Deformation and Behaviour of High Rise Filled Stopes at C.S.A. Mine, Cobar, N.S.W.

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SUMMARY. Measurements at Cobar C.S.A. Mine (N.S.W.) were made of stresses and deformations in the backs and walls of main stopes and in the stope fill to assess the safety of backs and walls, and to study the behaviour of the rock mass. The observations are compared with predictions for elastic intact homogeneous material, and the similarities with and departures from the predictions are discussed. Some new instruments were developed for the determination of pre-mining stresses, for observations of strain in the rock and settlement of fill.

1 INTRODUCTION

On behalf of the Australian Mineral Industries Research Association, the Division of Applied Geomechanics of the Commonwealth Scientific and Industrial Research Organization carried out an investigation into the parameters affecting the behaviour and safety of high rise cut-and-fill stopes. As a specific subject of study, the C.S.A. Mine of Cobar Mines Pty. Ltd. was chosen at which several lenticular steeply dipping orebodies, located en echelon, are mined by a mechanised cut and fill method.

The stopes are generally from 5 to 20 m wide, and up to 360 m long; in the eastern and western orebodies coplanar 180 m high stopes will be mined one above another separated by approximately 15 m high crown pillars. The main stopes are wider and higher than those previously mined by cut and fill methods in Australia, and those which have been studied elsewhere (Refs. 1, 2, 3).

In a previous paper, Aitchison et al (Ref. 4) presented aspects of the investigation concerned with the functions, properties and behaviour of fill at this mine. The present paper deals with the behaviour of the rock around the mine openings and the rock-fill interaction and comments are made on the performance of a range of instruments (some recently developed) for in situ observation.

2 DESCRIPTION OF THE C.S.A. MINE

The C.S.A. Mine orebodies occur as sub-parallel zones of mineralisation in a fairly uniform sequence of chloritic slates, quartzites and siltstones (Fig. 1)(Ref. 5). Most of the local bedding planes dip steeply to the west and the main cleavage dips at 75 degrees to the east. Both features are evident in all but the strongly mineralised areas of the mine. Intense shear zones, associated with the cleavage, often occur in areas adjacent to the orebodies, and a set of sub-horizontal joints, filled and unfilled, can be traced in the country rock and mineralised area.

The oreshoots appear as veins of chalcopyrite, pyrrhotite and pyrite in slates, or as a fine-grained homogeneous mixture of pyrrhotite, galena, sphalerite, chalcopyrite and pyrite in siliceous siltstones. The individual orebodies dip east at approximately 75 degrees and pitch northward at 8(' degrees. The length usually lies between 60 and 360 metres.

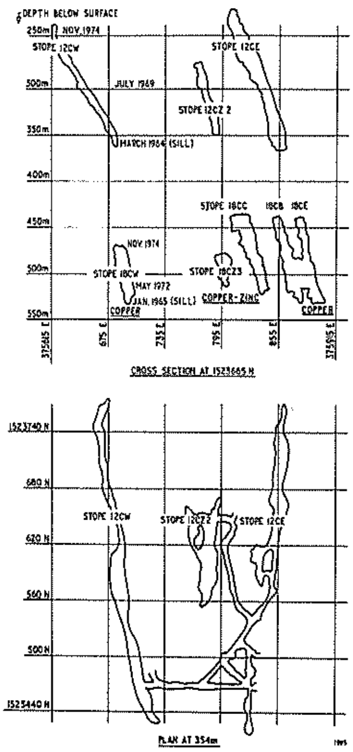

Fig. 1 Layout of stopes at the C.S.A. Mine

Most of the C.S.A. orebodies are currently mined as cut and fill stopes over their full strike length taking lifts 4.5 m high. The stopes were silled at approximately 360 m and 540 m below surface (Fig. 1). Hydraulic fill is obtained by cycloning the sand tailings from the concentrator to remove the 10 μm clay size fraction. The details of the method can be found in Refs. 6, 7, 8.

3 ROCK PROPERTIES

The rock properties found in laboratory and in situ tests are summarised in Table I, and show a large variation over the area of the mine.

4 PLANNING ROCK MECHANICS INSTRUMENTATION

Three considerations influenced the planning of the rock mechanics instrumentation at the C.S.A Mine:

(i) The instrumentation should be directed towar.

