The Key to Safe, Sustainable Mining

Rock mechanics – the science of how rock and rock mass behave – is a complex world containing some of nature's best-kept secrets. In modern mining, however, it serves only one purpose – to provide a basis for safe, productive, and sustainable operations.

In order to control rock, miners must first acquire an understanding of how rock behaves, both in its undisturbed, natural state, as well as in relation to stress when that natural state is disrupted as mining progresses. This requires a thorough knowledge of rock mechanics.

Rock mechanics will reveal the natural characteristics and behaviours of rock and rock mass, but more importantly it is used to assess how the rock is most likely to react under stress and disturbance caused by various types of excavation.

For the mine planner, the primary objective is to use the information gained through the study of rock mechanics to design suitable rock reinforcement systems that will provide a safe, productive, and sustainable working environment.

Characteristics

In order to assess the reinforcement requirements of a mine, the basic characteristics of the rock types in the mining area are a good place to start.

The mine planner needs to establish:

- A definition of the structural fabric of the rock mass, including aspects such as joints, faults, shear zones.
- An evaluation of the mechanical parameters of the intact rock and structures.
- An identification and quantification of the failure modes based on stress and structural analysis.
- The influence of the excavation mode, and the design of the rock reinforcement itself.
- Water flow and water pressure.

Stresses, rock strength, water pressure and rock structures are the four most important factors affecting the stability of any excavation in natural strata material. The combinations of various stress regimes and jointing will dictate the behavior of the excavation. The intensity of rock stresses varies from very low to very high, and the intensity of jointing from massive rock to sugar cube structure or intensely schistose, as shown in Figure 1.

Massive rock will draw most of the intact rock strength, but it will also accumulate load and can fail violently under the right conditions. Very fractured rock will tend to yield to stresses and often deforms in a problematic manner. In addition, the shape, size and orientation of the excavation also affect the way the rock mass responds.

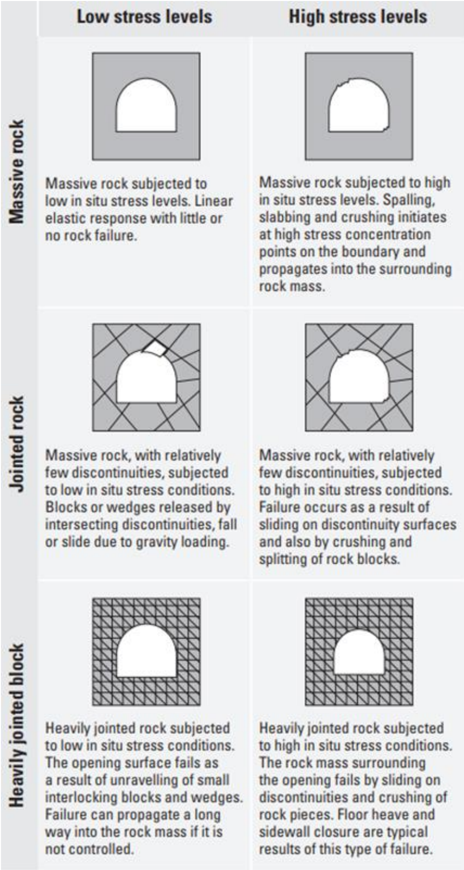

Figure 1: Stability challenges as a consequence of stresses and rock structure. Source: Support of Underground Excavations in Hard Rock, Hoek E., P.K. Kaiser and W.F. Bawden. 1995, Balkema.

With this basic knowledge in hand, the next step is to understand the actual structure and strength of the rock in and around the mining area. This is done using a combination of methods, including systematic core evaluation, mine mapping and seismic measuring.

Today's seismic systems using geophone accelerometers (GAC) and advanced software for modeling and measuring seismic events and stress changes over the lifetime of a mine are invaluable tools, and these systems, together with core sampling using advanced exploration drill rigs, make data collection easier and more reliable than ever before.

By using the information gained from a series of closely positioned exploration holes, engineers obtain a total picture of the rock mass in a given area, which will have a large impact on how infrastructure and mine design models are computed. Equipped with a wireline system, today's exploration drill rigs are capable of extracting quality core samples from as far down as 3 000 m.

After rock samples have been taken, they are then subjected to different types of investigations such as Uniaxial Compressive Strength (UCS), whereby a core sample is compressed in the actual direction until failure. Stress analysis using analytical or numerical methods is also more commonly performed on site, and the results are also easier to analyze thanks to today's advanced computer software that offers 3D visualization and multiple options for data storage (see Figure 3 and 4). In addition to the diamond drilled core that has been obtained, a number of additional probing techniques will be employed, including over coring and hydraulic fracturing, both of which are used to measure in situ stress levels.

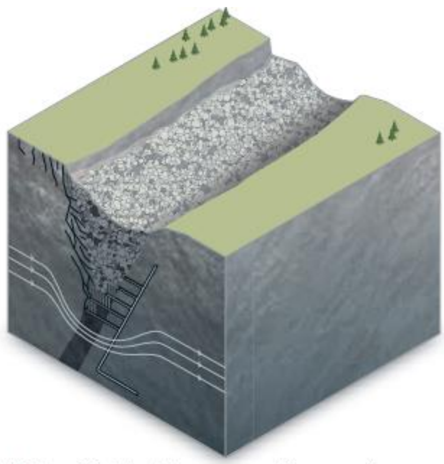

Figure 2: Buildup of high-level stresses around the excavation area, a problem that increases with depth.

