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A Rock Mechanics Survey and its Use in an Underground Stability Analysis at Kambalda, W.A.

By

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SUMMARY.- A basic rock mechanics survey at the Kambalda Nickel Mines in Western Australia was carried out and the resulting data was used in a structural mine design example.

The survey consisted of - a structural geological investigation,
the determination of the virgin rock stress field at the Durkin Mine,
and the ascertainment of the physical engineering parameters of some Kambalda rocks.

These results were combined into a mathematical model, and using the "finite element" technique, a study was made of the variation in ground movement occurring near the Durkin shafts, caused by different mining methods and mining sequences.

A residual rock stress field with high horizontal stresses and a vertical stress greater than a gravity induced stress, was measured at a shallow depth in the Durkin Mine. This stress field, when simulated in conjunction with the rock mass material properties, in the finite element model, gave several significant results. The roof or back of most underground openings was naturally prestressed, indicating probable stable roof conditions. Very little stress change occurred in stope pillars and the rock surrounding the Durkin shafts when different mining methods were simulated.

I.-INTRODUCTION

Prior to any engineering structural design, four basic quantities must be defined:-

- (a) The geometry of the proposed structure
- (b) The nature of, and the relationships between the component physical parts of the structure
- (c) The physical engineering properties of all component parts
- (d) The loads acting on the structure and thus the stresses induced in its component parts

The combination of these quantities defines the mathematical model of the structure.

"Rock mechanics is the theoretical and applied science of the mechanical behaviour of rock; it is that branch of mechanics concerned with the response of the rock to the force fields of its physical environment!"*

In mining design, the science of rock mechanics is used in conjunction with conventional engineering mechanics because rocks are the physical components of the engineering structure.

The role of geology in rock mechanics is of paramount importance. The materials involved are rock masses that either exist in, or have been extracted from a geological environment. The characteristics of the rock masses are a function of their mode of origin and of the subsequent geological processes that have acted upon them. These events, combined during the geological history of a given area, lead to a particular lithology or rock type, to a particular set of geological structures and to a particular insitu state of stress (Ref. 1).

*Definition by the Committee on Rock Mechanics, National Academy of Sciences, in "Rock-Mechanics Research", Natl. Acad.Sci.-Natl. Res. Council, Washington, D.C., 1966.

The work reported in this paper was aimed at introducing the subject of rock mechanics to people responsible for applied mining design. Being in a new mining environment, the Kambalda Nickel Mines of Western Australia were used to furnish actual data obtained by a rock-mechanics survey, with the object of fabricating a mathematical model of the physical geological environment in which future mining operations would be undertaken. More specifically the results were used to simulate ground movement around the Durkin Shafts when different stopeing methods and sequences were analysed.

II.-INSITU ROCK STRESS DETERMINATION

Using the United States Bureau of Mines (U.S.B.M.) 3-component Borehole Deformation Gauge, (Ref.2), underground rock stress determinations were carried out from the 3-level plat of the Durkin Haulage Shaft. A total of 15 independent diametral deformations was recorded after overcoring 3 diamond drill holes oriented in 3 mutually different directions.

To calculate the complete state of stress at a point requires the measurement of six independent deformations from at least 3 non-parallel boreholes (Ref. 3). Using the statistical method proposed by Panek (Ref.4) more than 6 sets of deformation equations were combined to calculate the least squares estimate of the rock stress field. Starting with 15 sets of equations, a computer was

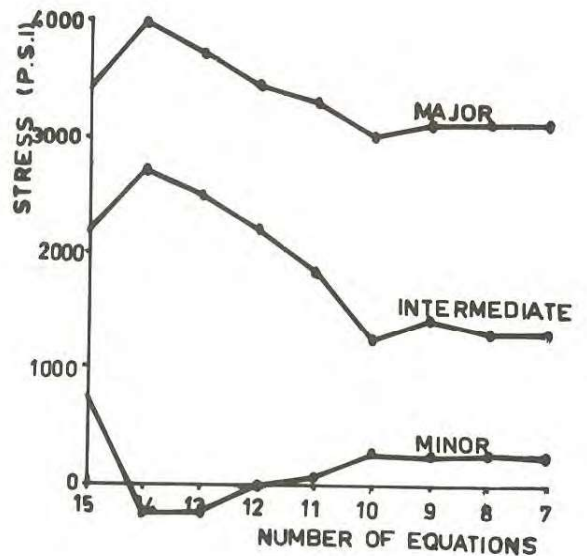


Fig. 1 Variation in Principal Stress Magnitude with Number of Reduction Equations

used to remove, in turn, the statistically most unacceptable equation and then calculate the stress field. In Fig. 1 the change in principal stress magnitudes with decreasing number of equations emphasises the need for