TABLE I

ROCK PROPERTIES

Elastic Modulus

Test	Mean GPa	Std. Dev. GPa	Orientation
Uniaxial compression tests (Ref. 9) on 137 NX specimens from 400 to 420 m levels (airdry)	78	14	Vert. : NS : EW No correlation
30 flatjack tests 300 to 550 m levels (in-situ)	80 60 50		- North-South - Vertical - East-West
Biaxial compression tests from overcoring tests on 15 cm dia. hollow cores			
Level 245 m	65		
638 m	55		
(water saturated)			
Uniaxial compression tests on 21 NX specimens from			
Level 245 m	40	10	30° to 60° to
638 m	39	-	bedding
(water saturated)			(insufficient data tests continue)

Uniaxial Compressive Strength

Test	Mean MPa	Std. Dev. MPa	Orientation
137 NX specimens from 400 to 420 m levels (Ref. 9) (airdry)	116	32	Vert. : EW : NS 1 : 1 : 0.6
Specimens from			
Level 245 m	45	24	30° to 60° to
638 m	66	37	bedding
(water saturated)			(insufficient data tests continue)

The effect of mineralization in the normal range of ore content was low (Ref. 9).

monitoring the main modes of failure of the rock in the mine.

(ii) The instrumentation should provide a better insight into the behaviour and properties of the rock fill system and provide information for comparison with theoretical predictions of the behaviour.

(iii) Proposals for instrumentation were to comply with the mine production requirements.

Fig. 2 illustrates presumed areas of loosening which influenced the planning of instrumentation and illustrates the layout and types of instruments used in the western stopes of the mine:

(i) Instability of the backs was expected to be associated with dilation along structural defects and high stress levels in the backs.

(ii) Instability of the walls, if any, was expected to commence in the haunches (areas in hanging walls and footwalls adjacent to the back) and to progress outwards as the stope was raised. Wall deflections into the stope were expected to be several times greater than those predicted using the modulus of intact rock despite the supporting effect of the fill. Rock movements in the direction parallel to the stope, in the haunches, were expected to show the passage of a supposed "front-of-loosening".

(iii) Rock stresses in the immediate stope back were expected to be less than for an intact elastic rock mass because of loosening within the backs and walls (as the latter would make the effective width of the stope to intact rock greater than the actual width).

Theoretical analyses, using finite element, complex variable and photoelastic methods, were carried out and used in planning the investigation and for interpretation of observations (Refs. 10, 11, 12, 13, 14, 15). So far all analyses used for the latter purpose were based on the assumption that the rock behaves as an elastic homogeneous material, but programs based on more complex material behaviour have been developed since the commencement of investigations.

The mining cycles at Cobar are long and only a partial assessment of the mine behaviour is made at this stage.

5 PRE-MINING STRESSES AT THE C.S.A. MINE

Pre-mining stresses were measured by the doorstopper method (Ref. 16), a triaxial cell of CSIR/North Broken Hill (Refs. 17, 18) and by parallel measurements using the USBM borehole deformation gauge and hollow inclusion triaxial stress cells (Ref. 19) (Fig. 2, test 12).

The hollow inclusion cells basically consist of thin-walled epoxy pipes in which nine electrical strain gauges are embedded along the circumference (Fig. 3). The cells are cemented into EX size pilot holes and overcored with thin-walled 15 cm outside diameter coring bits. Relaxation strains are observed continuously during overcoring. Cells have been developed for horizontal and up holes and down holes and used successfully since the middle of 1973.