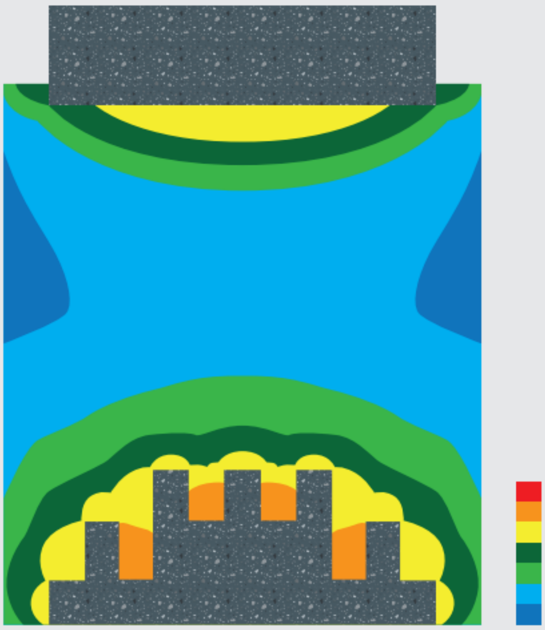

Figure 3: Stress changes in sublevel open stoping as mining proceeds upwards. The warmer the color, the higher the stress.

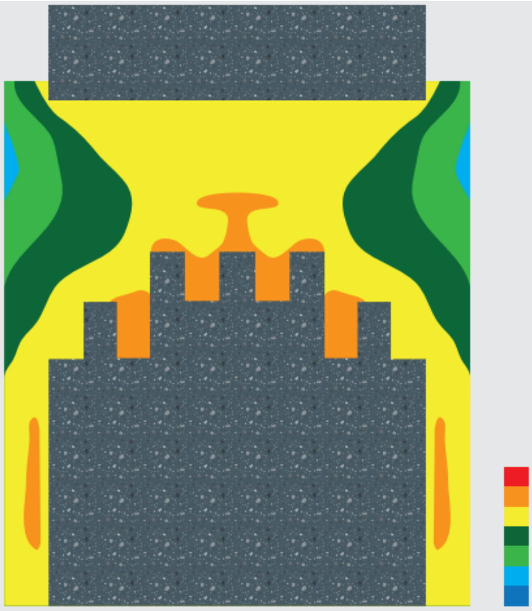

Figure 4: Gray indicates the area that is mined out and backfilled. The smaller the above-lying ore pillar gets, the higher the stresses in the remaining ore become.

However, it must be kept in mind that despite the accuracy of modern technology, stress analyses are not foolproof, and there is always an element of uncertainty and unpredictability. A sudden rock burst or an unexpected rockfall can always occur and the repercussions are often severe. Therefore, a wide margin of error and over-dimensioned rock support is the safest policy. As an example, when hard and massive rock fails as a result of high stress, it generates all manner of fragmentation from small to large blocks. This is a clear sign that the rock is overstressed and is rupturing in a brittle and uncontrolled way.

This could also be the precursor of bigger seismic events and dynamic failure. It is, therefore, imperative that the rock reinforcement system is designed specifically to cope with this possibility in mines facing this problem. If, on the other hand, rock support is carried out without taking seismicity into consideration, the system will almost certainly not be able to withstand a seismic event of high magnitude, irrespective of the extent of the support, the quality of the equipment or how well the system has been installed.

Numerical modeling

Long-term excavation planning can benefit from detailed analysis such as numerical modeling. Stress regimes can be predicted, and mining sequences optimized to keep the stress levels evenly balanced. It is crucial, however, as stress fields are changed continuously during mining, that rock mechanics engineers are always aware of this factor and employ rock reinforcement whenever critical stress levels have been predicted. The trick is to avoid increased stress in notoriously sensitive rock areas, such as in competent rock where structures are known to fail considerably.

For day-to-day operation, numerical analysis will give results that must be confirmed by field observation, but can be used to plan with the right kind of conditions in mind. This applies especially for the rock reinforcement and support aspects. Some rock reinforcement and support that can be perfect for static conditions may become quite inadequate when confronting seismic events or high stresses and deformations. It is then important to be able to predict future conditions, and use rock reinforcement that will still be adequate when conditions change, or will warn when in situ conditions are close to exceeding the rating of the chosen support system.

Growing awareness

These days, whenever a new mine is planned, rock mechanics is invariably involved right from the beginning. This reflects a growing awareness of the importance of safe and sustainable mining. In addition, it shows a greater appreciation for the negative consequences of frequent disruption to operations in terms of lost-time injuries and productivity losses. At the same time as rock mechanics is becoming recognized as an indispensable element of mine planning, a great deal of research is also being conducted into sequence planning with a view to improving the excavation process, further contributing to safety and sustainability. As a science, rock mechanics is not new. But what are new are the tools that enable calculations and assessments of rock structures and the enormous possibility for data collection.

If a mine is to be planned for sublevel stoping, to use one example, through access to rock mechanics data, the mine manager will ascertain the exact shearing capacity and compressive strength, say 300 MPa, of the rock mass. He or she will then know which rock bolts and what other type of rock reinforcement to employ, and how frequently it should be carried out to secure the environment for infrastructure and mining operations.

It is certainly true that rock reinforcement has advanced tremendously since the wooden posts and beams of the early days of mining. The availability of numerical models that can be run through computer software and the active transfer of knowledge and technology between research and mining operations are unprecedented.

This, coupled with the development of modern drilling and core sampling technology, has enabled mines all over the world to develop fast and effective rock reinforcement practices that benefit safety as well as productivity. Nevertheless, the mining engineer can never stop learning about the challenge of controlling rock, and clearly, the more knowledge that is gained about rock mechanics the better.