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Three-dimensional Stress Analysis of Block Caving Mining Layouts

G.S. ESTERHUIZEN

Department of Mining Engineering, University of Pretoria, South Africa

The block caving mining method is used to mine large orebodies in weak rock types. The layout for block caving requires that a considerable amount of development is carried out on the extraction drives and drawpoints at the bottom of the caving block. The development further weakens the rock mass, and stability problems arise in the extraction drives and extraction pillars.

This paper describes the application of three-dimensional boundary element models in analysing alternative extraction level layouts for a block caving mine. The objectives were to establish whether the use of lateral pillars between drawpoints was warranted, and whether the lateral pillars should be offset or not. The stability of the rock mass within the pillars as well as the stability of the extraction drives were taken into account.

The results showed that after undercutting, the horizontal and vertical stresses in the extraction level would be reduced. The lateral pillars would significantly improve the stability of the extraction pillars and extraction drives. There would be a minor improvement in stability if the lateral pillars were offset.

Introduction

The block caving method is used to mine weak orebodies with large horizontal dimensions. The method relies on the ability of the ore to break up without drilling and blasting. A block cave is normally developed by driving a series of tunnels from which long holes are drilled to form an undercut. At a convenient distance below the undercut level, an extraction level is developed, from which the caving ore is drawn. Modern block caving mines use load-haul-dump units to load and haul ore from the drawpoints to ore passes, which are usually located outside the orebody.

The stability of the extraction level is a major concern in block caving mines for the following reasons:

- The drawpoints must be spaced about 10 to 15 m apart to ensure even drawdown of the caved ore. The load-haul-dump units require large tunnels to operate in. As a result up to 40% of the solid rock is removed on the extraction level;
- Hangups of ore in drawpoints may result in excessive loading of the rock

mass in the extraction pillars.

It is difficult to assess the consequences of changes in the layout of an extraction level, because the excavations are fully three-dimensional. However, three-dimensional stress analysis programs may be used to assist in the evaluation of complex layouts in three-dimensional stress fields.

This paper describes comparative analyses which were conducted to evaluate three extraction level layouts for a block caving mine.

Extraction level layouts

The layout of an extraction level depends on the required distance between drawpoints, the size of loading equipment and the properties of the rock mass. The three layouts discussed in this paper were designed for a load-haul-dump operation, with drawpoints spaced 13 m by 15 m apart. The undercut level was 15 m above the extraction level. The following three layouts were considered:

Continuous trench layout

The layout, shown in Figure 1, is relatively simple to develop and had been used in the shallower levels of the mine. The extraction pillar was free standing, without lateral support between drawpoints.

Trough layouts

A common method of improving the stability of the extraction pillar is to provide lateral support in the form of pillars between drawpoints. In this type of layout the lateral pillars are referred to as minor apices. The minor apices may be placed in a rectangular pattern, as in Figure 2, or they may be offset, as shown in Figure 3.

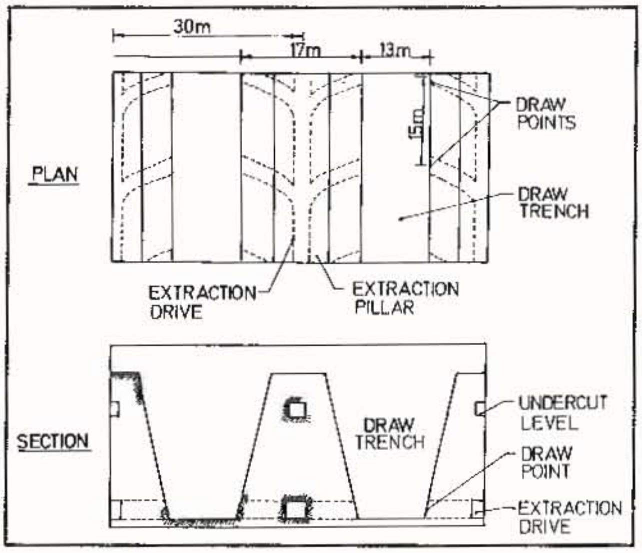

FIGURE 1. Plan and section showing the continuous trench layout

Objectives of stress analysis

The continuous layout was favoured by the production personnel, because it would be easier to

