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The design of pillars in the shrinkage stoping of a South African gold mine

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SYNOPSIS

This paper describes the method used at Agnes Gold Mine in the calculation of pillar strengths, which involves a back-analysis type of approach. The results obtained there are comparable with those obtained by accepted formulae for pillar strength.

It was found that a stress level of 70 MPa for the width of combined pillars (i.e. crown and sill pillars) causes failure of the reef drives as well as the tops and bottoms of the stope side walls. As shrinkage stoping to depths of more than 650 m would result in very low percentage extractions, alternative methods of stoping will have to be investigated for these depths.

SAMEVATTING

Hierdie referaat beskryf die metode wat by Agnes-goudmyn vir die berekening van pilaarsterktes gebruik word wat 'n terugontledingsbenadering behels. Die resultate wat daar verkry is, vergelyk goed met dié wat volgens die aanvaarde formules vir pilaarsterkte verkry is.

Daar is gevind dat 'n spanningsvlak van 70 MPa vir die breedte van gekombineerde pilare (d.w.s. kruin en drumpelpilare) swigting van die rifstrekgange en die bo- en onderkante van die sywande van afbouplekke veroorsaak. Aangesien krimpafbouing tot dieptes van meer as 650 m tot baie lae ekstraksies sal lei, sal alternatiewe afboumetodes vir hierdie dieptes ondersoek moet word.

Introduction

The shrinkage method of stoping with pillar support has been used at Agnes Gold Mine since mining started there. Until recently, rock instability did not have any detrimental effect on safety or production, but now sill pillars are failing, not only on the current production levels, but also in shallower worked-out areas. The incidence of failure raises questions as to whether the dimensions of the pillars are adequate at the current working depths and what their size should be at greater depths.

Although formulae for pillar design have been developed for South African coal mines by Salamon and Oravecz[1], little work has been done on this subject for hard-rock mining. Coates[2] gives formulae for pillar strengths that are being used in Canadian mines, and the matter has been investigated in South Africa by De Jongh[3].

The applicability of the formulae to mines such as Agnes Gold Mine was investigated by means of a back-analysis type of approach. The application of the method is illustrated here by the calculation of future pillar sizes for Agnes Gold Mine.

Description of Agnes Gold Mine

Agnes Gold Mine is situated in the Swaziland Supergroup in the eastern Transvaal, Republic of South Africa. This Supergroup, approximately 3,5 billion years old, consists in the main of argillaceous and arenaceous sediments together with a volcanic sequence, which has been intruded by a basic to ultrabasic suite. The Agnes deposit comprises large low-grade reserves of consistent value, which are found in the shales of the Clutha Formation. The reef is situated in steeply dipping (85 to 90°), intensively laminated metamorphosed shale.

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Sulphide mineralization occurs in strata-bound zones that are 1 to 2 m wide, these being the economic gold horizons. Two of these 'shoots' are being mined at present: the Woodbine and the Giles. The extent on strike is shown in Fig. 1; they are open-ended at depth.

The uniaxial compressive strength of the rock in the hangingwall and footwall, as well as that in the reef horizon, is 80 to 100 MPa at right-angles to the bedding planes. Horizontal joints spaced approximately 1 m apart are found on most levels. These joints are tightly closed, but form preferential planes of failure when subjected to higher levels of stress. There being no evidence to the contrary, the vertical primitive stress is assumed to be a function of the depth of overburden, while the horizontal virgin stress at right-angles to the orebody, as determined by the hydro-fracturing technique, is 0,85 of the vertical primitive stress.

The vertical projection in Fig. 1 shows the extent of mining on the Giles and Woodbine shoots to date. Fig. 2 is a generalized section of these two shoots showing their spatial relationsip, and Fig. 3 gives the standard layout for sill and crown pillars.

Back Analysis

Calculations of the stress level at which pillar failure occurs gives some measure of pillar strength. This implies that there is a reliable method for the calculation of stress.

From the geometry of the Mine (Fig. 1) it was concluded that a two-dimensional approximation can be made without the introduction of a significant error. It was therefore decided that the boundary-element method developed by Crouch[4] should be used. The Minsim programme, which incorporates the influence of the third dimension, was used as a check on this assumption. The Minsim results compared well with those obtained by the two-dimensional approximation.

