Australian Centre for Geomechanics Newsletter – 2002

Interpretation of microseismic monitoring data using numerical modelling

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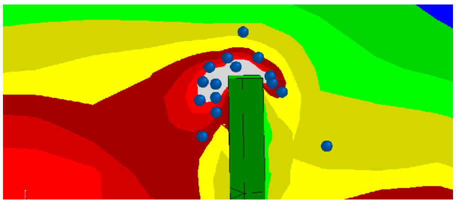
Microseismic monitoring is generally implemented for the purpose of improving our understanding of how the rockmass behaves in response to mining. To make use of this data, it must be related to tangible aspects of the rockmass response. While very reliable observations of exactly when events occur can be obtained, it is much more difficult to accurately determine where these took place, and even more difficult to determine exactly what happened (i.e. what physical mechanism occurred). Interpretation is necessary to get the most from this data and meet our monitoring objectives. As numerical modelling simulates the rockmass response, it can be used to test a variety of possible mechanisms and hence provide explanations for the observed seismicity. Since microseismic data is often expensive and difficult to obtain, the added work required for quality interpretation is readily justifiable.

Comparison of microseismics and modelling to determine far field stress orientation.

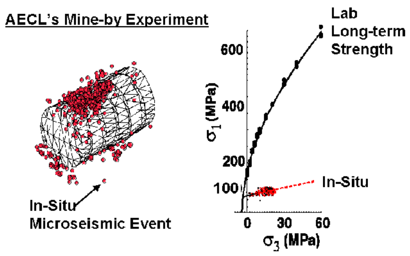
The geometric pattern of seismic activity reflects the orientation of the stress concentrations.



In this example illustrated above, seismicity was used to determine the far field stress orientation. Multiple stress analyses were conducted on the same geometry, but with many different orientations for the far field stress. By finding the best match between contours of maximum shear stress ½(σ_1-σ_3) and observed seismicity, the orientation of the far field stress can be inferred. Of course, far field stress orientation can also be inferred by looking at the orientations of the most seismically active structures across the mine. More detailed investigations could be used to determine whether the stress orientation changes as mining progresses into new areas.

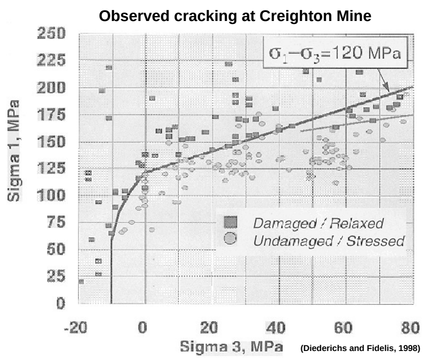
Comparison of microseismics and modelling to delineate seismically active/fracture zones.

The presence of seismic activity indicates when and where new cracks are forming.

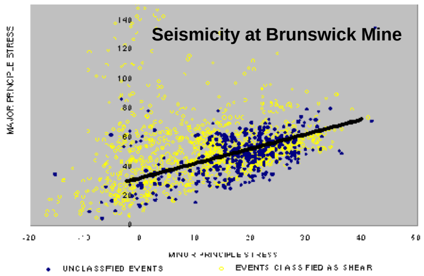


(Martin, 1997)

At AECL's underground research laboratory (Martin, 1997), stresses were calculated at seismic event locations. It was found that these stresses could be fit by a line given by $\sigma 1 - \sigma 3 \approx 60$ MPa.



At Creighton Mine, Landriault (1989) observed cracking around advancing mining using a borehole camera. Subsequent stress analyses by Diederichs and Fidelis (1998) showed that the extent of the cracking could be described by $\sigma 1 - \sigma 3 \approx 120$ MPa.



(Beck, 1998)

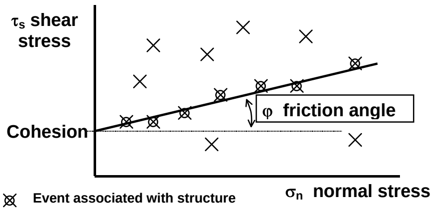
A similar result was found at Brunswick Mine (Beck, 1998). Here, after events classified as being associated with structure were removed (more on this below), it was found that these stresses could be fit by a line given by $\sigma 1 - \sigma 3 \approx$ 30 MPa.

These three back analysis examples suggest that the extent of cracking ahead of advancing mining, whether observed with a camera or from seismic activity, shows a strong correlation with numerical modelling. Here we have characterized a rockmass strength parameter that can be used to predict when and where we expect cracking to occur.

Repeated back-analyses could be used to determine whether this strength parameter changes value as mining progresses into new areas. This would allow us to identify locations where the lithology is changing, possibly the first step in identifying hazardous anomalies. This also allows us to identify seismicity that fails to fall into this pattern, and must be attributed to some other mechanism.

Comparison of microseismics and modelling to characterize shear strength properties

The presence of seismicity indicates where structures are active.



(after Beck, 1998)

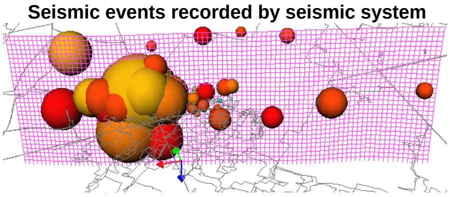
At Brunswick Mine, stresses were calculated at seismic event locations (Beck, 1998). The local shear and normal stresses at the orientation of each of three know joint sets were then determined. By comparing these local stresses to a strength envelope it was found that events could be classified as being either associated with either one of the three joints sets or the intact rockmass (this was illustrated above).