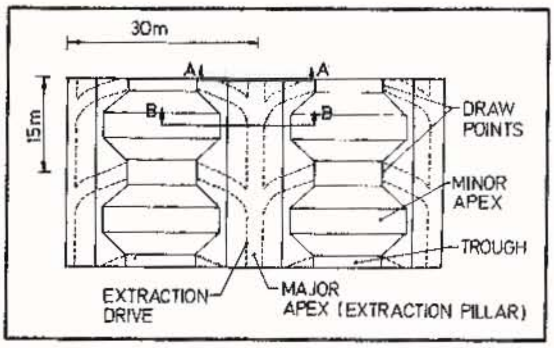

FIGURE 2. Plan showing the rectangular trough layout

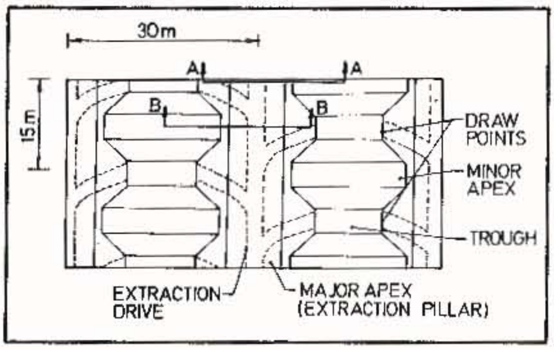

FIGURE 3. Plan showing the offset trough layout

develop, and had worked successfully on the mine. The trough layouts were more difficult to develop, and it was feared that high horizontal stresses may be concentrated in the minor apices, which could damage the extraction drives.

The objectives of the three-dimensional modelling were therefore:

- to quantify the improvement in stability brought about by minor apices;
- to determine whether high horizontal stresses would be transmitted along the minor apices;
- to establish whether there would be any difference between the stability of the offset and the rectangular trough layouts.

Method of stress analysis

Two-dimensional stress analyses were initially carried out to determine the stress conditions in the floor of a caved block. The results were used to define the external loading of the three-dimensional models.

The two-dimensional analysis was carried out using the BESOL series of boundary element programs[1]. The model used in the analysis is shown in Figure 4. Far field stresses were specified to load the model. A plane of symmetry was specified to reduce the number of elements used. The height of the undercut was extended upwards in subsequent runs to assess the effect of caving. Distributed loads were then applied to the lower surfaces of the model to simulate cave loading.

The MBEM program[2] was used to model the layouts in three-dimensions. The program is a three-dimensional boundary element formulation which allows both