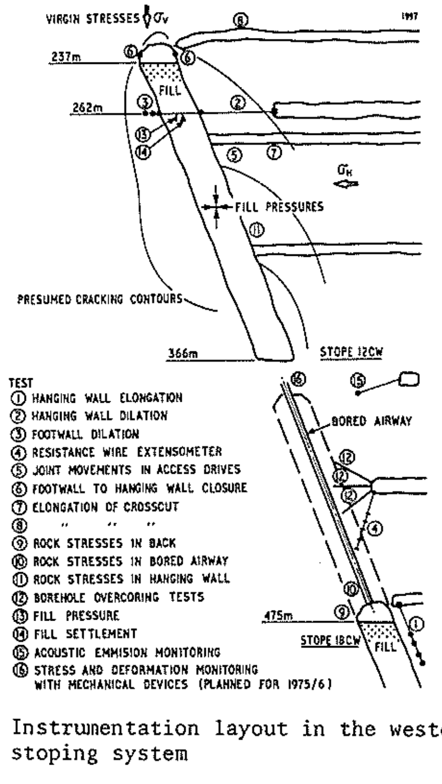

Fig. 2 Instrumentation layout in the western stoping system

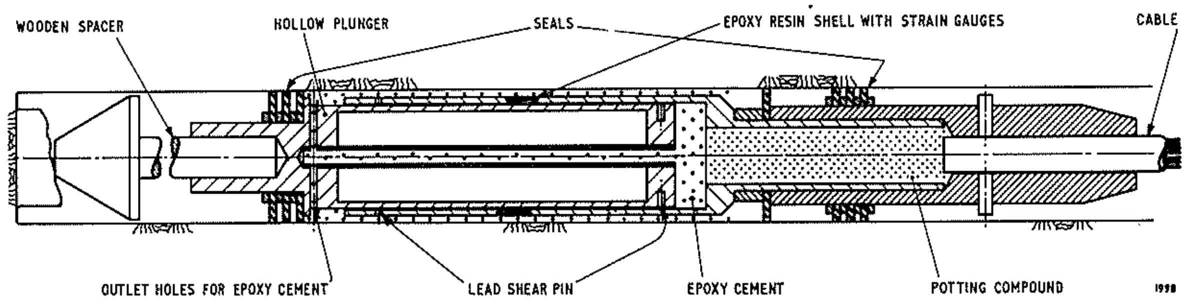

Fig. 3 Hollow inclusion triaxial stress cell

The results of the pre-mining stress determinations carried out at Cobar at different locations in the mine are presented in Fig. 4. The scatter of results is indicative of the variation of rock properties and structure of the rock mass and, taking into account that the tests were carried out over a large area, is not excessive.

All normal stress components at Cobar increase with depth below surface, the horizontal pressures being greater than the vertical and the east-west pressure greater than the north-south pressure. In this last respect, the Cobar field is similar to the majority of areas where stress determinations have been made in Australia (Ref. 20).

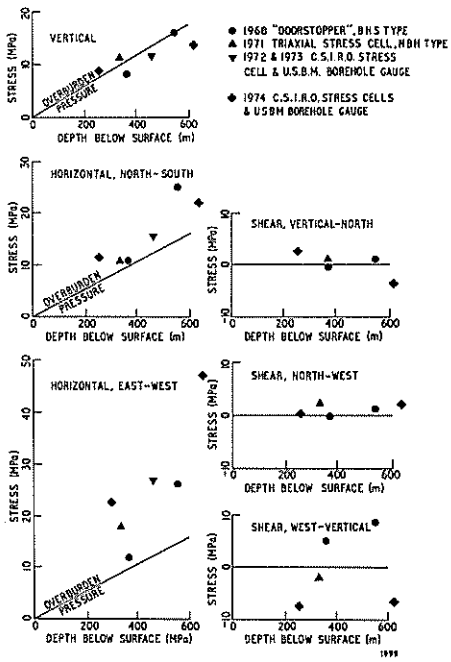

Fig. 4 Pre-mining stresses

6 OBSERVATIONS OF THE ROCK AND FILL BEHAVIOUR IN THE MINE

(a) Measurement of Stresses at the Surface of Mine Openings at C.S.A. Mine

Stresses at the surface of mine openings were measured using the flat jack technique in three drives, and on two occasions in Stope 18CW (Fig. 2). On the second occasion measurements were deferred because of rescheduling mining operations. A new series of tests in 18CW Stope is now in progress. Stresses in drives (example Fig. 5a) were similar to those expected from the magnitudes of pre-mining stresses. The available results from the stress measurements in the stopes show stresses in the back to be lower than could be expected from pre-mining stresses (Fig. 5b). Apparently, the high predicted stresses in stope backs, approaching the rock strength, do not develop because of stress-relieving. This may be facilitated by the low arch produced in the backs by controlling the length of the holes drilled for each lift firing.

