In situ stresses in mining areas in South Africa

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Synopsis

The safety of mining operations is significantly influenced by the *in situ* stress fields in which the mining excavations are created. From the point of view of planning of mining operations, the *in situ* stress field is a most important input parameter for valid modelling of excavations.

Many *in situ* stress measurements have been carried out for mining and civil engineering projects in southern Africa over the past 30 to 40 years. A database of *in situ* stress measurement results and observations has been compiled. This paper presents results extracted from the database which are considered to be of particular interest to mining areas in South Africa. The database will permit the estimation of likely stress conditions in new areas of mining, provide a basis for evaluation of results from future *in situ* stress measurement programmes, provide a basis for comparison of observed behaviour with expected behaviour, and provide a source of data on which realistic design and layout analyses can be based.

The information contained in the database indicates that horizontal to vertical stress ratios in the Carletonville, Klerksdorp and Rustenburg areas are significantly higher than the value of 0,5 which is commonly used in mine layout planning.

Introduction

The safety of mining operations is significantly influenced by the *in situ* stress fields in which the mining excavations are created. In a physical sense, the stresses may have a beneficial effect in being of sufficient magnitude to confine the rock mass well and thus promote stability. However, if the stress magnitudes are too low, this confinement effect is reduced and instability may result. Conversely, if the stresses are too high, fracture and failure of the rock mass may be induced, again potentially causing instability.

From the point of view of planning of mining operations, the *in situ* stress field is a most important input parameter for modelling of excavations. If the assumed input values for the stresses are incorrect, it is possible that layout or other modelling, and conclusions therefrom, may be invalid. This may have significant and adverse implications for stability and safety.

A database of *in situ* stress measurement results and observations has recently been compiled. This represents an update of the information previously reported by Gay (1975), Orr (1975) and the World Stress Map (Anon. 1997). This paper presents results extracted from the database which are considered to be of particular interest to mining areas in South Africa.

Source of data

Many *in situ* stress measurements have been carried out for mining and civil engineering projects in southern Africa over the past 30 to 40 years. Some of these data have been published, but many are contained in mine, company and owner organization records. Other data of value include observations of stress effects such as borehole breakouts or 'dog earing' in holes, shafts and orepasses. Sourcing of the data has come directly from literature searches, searching of internal libraries to locate technical reports, from knowledge of the location of project file information, and from knowledge of problems which have occurred on mines, such as stress spalling in shafts, which could yield relevant information.

Content of the database

The desired amount of data on *in situ* stress measurements and observations was not always available for each data point. However, where possible, the following information was captured into the database:

- ➤ the location (coordinates and depth below surface)

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- the mine or project
- the rock type in which the measurement was made, and its deformation properties
- the geology of the area
- the *in situ* stress components in the north-south, east-west and vertical directions, and the corresponding shear stress components
- the *in situ* principal stresses and their orientations relative to north
- an estimate of the overburden stress
- comments relevant to the measurement
- gradings of the qualities of the individual measurements and the groups of measurements on a subjective/quantitative basis.

Measurements or observations were captured into the database as individual records, and as a group of records obtained at a single site. Prior to entering the data, the quality of the data was evaluated and graded. Gradings of record quality were generally made for both the individual records and the group records. The descriptions of the various data grades are given in the Appendix.

As can be seen from Figure 1, there is a reasonable distribution of *in situ* stress data across South Africa.

In situ stress conditions in mining areas of South Africa

Of interest with regard to mining operations are the orientations of the horizontal secondary principal stresses, and the ratios of these horizontal stresses to the overburden stress. Figure 2 shows the orientations of the better quality data. It can be seen that the horizontal secondary principal stresses tend to be aligned approximately in the NW-SE and NE-SW directions in most locations.

The major and minor horizontal secondary principal stresses are plotted in Figures 3 and 4, respectively, as a function of depth. The ratios between the major and minor horizontal stresses and the vertical stresses are plotted in Figures 5 and 6 respectively, as a function of the depth. The general trend is that the horizontal values are equal to, or greater than, the vertical stresses. It is known that the Northern Cape is a high horizontal stress area (Nieuwoudt and Rozendaal, 1990) and that, at shallow depths, horizontal stresses commonly exceed the overburden stresses. In addition to this, however, the data for the Carletonville, Klerksdorp and Rustenburg areas, indicated clearly on Figures 3 to 6, show that horizontal stresses are also significant in these areas. It can be seen that the assumption of a horizontal to vertical stress ratio of 0,5, which is commonly made for mining layout analyses, is generally not valid. The implication from this is that the effect on mine layout design criteria of horizontal stresses differs from the 0,5 ratio commonly assumed and should be evaluated. It can also be seen that the major and minor horizontal principal stress components are not equal. The effect of this on mine layout planning also needs to be evaluated.