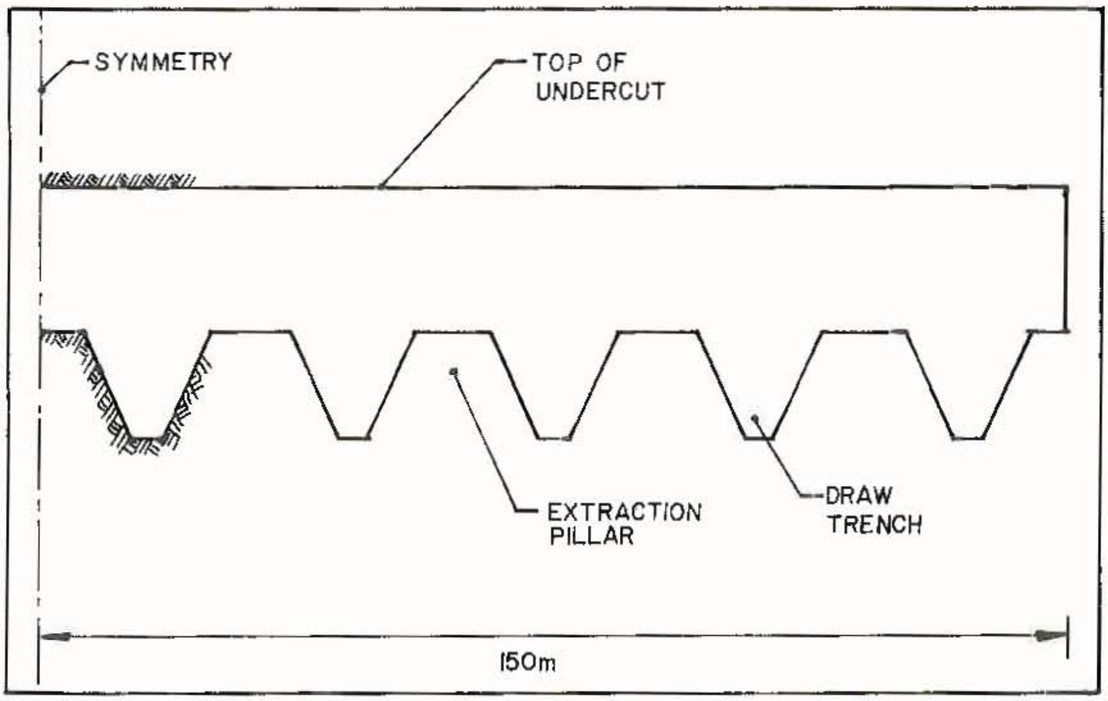

FIGURE 4. Two-dimensional boundary element model of block cave

displacement discontinuity and boundary elements to be modelled simultaneously. Due to practical limitations on the size and complexity of the model, only a portion of the entire block cave could be simulated. One of the models is shown in Figure 5. Two planes of symmetry were used to reduce the number of elements in the model.

The sides of the models were loaded by applying external loads determined by the two-dimensional model. Stresses were calculated at numerous points in the three-dimensional models. Failure criteria were then applied to evaluate the stability of the extraction pillars and extraction drives.

Input data

The ore which was to be extracted by the block cave was only 175 m below the bottom of the previously caved open mine. As a result, stress levels were relatively low.

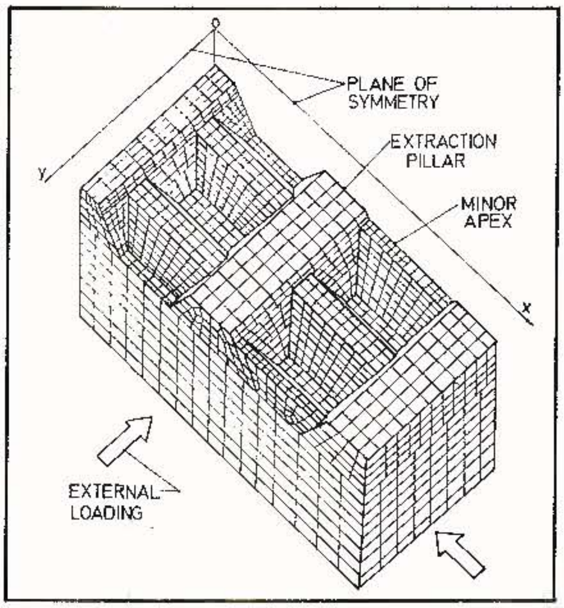

FIGURE 5. Three-dimensional boundary element model of portion of offset trough layout

The field stresses used in the models were 6,5 MPa in both the horizontal and vertical directions. The rock properties were as follows:

Modulus of elasticity = 60 GPa
Poissons ratio = 0,2
Density of rock = 2,7 t/m^3

Criteria used in evaluation of output

The extent of failure of the rock mass was assessed by using an empirical rock mass failure criterion[3]. The rock mass was rated as a fair quality rock mass with the uniaxial compressive strength of intact rock samples being 120 MPa.

A failure index was calculated which expressed the stability of the rock at a point in terms of the amount by which the rock strength exceeds the maximum principal stress. The results of the analyses were compared on the basis of the improvement of the index.