In the calculation of the regional influence of mining, the

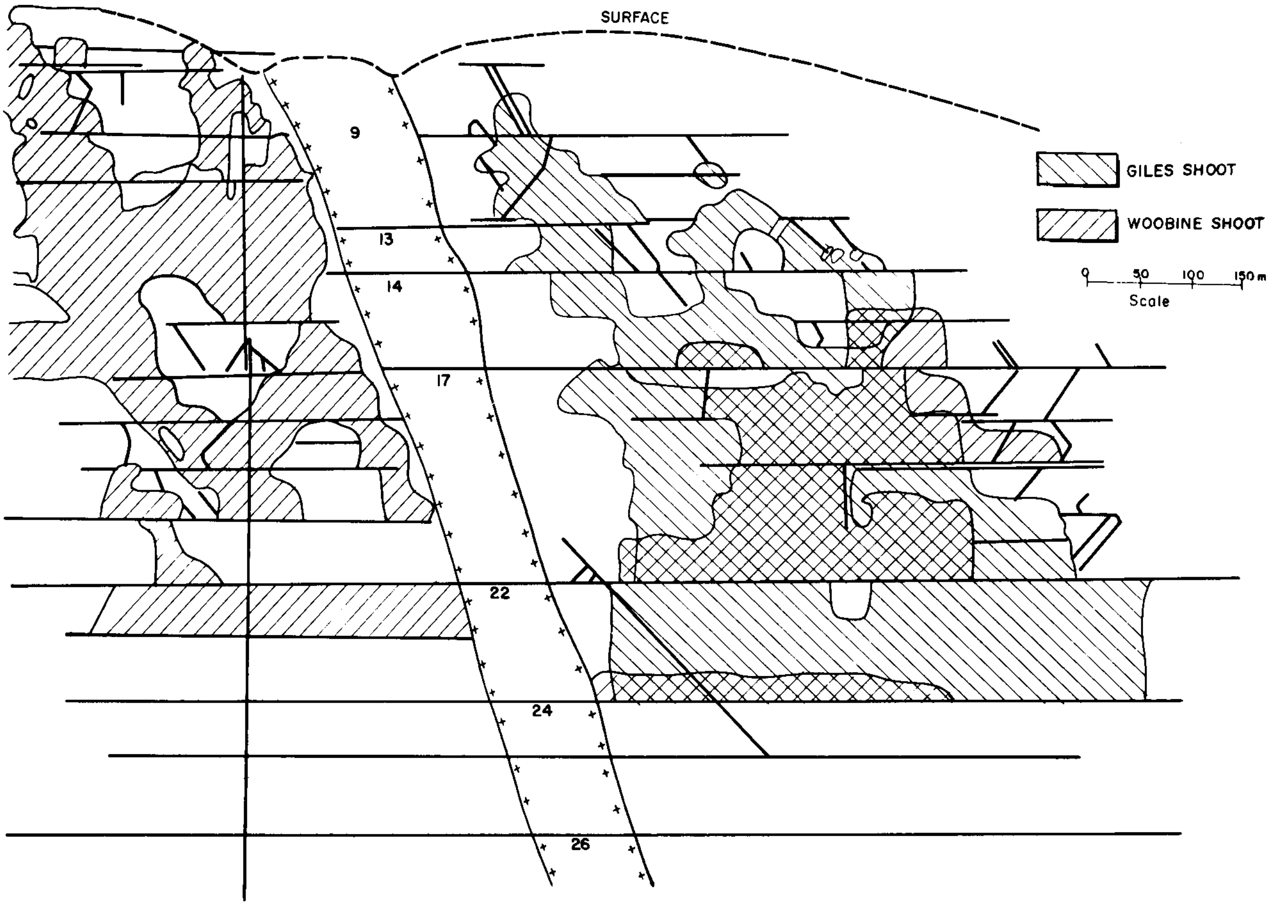

Fig. 1—Vertical projection of Agnes Gold Mine looking south

crown and sill pillars were treated as 'combined pillars'. The mining levels where pillars had failed were selected, and stress levels were calculated for the combined pillars. Visible signs of instability in sill pillars are apparent at 70 MPa, and at 120 MPa the reef drive becomes inaccessible owing to total pillar failure.

