite element calculated movements.