Conclusions

The database of stress measurement and observational data that has been developed will provide the mining industry with a valuable source of information. The database will permit:

- estimation of likely stress conditions in new areas of mining
- a basis for evaluation of results from future *in situ* stress measurement exercises
- a basis for comparison of observed behaviour with expected behaviour
- a source of data on which realistic design and layout analyses can be based.

From the information contained in the database it has been shown that horizontal-to-vertical stress ratios in the Carletonville, Klerksdorp and Rustenburg areas are significantly higher than the value of 0,5 which is commonly used in mine layout planning.

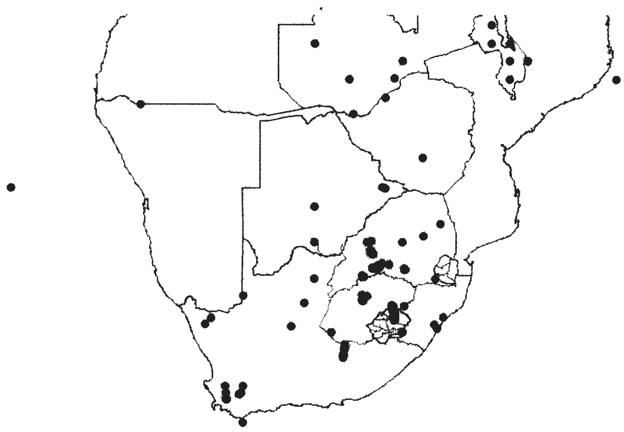

Figure 1—Locations of *in situ* stress measurements data

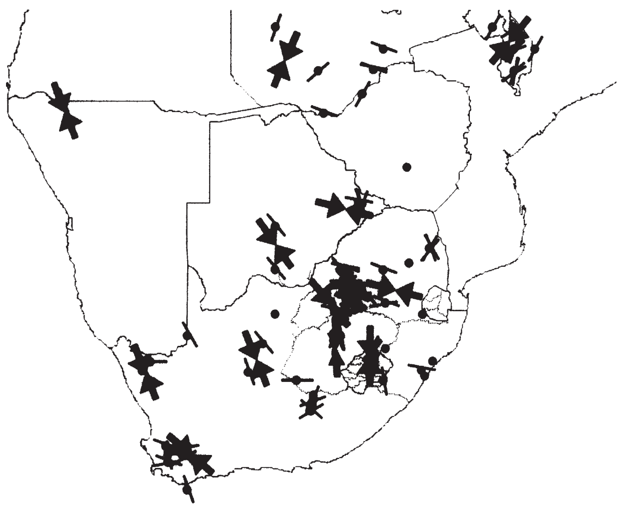

Figure 2—Orientations of the major horizontal stresses

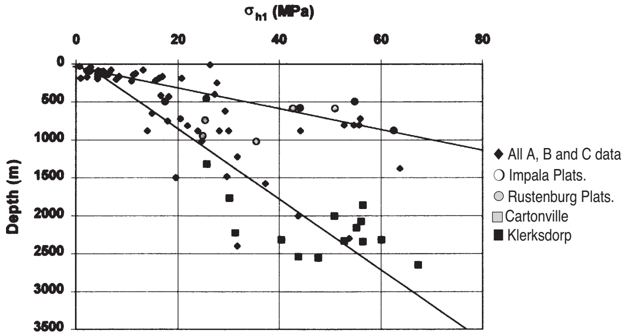

Figure 3—Stress vs depth

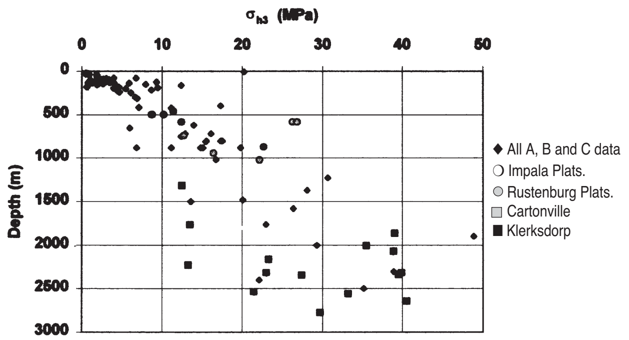

Figure 4—Major horizontal stress vs depth

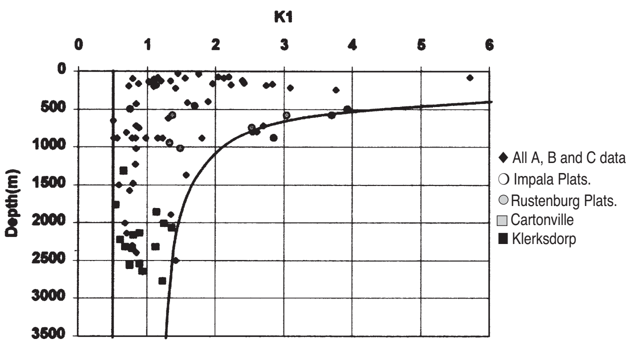

Figure 5—Major horizontal K1 vs depth

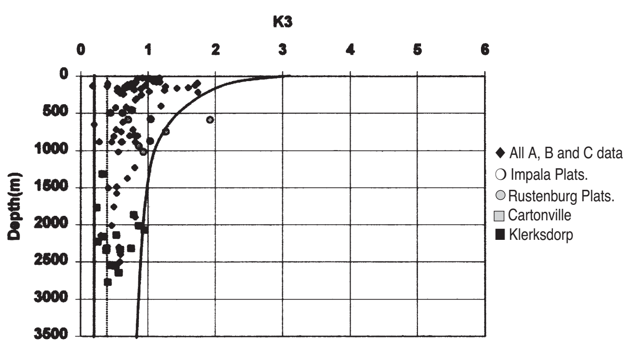

Figure 6—K3 vs depth

Appendix: Grading of data

Group measurement grading

Grade A

a) Physical measurements, such as overcore, rock slotter, hydrofracture, etc, in which measurements were carried out in two or more boreholes beyond excavation influence, and the results of at least 80% of the measurements are in close agreement (normal stress components (Sx, Sy, Sz) generally within approximately 10% of the average).

b) Direct physical measurements of breakout (dog ear) orientations (where breakouts can be seen visually, not by remote observation) in vertical or sub-vertical circular excavations such as bored shafts or ore passes, and where the breakouts persist over a length of at least three diameters.

Grade B

a) Physical measurements, such as overcore, rock slotter, hydrofracture, etc, in which measurements were carried out in two or more boreholes beyond excavation influence, and the results of at least 50% of the measurements are in close agreement (normal stress components (Sx, Sy, Sz) generally within approximately 20% of the average), or where the measurements are of Grade A quality, but have been carried out in a single borehole.

b) Remote physical measurements in vertical or subvertical shafts or ore passes in which breakouts persist over a length of at least three diameters, or in boreholes in which breakouts persist over a length of at least 10 metres.

Grade C

a) Physical measurements, such as overcore, rock slotter, hydrofracture, etc, in which measurements were carried out in two or more boreholes beyond excavation influence, and the results of at least 50% of the measurements are in reasonable agreement (normal stress components (Sx, Sy, Sz) generally within approximately 35% of the average), or where the measurements are of Grade B quality, but have been carried out in a single borehole.