Pillar Design

In the past, pillar sizes at Agnes Gold Mine were based largely on the experience of line staff. However, with the onset of failure of some of the pillars, it became apparent that a more sophisticated approach was required. The work already mentioned makes it possible for procedures to be developed by which pillar sizes can be calculated. Use is made of the concept of a safety factor, defined as the calculated pillar strength divided by the calculated stress imposed on the pillar.

For stable situations, the factor can vary between 1 and 6, the magnitude depending on the reliability of the two values; the higher the magnitude, the less reliable the calculation. In the present pillar design, a safety factor of 1,5 was accepted. This value has been used by other authors[3], a value of 1,65 being used for coal mines in South Africa.

Pillar Strength

The strength of a pillar depends on the following:

(a) geometrical parameters (the width-to-height ratio and the shape of the pillar),
(b) the strength of the rock mass, and
(c) the presence and orientation of joints and other weak zones.

Geometry

The effect of width-to-height ratio on the strength of coal pillars as determined by Salamon and Oravecz[1] is expressed by the following formula:

$$\text{Pillar strength} = Kw^{0,46}/h^{0,66}\ \text{kPa}, \qquad (1)$$

where K = strength of 1 m^3 of coal as measured in the laboratory
w = pillar width in metres
h = pillar height in metres.

The superscripts 0,46 and 0,66 are applicable to coal mines. Other authors have ascribed values of 0,5 and 0,75 as being applicable to hard-rock mines[3]. The latter values are used in this paper.

This formula is applicable only to square pillars, and, if rectangular pillars such as the crown pillars shown in Fig. 3 are used, the formula has to be modified. The 'effective width' is then used instead of the actual width:

$$\text{Effective width} = 4\,A/C, \qquad (2)$$

where A = pillar area
C = pillar circumference.