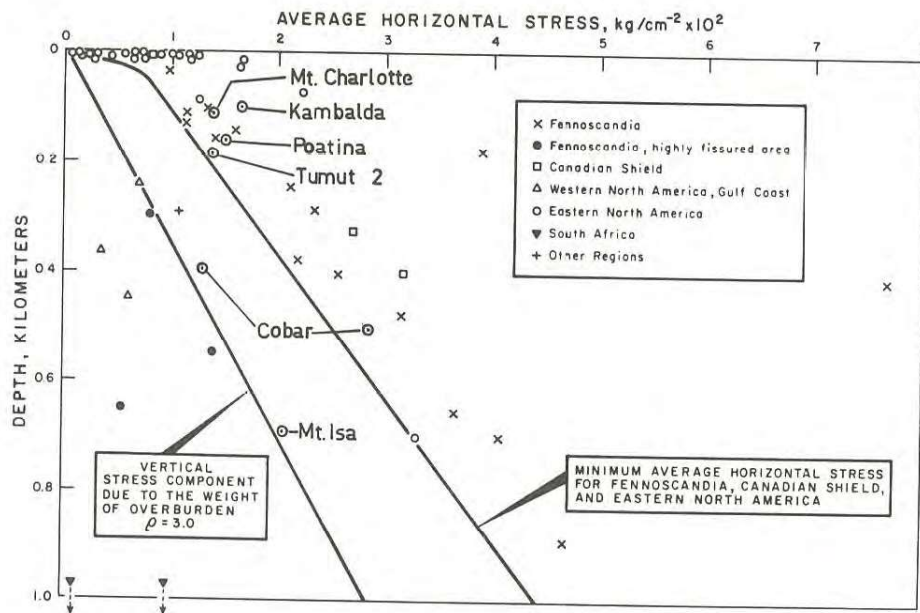


Fig. 2 World Wide Stress Field Results (After Hast Ref. 6)

enough deformation measurements to be made to allow a statistical analysis to be performed to produce the final answers. This condition most probably applies to a mathematical determination of any property of the geological environment.

The virgin rock stress at the Durkin mine was altered when the plat opening was mined thus the "as measured" stress is actually the altered virgin stress.

Using the "finite element" method (Ref.5) both vertical and horizontal sections of the plat were simulated and analyses gave the unconcentrated virgin rock stress that should have been acting prior to excavation of the plat opening.

The rock stress acting approx. 300 ft. below surface in the Durkin Mine was calculated to be

- 3600 psi - horizontal east-west
- 1200 psi - horizontal north-south
- 1080 psi - vertical

These results were particularly significant considering the shallow depth at which they were measured. Fig. 2 is a plot of rock stresses measured world wide by Hast (Ref. 6) and Kambalda results with other Australian measurements are superimposed.

III.-STRUCTURAL GEOLOGICAL INVESTIGATION

The Kambalda Nickel deposits occur on the flanks of a small stratigraphic dome in an ultramafic (serpentinitic) sill like body lying conformably between two meta-basalt formations (Ref. 7).

Most of the detailed structural investigation was carried out on the Durkin shoot. This is generally a tabular ore body dipping approximately 30° to the north and striking approximately east-west with a 10° plunge to the east.

Survey work consisted of:

- (a) Inspection and logging of exploration drill core to ascertain general joint frequencies and positions and inter-relationships of the various Kambalda rock types.
- (b) Detailed underground structural mapping in all available openings in the Durkin shoot area. Using the "random line" logging technique, joints and discontinuities were recorded then plotted and contoured

on equal area stereographic projections, by computer. Fig. 3 gives a typical stereojoint pattern drafted from the computer output.

- (c) Recording physical characteristics of predominant joint types, then triple tube core-barrel sampling of them for shear testing.