Results

Stresses in the floor of the block cave

The results of the two- dimensional models showed that the stresses in the immediate floor of a caved block would be lower than the field stresses, see Figure 6. The stresses in the extraction pillar can be seen to decrease rapidly toward the top of the pillar. From these results it was apparent that the extraction pillar was in a low stress environment. The extraction drive should therefore be supported against the

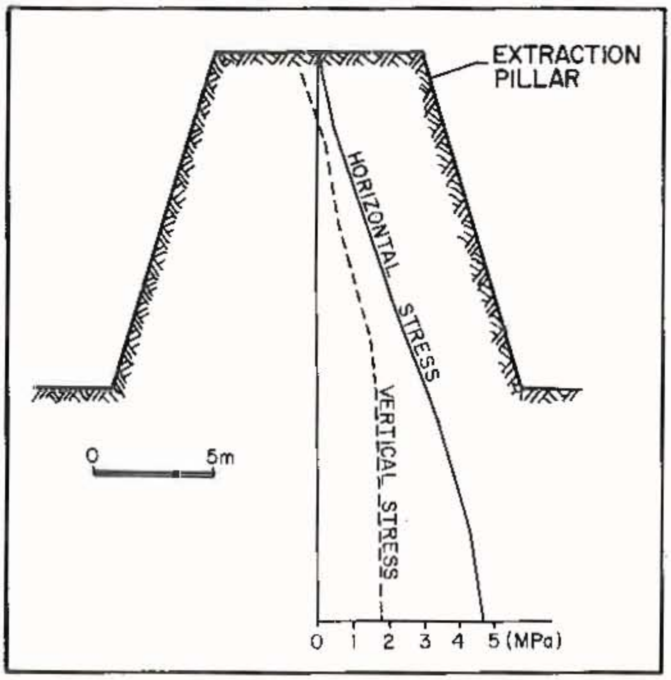

FIGURE 6. Vertical and horizontal stresses in extraction pillar

effects of a loosening rock mass, rather than the effects of increased stresses.

Effect of minor apices

The three-dimensional model of the offset layout has been selected to illustrate the effect of a minor apex on the stress distribution in the extraction pillar, as in Figure 7. It is clear that the minor apex has little effect on the stresses near the centre of the extraction pillar, but there is a considerable increase in stress in the immediate

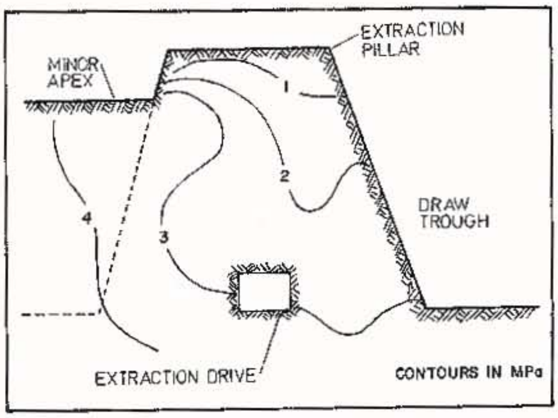

FIGURE 7. Contours of major principal stresses in minor apex and extraction pillar

vicinity of the minor apex. The stresses are all well below the applied field stresses.

The effect of the minor apices on the stability of the extraction pillar was determined by comparing the results of the two trough lay-outs to the results of the con-tinuous trench layout. the im-provement in the rock mass failure index was used as a basis for comparison.