b) Direct or remote physical measurements or good quality estimates in vertical or sub-vertical shafts or ore passes or boreholes in which breakouts persist over a length of less than three diameters, or in boreholes in which breakouts persist over a length of less than 10 metres.

Grade D

a) Physical measurements, such as overcore, rock slotter, hydrofracture, etc., in which measurements were carried out in two or more boreholes beyond excavation influence, and the results are indicative of trends in both stress and orientation components (normal stress components (Sx, Sy, Sz) generally within 50% of the average), or where the measurements are of Grade C quality, but have been carried out in a sinlge borehole.

b) Direct or remote physical measurements or estimates in vertical or subvertical shafts, ore passes or boreholes in which breakouts are very localized.

Grade E

a) Physical measurements, such as overcore, rock slotter, hydrofracture, etc., in which results are too variable to indicate trends in both stress and orientation components.

b) Direct or remote physical measurements or estimates of breakout orientations which give contradictory indications.

b) Measurement data with inconsistencies which could not be resolved.

Individual measurement grading

For overcore stress measurements it is possible to calculate a standard deviation for the normal stress components. Where the values of the standard deviations were provided in the sources of data, the following system was used to grade the individual measurements. The maximum value of standard deviation of each of the normal stress components (stdSx, stdSy, stdSz), as a percentage of the normal stress component (Sx, Sy, Sz), was used as the grading parameter. The grades were assigned according to the following ranges in the grading parameter:

Grade	Grading Parameter
A	<20%
B	20% - 30%
C	30% - 40%
D	40% - 50%
E	>50%

Acknowledgements

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Underground 'Spraypond' in Tuks lecture room

Final year students from the University of Pretoria recently designed and built a fibreglass spraypond, to simulate the actual cooling of air in a deep underground mine. According to the lecturer in charge of the project, Mr Ronny Webber, the experiment was a great success, as it gave the students the chance to be involved in the actual design and working of a typical spraypond underground. At this stage, ice is used to provide the cooling that is needed in the fibreglass chamber, while a heater and fan arrangement supplies the hot air to the 'tunnel'. Experimental results have shown that the energy calculations that were done from the experiment, were fairly accurate. Professor Andre Fourie of the Department of Mining Engineering has said that the Mining Department has, for the last few years, embarked on Problem Solving Based Education and that experiments like this one, really helped in developing the actual practical skills of the students involved and also to understand the actual problems related to 'real life' mining. ◆

Final year students with Mr Ronny Webber at the spraypond built at the Department of Mining Engineering of the University of Pretoria