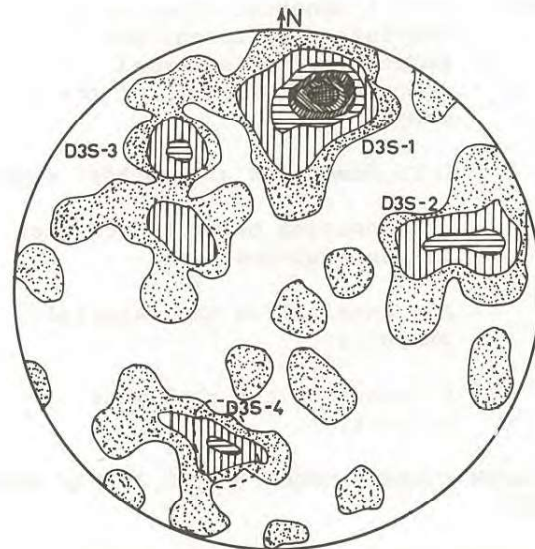


Fig. 3 Joint Contour Diagram

IV.-LABORATORY PHYSICAL ROCK PROPERTY TESTS

A series of laboratory tests was undertaken to determine physical properties of the Kambalda rock types. The various tests carried out were:

- (a) Unconfined compression tests
- (b) Triaxial compression tests
- (c) Tensile (Brazilian) tests
- (d) Joint shear tests using the recently designed and built University of Melbourne shear box (Refer to Paper by E.P. Waghorne to be presented at this conference, for shear box details).

V.-ROCK MASS PHYSICAL PROPERTIES

The method of Protodyakonov (Ref. 9) was used to reduce laboratory test values to those of the rock mass. As the work by Deshwar (Ref. 9) gave accurate predictions of ground movement using Protodyakonov's

technique this method was employed at Kambalda.

The rock structural discontinuity statistics were combined with the laboratory test results in equation (1) to predict the rock mass properties.

$$\frac{P(\text{material})}{P(\text{mass})} = 1 + \frac{b(m-1)}{b+L} \quad (1)$$

where : m is a constant known as mass fracture coefficient and is related to the uniaxial compressive strength of the sample

L is dimension of the test sample

b is spacing between rock mass discontinuities

P (material) is the material property

P (mass) is the rock mass property

VI.-FINITE ELEMENT MODEL OF THE DURKIN SHAFT AREA

A two dimensional computer analysis was made on a vertical east-west section passing through the Durkin shafts. The mining methods and sequences considered were :

- (a) Open slot stoping to two different shaft pillar sizes (ore pillar width = $\frac{1}{2}$ stope width).
- (b) Uncemented or cemented hydraulic sand fill placed in the stopes and then the ore pillars removed.
- (c) Longwall open stoping, retreating towards the shafts.

Stope and pillar layouts on the analysis section are presented in Fig. 4.

The finite element grid is shown in Fig. 5 and extends approximately 400 feet either east or west of the shaft. The model consisted of 399 three or four sided elements connected by 351 nodal points. The element density is greatest around the orebody and shafts as most structural changes occurred in these areas. Also computational procedure becomes more accurate with increasing element density.

The model loading system consisted of a vertical and horizontal tectonic stress field superimposed on a gravity loaded stress field. Model boundary pressures were adjusted until the stresses at the simulated stress measuring site were the same as the predicted insitu field stresses.

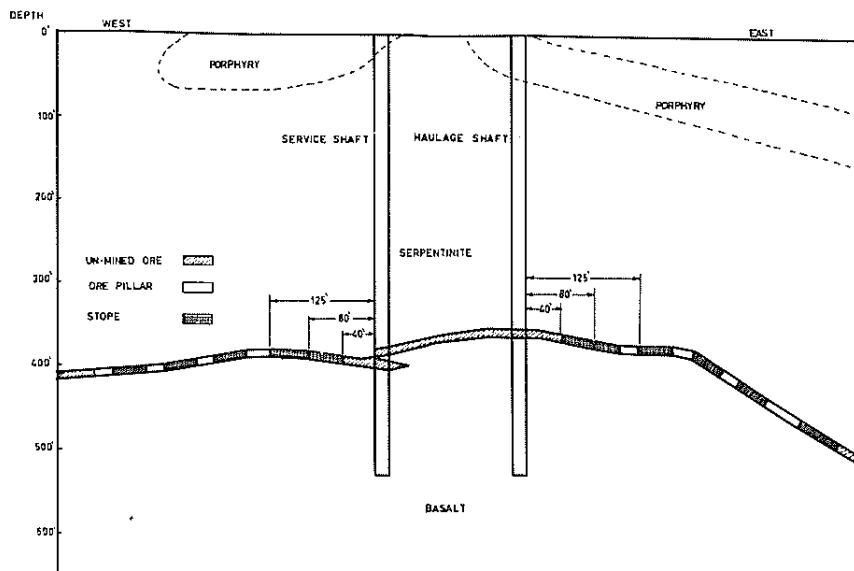


Fig. 4 Stope & Pillar Mining Layouts (E-W Section)