Strength of Rock Mass

The strength of test specimens is generally accepted as

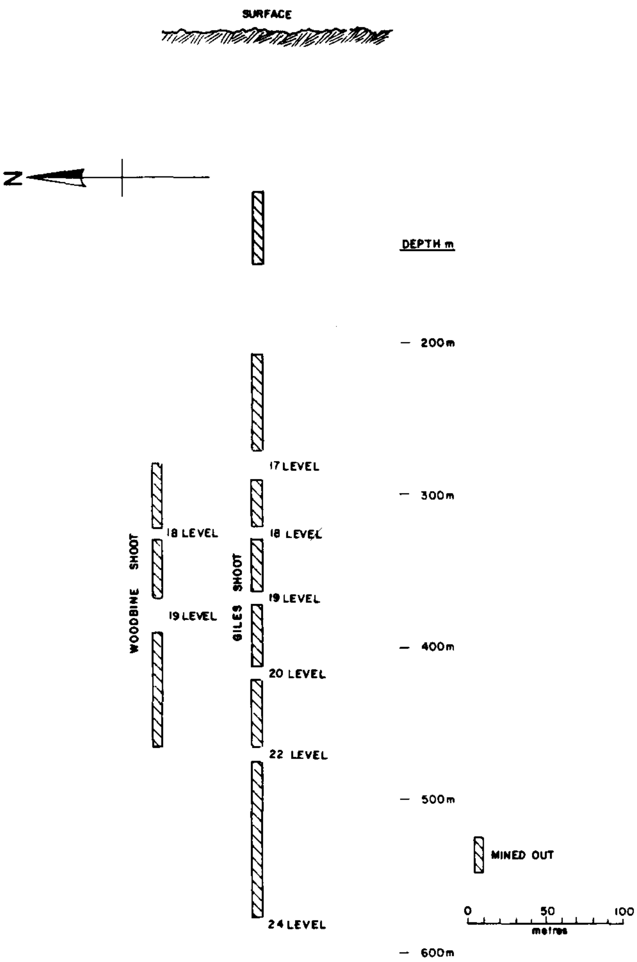

Fig. 2—Diagrammatic section through the workings at Agnes Gold Mine looking east

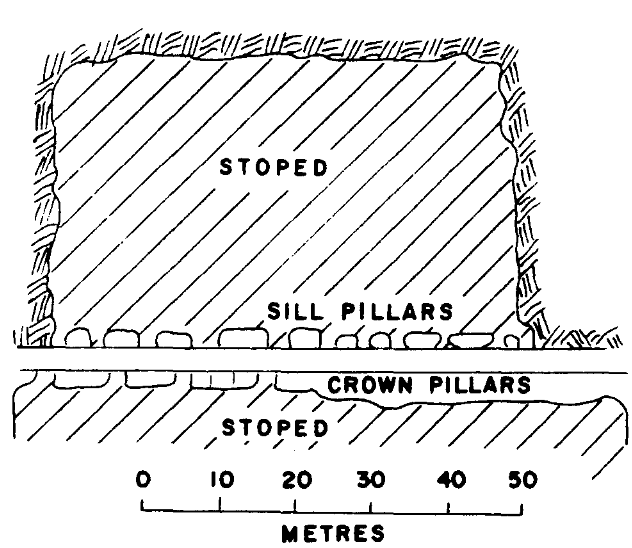

Fig. 3—Vertical projection of Agnes Gold Mine showing a typical layout of sill and crown pillars

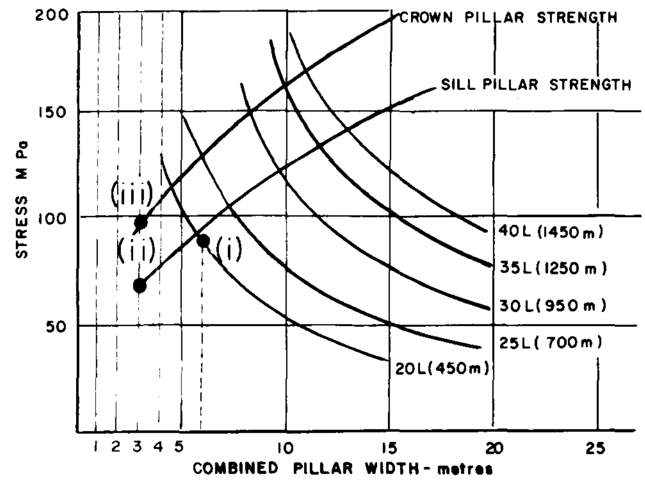

Fig. 4—Expected stress levels and pillar strengths for various levels and pillar sizes (distances refer to depths below surface)

the maximum value obtained in the test, but the actual strength of a rock mass is lower owing to the presence of geological discontinuities. This can be allowed for in the formula by modification of the equation as suggested by Wagner[5]:

$$\text{Pillar strength} = \left[\frac{(w)}{(wo)}\,0{,}5 \,/\, \frac{h}{ho}\,0{,}75\right] \sigma c \text{ kPa},. \quad (3)$$

where w = pillar width
wo = specimen width
h = pillar height
ho = specimen height
σc = uniaxial compressive strength.

Equation (3) was used for the calculation of the curves given in Fig. 4, a value of 80 MPa being used for the uniaxial compressive strength of the shale. The difference in the strength values for crown and sill pillars should be noted. The reason for the greater strength of the crown pillars is that the 'effective width' was used.

The formula for pillar strength given above generally gives reasonable results where the width-to-height ratio is less than 5. When this ratio is higher, the strength values are under-estimated and the results are conservative.

Pillar Load

The calculation of the stress levels on the combined pillar widths at various levels was based on the 'tributary area' theory. This theory states that, if the extent of mining is such that the edge effects of the unmined solid are excluded, the pillars support the overburden load evenly. The magnitudes of the stress levels calculated in this manner are initially over-estimates but, as mining progresses in extent, they are a fair approximation.

Since the orebody under consideration is vertical, the horizontal stress at right-angles to the orebody was used, the values being adjusted incrementally with increasing depth. The magnitude of the horizontal component of the primitive stress field at right-angles to the orebody was found to be 0,85 of that of the vertical primitive stress.

The stress values given in Fig. 4 were calculated for the various levels with different combined pillar widths.