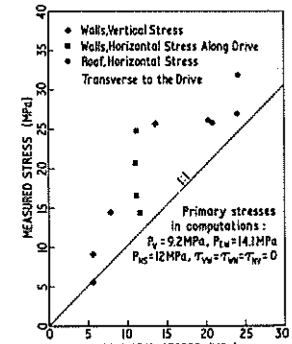

Fig. 5a Measured vs predicted stresses (stresses in sill drive, 12W stope)

(b) Length and Diameter Changes in Bored Airway, Stope 18CW

Measurements of length and diameter changes are carried out in a 1.8 m diameter bored airway, to gain information on horizontal and vertical stresses and deformation in the back of the stope as stoping proceeds. The locations of measuring targets and the readings during firing of a stope lift are shown in Figs. 2, 6a, 6b.

Contractions in length up the airway occurred between successive targets installed at 1.2 m spacing up to 5 m above the back (Fig. 6a). This was in the direction of the elastic effect of a horizontal stress field, but the magnitude is several times greater. The changes of diameter at the firing of a stope lift (Fig. 6b) exceeded theoretical predictions based on an intact modulus of 80 GPa and on a simple parallel-sided stope shape by factors of 3 to 5.

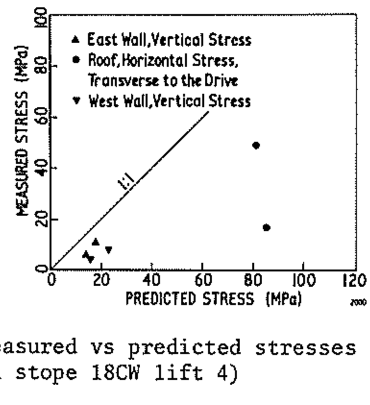

Fig. 5b Measured vs predicted stresses (stresses in stope 18CW lift 4)

Extensive rock fracture occurred on the north and south surfaces of the airway in agreement with concentration of east west horizontal stresses across the stope back (Fig. 6b).

A knowledge of the depth of zone of contraction above a stope back, which may be more stable than areas of dilation, may be of use in selecting

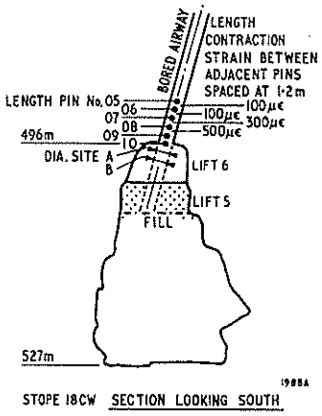

Fig. 6a Strain measurements in bored airway

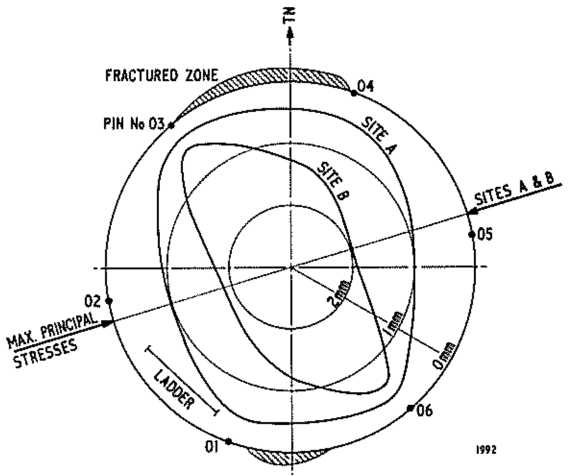

Fig. 6b Diameter changes in bored airway due to firing a stope lift

the length of rock bolting for back support. In this test, the contraction occurred from 1.2 m up from the back.

(c) Resistance Wire Extensometers

These instruments were developed as an alternative to wire or rod extensometers, to measure static and dynamic strains in the rock under adverse conditions such as blasting or corrosion.

The instruments consist of a stretched resistance wire encapsulated in epoxy resin plastic in thin-walled copper tubes approximately 25 mm outside diameter × 0.5, 1 and 3 m long. They indicate average strain along their length. Construction is such that several 120 ohm units with separate output leads can be plugged together and grouted into a drill hole in the rock. Details of design and operation can be found in Ref. 21.