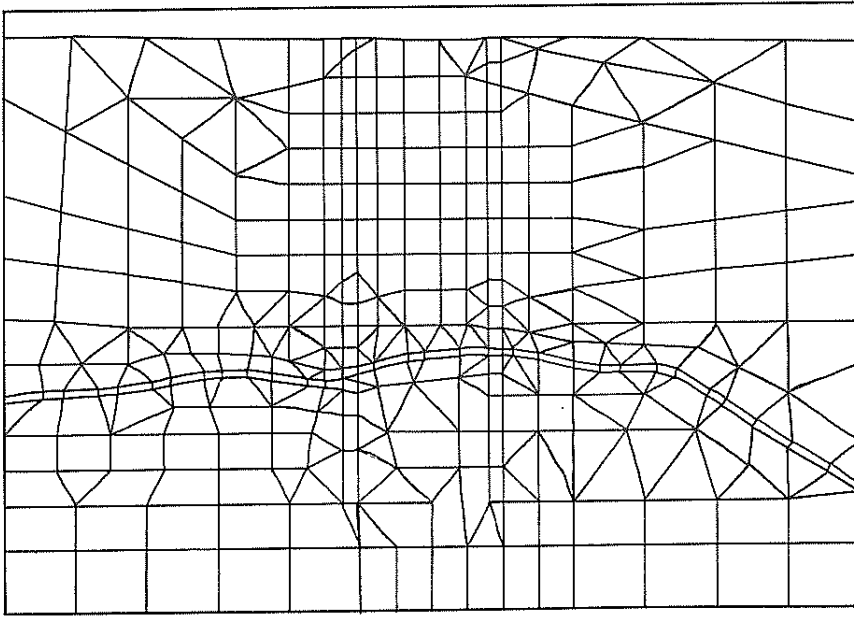


Fig. 5 E-W Section Through Durkin Shafts -
Finite Element Grid

VII.-RESULTS OF MINING SIMULATIONS

Results of each analysis of the various mining alternatives were contour plotted by computer. The plots obtained for each test were :

- (a) Major principal stress (psi)
- (b) Minor principal stress (psi)
- (c) Vertical displacement (subsidence)
- (d) Horizontal displacement

A typical vertical subsidence plot is given in Fig. 6.

From an assessment of all simulations it was obvious that hydraulic fill played very little part in ground control. In reality, it is known that once the rock has failed the fill does control ground movement. The finite element procedure however did not consider inelastic failure and thus caving of rock. This is a limitation in studies of total ground movement. However, prior to failure the fill appeared to provide negligible support.

Wide openings appeared to remain stable probably due to the 'prestressing' horizontal compression of the stope 'backs'.

Stresses within the shaft pillars changed very little in all the simulations thus concrete shaft linings would probably remain relatively low stressed.

Decreasing the shaft pillar radius by mining closer to the shaft brought the subsidence trough (high subsidence gradient) closer towards the shafts. In this case the location of fault or weakness zones would be expected to control any shaft movements.

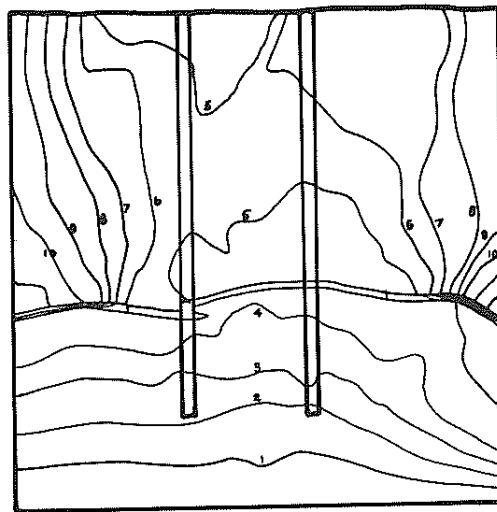


Fig. 6 Vertical Subsidence Plot

Ground movement monitoring stations would thus be required in these regions.

VIII.-CONCLUSIONS & DISCUSSION

The work described above was carried out with the aim of introducing to practising mining engineers the basic requirement of a rock mechanics investigation and to show the use of the data obtained in a structural mine investigation.

The results of the finite element analysis although probably not quantitatively realistic show the relative effects of different mining strategies or sequences.

With continual updating of the mathematical model as more detailed information becomes available the predicted results should quantitatively approach the actual measured values. Only with this constant updating will the method become a major decision making tool for use in long term planning and design.

IX.-ACKNOWLEDGEMENT

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