Pillar Sizes

The safety factor, as defined previously, is a useful measure of relative pillar stability. As an illustration, use is made of the graphical representation for level 20 in Fig. 4.

The stress acting on the pillars on that level for a combined pillar width of 6 m is 90 MPa (i). The strength of a 3 m crown pillar and a 3 m sill pillar is given as 70 MPa (ii) and 95 MPa (iii) respectively. Therefore, the safety factor for the sill pillar is

70/90 = 0,78;

and, for the crown pillar,

95/90 = 1,06.

Comparison of Results

The stress levels at which failure occurs as determined by the back analysis varied between 70 and 120 MPa. Failure starts at 70 MPa, and a progressive deterioration takes place until total failure occurs at 120 MPa. As depicted in Fig. 4, 3 m sill pillars on level 20 should start to fail at a stress level of 60 to 70 MPa, and crown pillars at 90 MPa.

As the back-analysis and pillar design formula both indicate that pillar failure starts at about 70 MPa, a measure of confidence can be placed in the use of the latter method in the prediction of pillar failure at greater depths.

Calculation of Pillar Sizes for Various Levels

The stress levels of combined pillars of various sizes at various depths can be determined from the curves in Fig. 4. The dimensions of individual crown and sill pillars can then be calculated, the ratio of sill-pillar width to combined-pillar width being kept constant at 0,55.

With a safety factor of 1,5 for design purposes, the values given in Table I were obtained for pillar dimensions and theoretical ore-extraction percentages at depth increments of 50 m. The stress levels for combined pillars of different sizes on the various levels were read off from Fig. 5. The size of the crown and sill pillars was then determined, and the safety factor calculated for these widths for the given stress levels.

TABLE I
PILLAR SIZES FOR VARIOUS LEVELS

Level	Width of combined pillar m	Width of crown pillar m*	Size* of sill pillar m	Extraction %
25	11	4	7 × 7	78
30	15	5	10 × 10	70
35	17	6	11 × 11	66
40	20	7	13 × 13	60

*Pillar sizes rounded off to practical dimensions.

Discussion

It is obvious that the percentage extraction decreases substantially with increase in depth, and the economic significance of this would be severe. In addition, it must be remembered that the square configuration required for sill pillars lengthens the distance between draw points to up to 13 m, which in turn results in a loss of the broken ore that collects on top of these pillars.

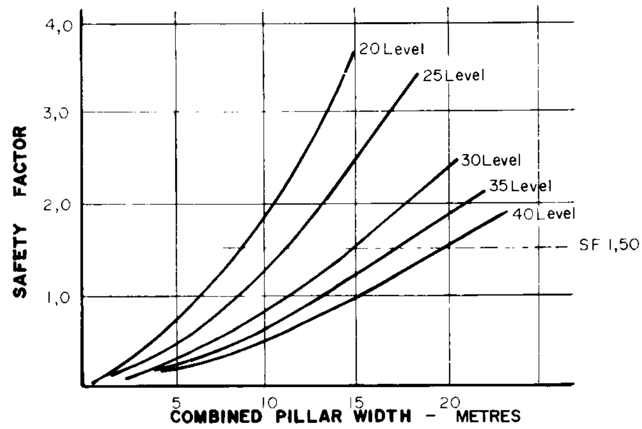

Fig. 5—Safety factor for the widths of the combined columns

Pillars of adequate size to prevent collapse of the workings do not represent the only criterion since dilution also increases with depth. This aspect is not discussed in detail here, but is a major factor in a consideration of the continued use of shrinkage stoping at depth.

In addition to the above, unless adequately designed pillars are left, the stress level on the reef drive itself increases substantially and sidewall scaling occurs, resulting in unstable conditions.

Conclusions

From the back analysis it was concluded that the stress level of 70 MPa for the width of combined pillars causes failure of the reef drives, as well as the tops and bottoms of the stope side walls. The use of standard formulae for pillar design gave similar values to those obtained by the back analysis, indicating that this design procedure is applicable to Agnes Mine. The introduction of relevant strength values would make this procedure applicable to other mines in a similar setting.

As shrinkage stoping to depths of more than 650 m would result in very low percentage extractions, alternative methods of stoping will have to be investigated for these depths.

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