The extensometers were used at Cobar to measure dilations in stope backs and walls of stopes 18CW and 18CB as mining progresses (Fig. 2, Ref. 20). Changes in the wall at the haunch of stope 18CW were up to 100 microstrain elongation, and in stope 18CB up to 700 microstrain elongation indicating opening up of cracks up to 3 m above the back. The output from one unit installed in a stope back was recorded on a tape recorder during firing of a lift. The record showed continuing sporadic strain changes up to one hour after the firing (when the tape ran out).

(d) Stope Wall Closures above Fill

Dilation of the rock into the stope in the walls just below the backs (Fig. 2) can be an initial stage of stope wall failure even in the absence of well defined cleavage or bedding planes as at Cobar. A three-hinge mechanism failure of stope walls in this area has been observed in a number of cut and fill stopes with the cleavage or bedding parallel to the ore vein.

Observations of stope wall closures were expected to be a guide to changes in the rock quality and to future behaviour of the main stopes as mining progresses upwards, and to permit comparison between stopes.

Arrays comprising 10 pairs of steel pins were grouted in opposite walls of a stope some 2.3 m below the back and 4.1 m apart along the stope. Initially these pins were anchored at about 300 mm depth and a standard survey tape and vernier were used to measure the distance between them. Later installations used pins anchored at 1.2 and 2.4 m depths with distance measurement carried out by a

TABLE II

STOPE CLOSURES AT 2.1 to 2.4 m BELOW STOPE BACKS ON FIRING THE NEXT 4.5 m LIFT

STOPE			STOPE CLOSURE DATA		
Stope No. /Lift No.	Height m	Width of stope m	L_p m	$\overline{\Delta w}$ mm	σ mm
12CZ2/18	79	10 15	0.3	9.3	-
				13.2	4.2
12CZ2/20	90	9 - 15	0.3	12.7	4.8
12CE/26	115		0.3	18.1	6.2
12CE/27	120	12	0.3	31.4	6.1
12CW/26	120	7 - 14	1.2	71.9	14.9
12CW/27	124	16 - 19	1.2	76.4	35.7
			2.4	69.8	27.6
18CW/3	12	18	0.3	12.7	2.5
			0.3	13.2	-
18CW/4	16		0.3	12.7	2.0
18CW/5	21	5 - 8	0.3	13.8	-
"	"		0.3	14.5	5.6
"	"		1.2	11.5	-
"	"		1.2	11.9	3.0
18CW/6.3	26	7 - 9	1.2	11.5	3.7
			1.2	14.3	4.2
18CW/7	30		1.2	10.9	3.6
				10.6	3.9

NOTES: L_p : depth at which reference pins were anchored in the stope walls
$\overline{\Delta w}$: mean change in stope width
σ : standard deviation of observations along the stope

Potts Extensometer. Changes in relative levels of pins were determined by precise levelling, in addition to wall closure measurements.

Table II summarizes the results of observations. As can be seen in stopes 12CZ2 and 18CW wall closures were about 10-15 mm and consistent with the "effective" deformation modulus of rock about 20-30 GPa.

Predictions of elastic wall closures for idealized rectangular stopes of increasing height to width ratio may be done by means of Figs. 7, 8. As yet no definite increase in wall closure rate with height of stope 18CW (indicated by the elastic analyses) was observed. High closures in stopes 12CE and 12CW are thought to be due not so much to the greater height of these stopes as to the less

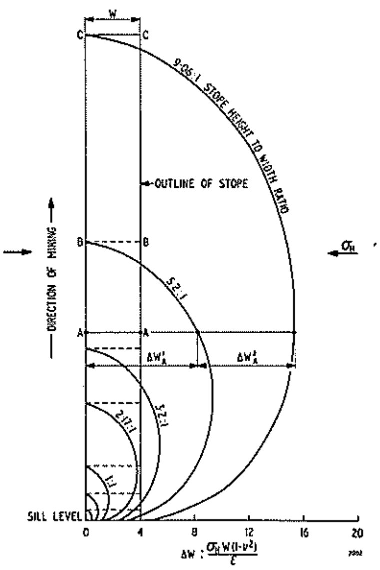

Fig. 7 Theoretical predictions of stope closures on upward mining of stopes. Note: ΔW_A = the reduction in stope width at A-A between the stages when the stope back passes A-A and reaches. B-B

competent rock. The hanging wall in 12CE has closely spaced cleavage planes which often open up visibly. Large closures of about 75 mm in stope 12CW were associated with block movement along a footwall fault. The area was closely watched but appears to be stable. Stope 18CW with comparatively good rock was chosen for an experiment with bench and fill mining in which up to 18 m high wall area will be exposed prior to back filling.

