SCALE MODEL STUDIES TO INVESTIGATE THE EFFECTS OF VARIOUS STRESSFIELDS ON THE STABILITY OF PILLARS BETWEEN MINE ROADWAYS

by

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ABSTRACT

This paper discusses experimental results of physical scale models employed to study the stability of a pillar between rectangular roadways. A programme of laboratory investigations utilizing a bi-axial test rig has been undertaken to examine the influence of various stressfields on the stability of pillars between mine roadways. The effect of pillar height/width ratio on the overall stability is studied. Observations of failure characteristics in and around pillars are discussed especially in relation to the various stressfields applied to the models.

INTRODUCTION

Investigations into the stability of mine pillars is usually concerned with pillar failures, whereas, investigations into the stability of mine roadways take into account rib spalling, also roof and floor deformation. Research workers have used several experimental techniques such as pneumoelasticity and the uniaxial compression of model pillars using a high stiffness testing device. These methods predict the typical behaviour of mine pillars. More recently numerical analysis by finite element and boundary element methods have been carried out in order to interpret and confirm experimental results, as well as to establish the proper sizing of pillar models so that the actual behaviour of a full scale model could be matched.

In an attempt to establish a more appropriate basis for the design of mine pillars, physical scale modelling was used to investigate the influence of stressfields on the performance of pillars between mine roadways. A series of physical model tests were conducted to simulate a pillar between two rectangular roadways. The main aim of the model tests was to compare the effect of three different stressfields on the stability of these pillars.

MODELLING THEORY

Dimensional analysis and scale factors

The scaling of different variants in the modelling of a prototype is achieved by the application of Buckingham’s II theorem, which states that a complete equation defining a system can be reduced to a functional relationship between a complete set of independent dimensionless products.

The deformation of a roadway can be expressed by the following general equation:

\[ C = f(L, \sigma_v, \sigma_h, \sigma_t, E, \nu, \ldots) \]

where:

- \( C \) = deformation
- \( L \) = geometry
- \( \sigma_v \) = vertical in-situ stress
- \( \sigma_h \) = horizontal in-situ stress
- \( \sigma_t \) = tensile strength of the rock
- \( E \) = Young's Modulus
- \( \nu \) = Poisson's Ratio

The relationship can then be written as a dimensionless expression as follows:

\[ C/L = f(\sigma_v/\sigma_c, \sigma_h/\sigma_c, E/\sigma_c, \nu, \ldots) \]

The dimensionless quantities of the function should be the same for the model as well as for the prototype. Under these conditions the following system of equations are obtained:

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\[ \frac{(C/L)_p}{(C/L)_m} = \frac{(C/L)_m}{} \]
\[ \frac{(\sigma_1/\sigma_2)_p}{(\sigma_1/\sigma_2)_m} = \frac{(\sigma_1/\sigma_2)_m}{} \]
\[ \frac{\eta_p}{\eta_m} = \frac{(\eta_1/\eta_2)_m}{} \]
\[ \frac{(E/\sigma)_p}{(E/\sigma)_m} = \frac{(E/\sigma)_m}{} \]

The subscripts \( p \) and \( m \) refer to the prototype and the model respectively.

Let \( L_m/L_p \) be a geometric scale factor which is chosen arbitrarily according to the size of the model and for these tests was chosen to be 1/60. The model density was 1380 Kg/m\(^3\) and by assuming the rock to have an average density of 2500 Kg/m\(^3\), then the density scale factor employed was \( \rho_m/\rho_p = 1380/2500 \). The strength scale factor equals the density scale factor multiplied by the geometric scale factor, i.e.,

\[ \frac{\sigma_1}{\sigma_2} = \frac{L_m/L_p}{\rho_m/\rho_p} \]
\[ = \frac{1}{60} \times \frac{1380}{2500} \]
\[ = \frac{1}{108} \]

Thus, the scale factor for \( \sigma_1, \eta_1, \eta_2, \) and \( E \) is 1/108.

**EXPERIMENTAL PROCEDURE**

The models were made of a mixture of fine casting plaster, graded sand and water. Table 1 shows the properties of the mix used and its underground equivalent. Throughout the tests the same model materials were used, since the aim of the investigation was to study the effect of the stress field on the stability of pillars between mine roadways. The strata thicknesses were kept the same for all the tests and no support was used in the roadways. Figure 1 shows the arrangement of the slabs for testing the model. All model strata were cured at 105°C to drive off moisture prior to testing. The dimensions of the model rectangular roadways were 80 mm wide by 40 mm high, giving underground equivalent dimensions of 4.4 m by 2.2 m respectively.

All the tests were conducted in a bi-axial compression rig with constraint applied along the axis of the model excavation. The internal dimensions of the test rig were 0.45 m by 0.45 m by 0.075 m and this rig consisted of twenty hydraulic rams connected with two hydraulic pumps, from which horizontal and vertical pressures were applied to the model. The pumps were individually used to activate the horizontal and vertical rams, hence the horizontal and vertical pressures were measured by means of two individual pressure gauges. Figure 2 shows the model test rig.