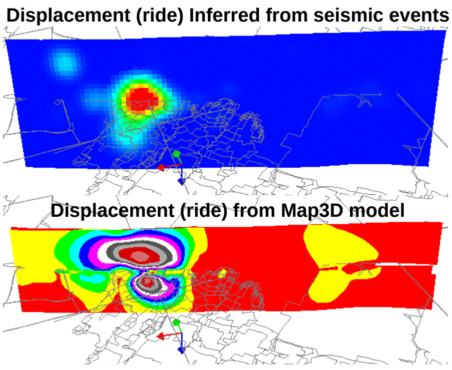
Here we have distinguished between events whose source lies in the "intact" rockmass versus those that can be associated with local jointing. Back-analyses were used to characterize the strength properties for each joint set and the intact rockmass. It is easy to see how this same concept could be extended to characterize major faults or dyke properties as well.

Comparison of microseismics and modelling to identify seismically hazardous anomalies

Analysis of seismicity can provide indications of the magnitude of displacement and stress drop, as well as when and where this occurs.

Seismic events recorded by seismic system



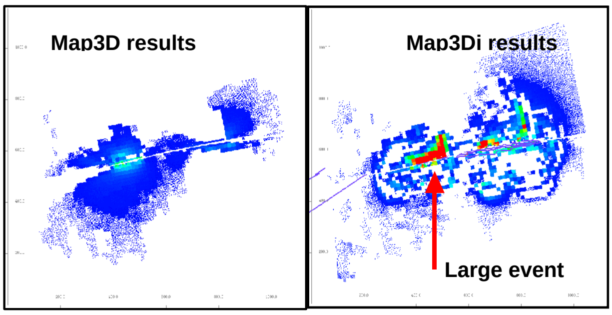


At a gold mine in the Klerksdorp area, South Africa (Hoffman. 2002), the seismic moment of the events was used to determine the cumulative displacement occurring on a fault. A non-linear fault slip model was run to determine the ride expected on the fault. The seismic displacement can be compared with the modelled displacement to identify potentially hazardous anomalies where the modelling predicts slip, but the seismicity has yet to occur.

Similar comparisons have been made by comparing apparent stress determined from seismicity, with modelled shear around an ore body. Hazardous anomalies are identified as locations where the modelling shows large excess shear stress, but the seismicity does not indicate large apparent stress (van Aswegen, 2002).

Coupling of microseismics and modelling to identify seismically hazardous anomalies

The above comparisons can be approached differently if instead of modelling the non-linear fault slip response (Map3D), we use the seismically determined displacements to prescribe the ride on a fault slip surface in the model (Wiles, Lachenicht and van Aswegan, 2001). When this latter stress analysis is run (Map3Di), it has the effect of dissipating excess shear stress in the seismically active areas, and redistributing stress to adjacent locations.



At Tautona mine (Lachenicht, Wiles and van Aswegan et al, 2001), the differential excess shear stress (difference between subsequent mining steps) was calculated from modelling. The results on the left and right show respectively results without and with the prescribed ride (determined from the seismicity) included in the analysis. The results on the right give a very clear indication of the magnitude 4 seismic event that occurred at this point in the mining sequence.

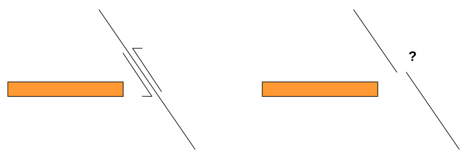
Coupling of microseismics and modelling too directly calibrate models

Model calibration normally proceeds by trial and error, attempting to determine model parameters that give us the best match with observed behaviour. We have little choice except to assume that strength parameters are uniformly distributed (e.g. across fault surfaces). However, by coupling microseismics with modelling, we have an opportunity to determine the heterogeneous strength distribution required so that our model will match exactly the observed response.

Once the stress analysis, incorporating the prescribed ride determined from the seismicity (Map3Di), is complete we can determine the redistributed shear and normal stresses acting on the fault surface. From these stresses it is relatively straightforward to back-calculate the shear strength distribution across the fault surface. If we now use this heterogeneous shear strength distribution to build a non-linear fault slip model (Map3D), it will deform with exactly the same ride distribution as originally observed from the seismicity. This gives us a model with two distinct features:

- Firstly, this model matches currently observed in situ conditions. In other words, the ride distribution on the fault matches the distribution inferred by the seismicity.
- Secondly, we have characterized the behavioural properties of the fault; i.e. we have determined the strength distribution necessary to bring about the observed deformations on the fault.

Such an heterogeneous strength distribution would likely include zones with high strength, where modelled stresses are high but slip has not yet been observed to occur. These zones can be considered to represent asperities on the fault surface.



I think it is clear that the resulting model is far better calibrated to observed in situ conditions than one could ever hope to achieve by using a best-fit homogeneous strength assumption. A homogeneous strength assumption would not allow for characterization of the observed asperity. It would appear that the procedure described here offers us an opportunity not only to locate detailed features such as offsets in faults, but also to go a long way towards characterizing their strength properties.

The author believes that a model calibrated in this way has the best chance of making accurate predictions that closely match in situ behaviour.

Conclusions

The use of numerical modelling for interpretation of microseismic monitoring results provides many opportunities to better understand and characterize rockmass response to mining. The coupling of these tools gives us a technique that can be economically used to identify geologic features that act as critical flaws in the rockmass response. I anticipate that use of this methodology will go along way towards improving the accuracy and reliability of model predictions.

Please forward comments or questions to support@map3d.com

Acknowledgements

Many of the ideas presented here are credited to R. Lachenicht and G. van Aswegan of ISS International.

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