(e) Stope Closure Beneath Fill

The closure between opposite walls of stope 18CB was observed beneath the fill by tape measurements through a vehicular tunnel. The closure attained 25 mm in three lifts (of 4.5 m) (Fig. 9). The theoretical closure for intact modulus behaviour for a single stope (18 mm) required augmentation for the effect of the interconnecting stopes 18CC, 18CE, mined concurrently. The comparison made suggests that there was no marked deviation from intact elastic behaviour.

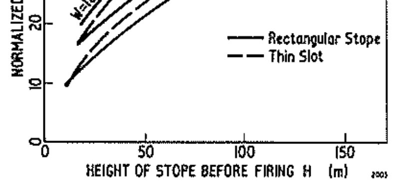

Fig. 8 Stope closure near back on firing a 4.5 m lift as function of stope height

(f) Hanging and Footwall Deformations

Deformations in the hanging wall and footwall (Fig. 2, tests 6, 7 and Fig. 10) were measured in Stope 12CW by means of reference wires anchored at different depths, using a Potts Extensometer Mk II. The wires passed across the stope through the fill in a 0.45 diameter corrugated iron pipe.

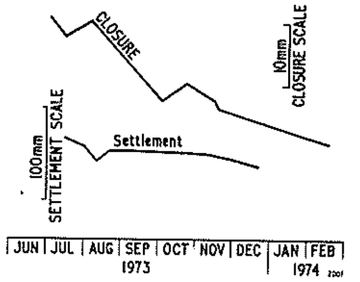

Fig. 9 Observations of stope closure and fill settlement from an ARMCO tunnel through the fill

(i) Hanging wall

Stress relief expansion of the 30 m thick layer of the hanging wall, adjacent to the stope, was observed, and was of the order of 6 mm in a 12-month period in which six stope lifts were taken (Fig. 10).

Changes occurred at the times of lift-firing overhead and also as lift-firing continued along the stope, and did not occur at times of no mining activity.

This demonstrates the three-dimensional influence at any one cross section of the stope. The influence was felt from firing lifts to the end of the stope approximately 70 m distant. This may be compared with the stope height (75 m).

The magnitude of movement agreed with an intact elastic response of the hanging wall to the horizontal stress field.

(ii) Footwall

During the first lift-filling after completion of the installation, the readings indicated dilation of the footwall to the depth monitored (8 m) (Fig. 10), amounting to 7 mm, which was equivalent to a strain of about 800 microstrain. Laboratory tests showed that the material took up 4% by weight of water but expanded less than 80 microstrain. Thus the effect underground was presumably due to pressure of free water from the fill in the many cracks in the footwall and its "lubricating effects".

Following this, the footwall wires did not perform satisfactorily, presumably due to leakage of fill into the pipe, either directly into the pipe, or indirectly through the footwall material, as the hole was not cased.