Altogether six models were tested: three models with pillar width/height ratio of one, and three models with pillar width/height ratio of two. For each pillar width/height ratio three specific tests were performed:

(i) Predominant vertical stress field \( (\sigma_1 = 2\eta_2) \)
(ii) Hydrostatic stress field \( (\sigma_1 = \eta_2) \)
(iii) Predominant horizontal stress field \( (\sigma_1 = 1/2\eta_2) \)

<table>
<thead>
<tr>
<th>Mix</th>
<th>Compressive Strength, (MPa)</th>
<th>Tensile Strength, (MPa)</th>
<th>Modulus of Elasticity, (MPa)</th>
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<td>25</td>
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Table 1. Model material and its underground equivalent

**RESULTS AND DISCUSSIONS**

Predominantly vertical stress field \( (\sigma_1 = 2\eta_2) \)

Model Number 1: \( \sigma_1 = 2\eta_2, \) \( w/h = 1 \)

At an applied vertical pressure of 0.8 MPa tensile cracks appeared in the centre of the floor under each roadway. As spalling ensued the material was pushed into the roadways. Figure 3 shows the pillar experiencing extensive distortion and this caused deformation of the roof and associated floor heave. Side spalling was also evident at the sidewalks of the roadways. At the end of this test the pillar height and width had decreased by 50% and 15% respectively.

Model Number 2: \( \sigma_1 = 2\eta_2, \) \( w/h = 2 \)

The characteristic shear failures at the corners of the openings prompted the floor beds to move up. The pillar was crushed, but not to an extent experienced in the previous case, i.e Model Number 1. Figure 4 shows the model after the test. There was no evidence of crack propagation along the roof of the openings, but cracks predominantly existed in the beds above the pillar. Side spalling of the roadways was also evident. The pillar height and width decreased by 35% and 10% respectively.

However, in comparing the two models under a predominantly vertical stress field, the second model with width/height ratio of two resulted in improved pillar and roadway stability.
Figure 1  Model dimensions and strata sequence

Figure 2  Model test rig and testing arrangements

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Figure 3 Model Number 1 after the test

Figure 4 Model Number 2 after the test

Hydrostatic stressfield ($\sigma_v = \sigma_h$)

Model Number 3: $\sigma_v = \sigma_h$, $w/h = 1$

Using a hydrostatic stressfield condition resulted in crack propagation in the roof and floor of the roadways within the early stages of loading. The pillar was crushed and as a result two failed cones appeared at the sides of the pillar, as shown in Figure 5. Spalling of the sidewalls was evident and as a result broken material fell into the roadways. Due to the spalling of the sidewalls the width of the solid pillar decreased leaving a solid centre core.

Model Number 4: $\sigma_v = \sigma_h$, $w/h = 2$

This model proved to be very stable up to an applied load of 0.8 MPa. However, after a certain level of loading was attained the pillar sidewalls started to spall and this resulted in deformation of the roof and floor strata. Figure 6 shows only limited side spalling and therefore the pillar width did not decrease to the
excellent experienced with Model Number 3. It was evident that the core of this pillar was very stable. The walls of the roadway facing the centre pillar remained stable and there was little, or no, evidence of side spalling.

With reference to Figures 5 and 6, it is clear that there was a general decrease in the stable width of the pillar in Model Number 3 (Figure 5). This model also experienced spalling of the sidewalls facing the pillar and fracturing of the strata below the pillar. In the case of Model Number 4 (Figure 6) this type of failure was not evident.

Predominantly horizontal stressfield ($\sigma_v = 1/2\sigma_h$)

Model Number 5: $\sigma_v = 1/2\sigma_h$, w/h = 1

In Figure 7, it is clearly observed that with a predominantly horizontal stressfield less stable conditions were experienced in the roadways with significant failure of the roof and floor. The immediate strata in

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the roof and floor failed along the edges of the pillar and the facing sidewalls. This resulted in the deformation of roadways adjacent to the centre pillar. The pillar itself did not experience high loading characteristics and hence its dimensions remained unchanged throughout the test. There was no evidence of crack propagation in the strata above or below the pillar. The sidewalls of the roadways were very stable and there was no evidence of side spalling.

Model Number 6: \( \varepsilon_v = \frac{1}{2} \eta, \quad w/h = 2 \)

This model test behaved in a similar manner to Model Number 5, where an extensive amount of floor heave and roof lowering occurred. The sidewalls of the roadways were very stable and the pillar maintained its original shape.

CONCLUSIONS

Considering the results collectively, the roadways proved to be more stable in hydrostatic stressfield conditions in comparison to predominant vertical and horizontal stress conditions. The vertical stress was mainly responsible for pillar failures and spalling of the sidewalls, whereas a high horizontal stress tended to cause extensive floor heave and roof failures.

The model test programme showed that with a predominant horizontal stressfield, the pillar width/height ratio does not affect the stability of the pillars.

Therefore, if pillars were to be designed in such conditions effort must be made at achieving minimum roadway roof and floor failures. It should also be mentioned that roof failures and floor heave were also evident in the predominantly vertical stressfield, which is mainly due to pillar failure.

However, in hydrostatic and predominantly vertical stressfield conditions, and especially in the latter case, the pillar width to height ratio plays an important role in the design of stable pillars. The lower pillar width to height ratio has more tendency to yield, whereas with a higher width to height ratio the yielding of the pillar is comparatively reduced.

REFERENCES


11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W., July 1982.