Figure 8 represents a vertical section through the offset layout, illustrating the zone in which the failure index was improved by more than 20%. A similar section through the rectangular layout is shown in Figure 9. The minor

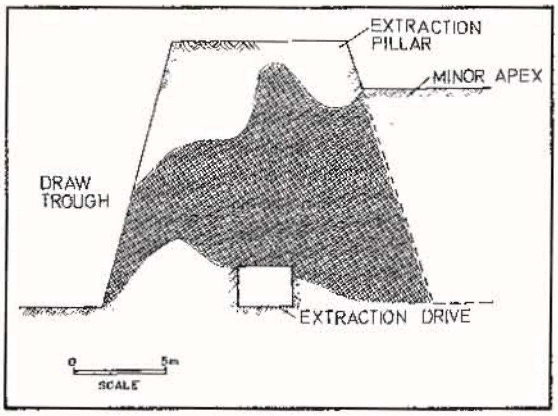

FIGURE 8. Zone of significant improvement in rock mass stability due to minor apex – offset layout

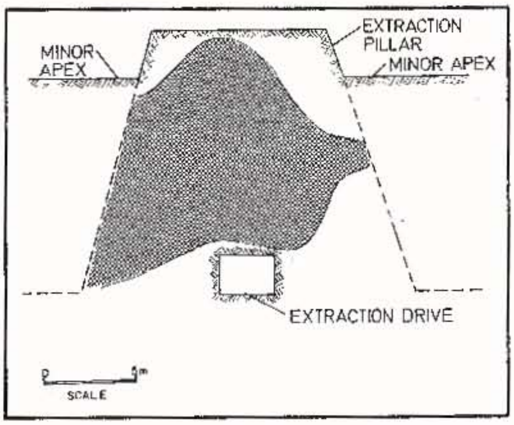

FIGURE 9. Zone of significant improvement in rock mass stability due to minor apex – rectangular layout

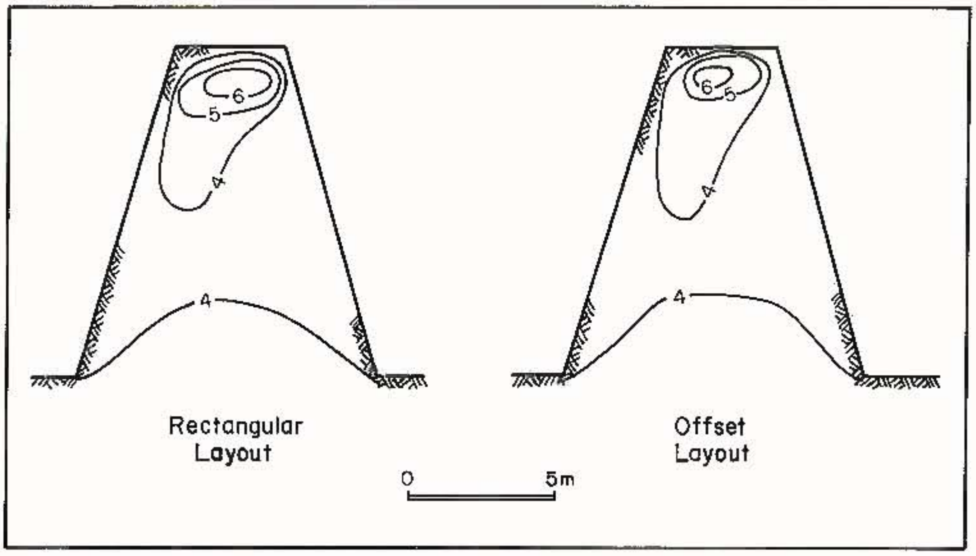

FIGURE 10. Vertical section through minor apices showing contours of horizontal stress

apices clearly have a significant effect on the stability of the extraction pillar. The improvement is essentially due to the increased confinement provided by the extraction pillar. The results also show that there is little difference between the offset and the rectangular layouts.

Horizontal stresses in the minor apices

The horizontal stresses which will be transmitted along the minor apices are shown in Figure 10. The stresses are higher than the stresses in the extraction pillar, but are still less than the field stresses. There is little difference between the offset and the rectangular layouts.

Conclusions

The block caving mining method requires complex extraction level layouts. The layouts are difficult to visualise on paper and are even more difficult to assess from a stability point of view. The investigation demonstrated that three-dimensional stress analysis methods are capable of providing good quantitative results on the stability of block caving layouts.

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