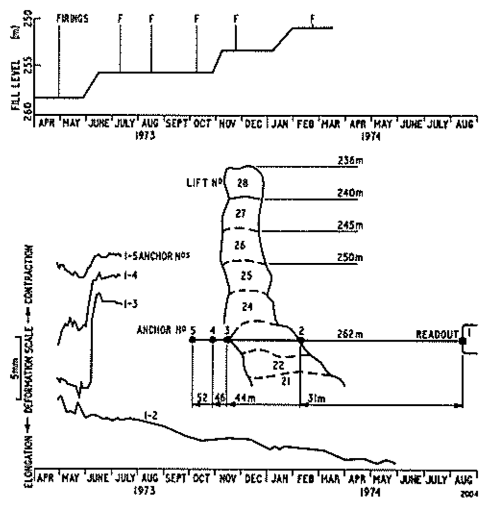

Fig. 10 Deformations in hanging wall and footwall Stope 12 CW

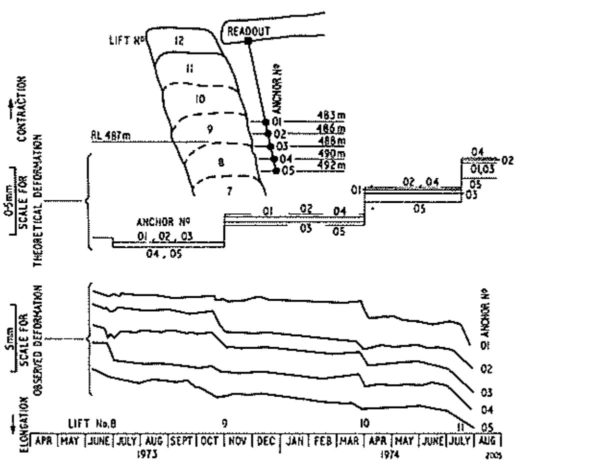

Fig. 11 Deformations in haunch - sub-vertical wire

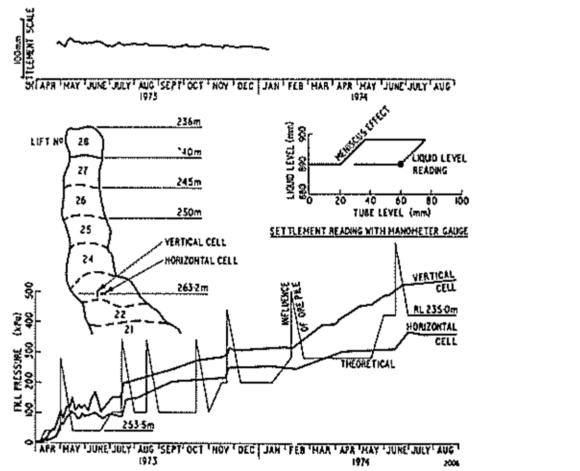

Fig. 12 Fill pressure and settlement, Stope 12CW

(g) Deformations at Haunch, in a Borehole Parallel to Dip of the Stope

A set of five wires and anchors was used to monitor deformation of a sub-vertical hole as the stope was mined up past the anchorages (Fig. 2, test 7 and Fig. 11).

The figure shows the progressive elongation (downward movement of the anchors relative to the reference station above) for successive lifts. The magnitude and sign of the observations are different from the predictions (Fig. 11), but detailed analysis is not complete. One installation intersected by the stope was damaged during blasting.

(h) Length Measurements along Cross-Cuts

Measurements of changes of length along cross-cuts were made using a Potts extensometer and tapes (Fig. 2).

Changes over a 12-month period were of the order of 2 mm elongation in successive 20 m base lengths and were in accord with the elastic movement of intact rock.

(i) Behaviour of Fill

(i) Fill pressure

The pressure developed in the fill was measured by three types of earth pressure cells (Fig. 2).

- Aluminium capsules about 70 mm in diameter with 40 mm diameter diaphragms provided with a special configuration of strain gauges (Ref.22).
- Oil-filled flat cells, 0.35 m diameter, with electrical transducers ("Freyssi" jacks).
- Oil-filled flat cells, 0.3 m square, with copper tubing to Bourdon gauges in a nearby access. This type was also to be used for modulus tests of the fill at depth.

Results from the first type only are given here as trouble was experienced with the other cells. They show pressure increments occurring in steps at the time of lift-firing, with no change between firings. Total changes on cells measuring vertical pressure and pressure across the stope were about the same as the theoretical gravity pressure of the fill, but with a slightly greater horizontal than vertical pressure. Note however that no changes occurred in response to lift-filling or removal of the ore-pile above the fill (Fig. 12). After 18 months service, the cell for horizontal pressure showed some drift (Apr., May, 1974, Fig. 12) and both cells began to show reduced insulation resistance.

(ii) Fill settlement

Fill settlement was measured at a series of points across Stope 12CW by means of a 10-point liquid-level indicator comprised of 10 small bore nylon tubes carried in a semi-rigid plastic pipe across the stope. (Fig. 2, test 4).

After 9 months service the plastic pipe developed a break within the stope, possibly from distortion due to stope closure or fill settlement at the stope wall. A pipe with axial extensibility to permit length adjustment, but diametral stiffness to resist fill pressure, appears to be necessary.

Over a period of 9 months, fill settlement showed no change within ± 4 mm (Fig. 12) at 4 points near the middle of the stope, except for the effect of the first firing above the installation which was missed.

The fill settlement was measured by precise levelling in another stope (Stope 18CB) at a vehicular tunnel which passed across the stope (Fig.12). The settlement of the first and subsequent firings overhead observed to date was of the order of 15 mm total.

The change of shape of the tunnel indicated higher vertical than horizontal fill pressure along the stope.

The settlement in both areas was negligible compared with free settlement under gravity.

Contributory factors, affecting the fill pressure and settlement observations, appear to be: (a) shakedown of the fill due to impact of the broken ore; (b) friction on the walls; (c) closure between the stope walls, which keeps up the pressure and tends to reduce the settlement; (d) locked-in pressure increments in the aluminium cells occurring at lift-firing, due to the high un-loading modulus of the fill relative to the stiffness of the aluminium cells, resulted in a lack of response to the removal of the ore-pile, the closure in the interval between firings, and the pouring of a lift of fill. From theoretical analyses, fill pressures were expected to be small.

Fill pressures increasing at the observed rate will be effective against progressive unravelling of the walls, but have minor direct influence on rock stress and deformation around the stope except through control of unravelling.

(j) Acoustic Emission Monitoring

Rock noise was recorded from accelerometers located near the future crown pillar area some distance above the stope backs (Fig. 2). In the first hour after firing a stope back, the noise count (frequency of 'events' or clicks) reduced from a high to a relatively low level. The noise source is assumed to lie in fractured or highly stressed areas in the back. This will be investigated in future tests by recording simultaneously rock strain from resistance wire extensometers installed in the backs.

The acoustic emission from the areas of future crown pillars remains very low at the present stage of mining.

(k) Movements on Joints in Access Drives, Hanging Wall, Stope 12CW

Joints in access drives were selected for observation of movement with a mechanical extensometer (Fig. 2, test 14) (Ref. 23). They ranged from apparently tight joints to shear fractures.

From the measurements taken as the stope was raised past the access drive, it appeared that the rock behaved as intact material but some superficial defects occasionally augmented the elastic movement. The biggest movement was on one shear fracture which showed a slip of 1 mm; but the majority of joints showed no movement whatever. The results provided no evidence for the supposed "front-of-loosening".

7 SUMMARY AND CONCLUSIONS

(i) The analysis of stopes as openings in an elastic medium was useful as a reference for observed behaviour. The observations suggest behaviour close to that of intact material of all but the surface rock around the stopes. The shape and depth and properties of the disturbed zone around the openings are of importance in determining the modifications to be made to the theoretical analysis but the present information is insufficient to detail the pattern.

(ii) In the stopes at Cobar, the present type of fill exerts only low pressures against the stope walls. The pressures are not large enough to have any significant effect on the stresses in the stope backs. They are,however, sufficient to prevent the rock from unravelling into the stopes.

(iii) The following techniques and instruments gave satisfactory performance: wall closure measurements above fill; the hollow inclusion stress cells; the USBM borehole deformation gauge; the aluminium fill pressure cells (a higher stiffness may be of advantage); resistance wire extensometer (with simplified construction); the arrays of pins for observing joint movements; the closure and settlement in the ARMCO vehicular tunnel and acoustic emission monitoring.

(iv) Modification of multi-point liquid level indicators has been discussed previously; the multi-anchor and wire extensometers require improved anchorage for close blasting and improved protection against fill for wall closure measurements. The bored airway measurements were exploratory.

(v) The areas of greatest interest for future monitoring are the backs of stopes 12CW, 12CE and 18CW, the hanging wall of stope 12CW, the crown pillars between the upper and lower level stopes, areas in stope backs with intersecting shears, and the shears in the walls dipping downwards into a stope.

8 ACKNOWLEDGEMENTS

Mr. J. Ashcroft, one of the co-authors of this paper, died during the preparation of the paper. Our sorrow is expressed at the loss of a good friend and colleague.

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