Why Rock Stress Matters and How to Measure It

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In all cases of dealing with rock there needs to be some idea of the stress levels that are being dealt with, how they relate to the rock mass and the planned mining method. This may simply be by an observation of the situation. For example, if the rock mass contains open joints or joints that are filled with soil, or highly weathered material, the stress transmitted across these will be negligible and any design within that rock mass will be governed by gravitational forces. If a rock mass exists that contains frequent, persistent jointing then the stress within it is likely to be controlled by the friction within the joints. Depending on the joint orientation this may be determined by gravity. It is possible to have highly variable levels of stress in near surface rocks as well as those at greater depth. The more competent the rock, the more variability may be found, as joint friction ceases to be a limiting factor on stress.

Figure 1: Sigra IST stress measurement tool in use in HQ wireline coring

Stress matters because it controls virtually every aspect of mining or excavation. A mine requires stability in its permanent development works. If the stress level is too low then there is a lack of friction within the rock mass and blocks may drop out of the excavation. If the stress is too high then rock failure may occur. Failure may be due to shear or the development of tensile stress around stress concentrations. The manifestation of failure under high stress may be in many forms depending on the rock type. It may be shear along the bedding plane, strain bursts, the yielding of pillars or compressional failure of a shaft. Examples of these are shown in Figure 2.

A mining method may also require a particular stress level for the operation of the extraction process. For example, block or sub level caving operations require the rock to cave. If the rock is jointed then it will probably do so under gravity unless the rock stress provides too much friction across the relevant joint sets. If the rock lacks joints, or has jointing at an unfavourable orientation for caving process to take place, then caving will only work if the rock stress is adequate to cause failure of the rock mass. In the absence of this either preconditioning of the rock mass will be needed or another mining method found.

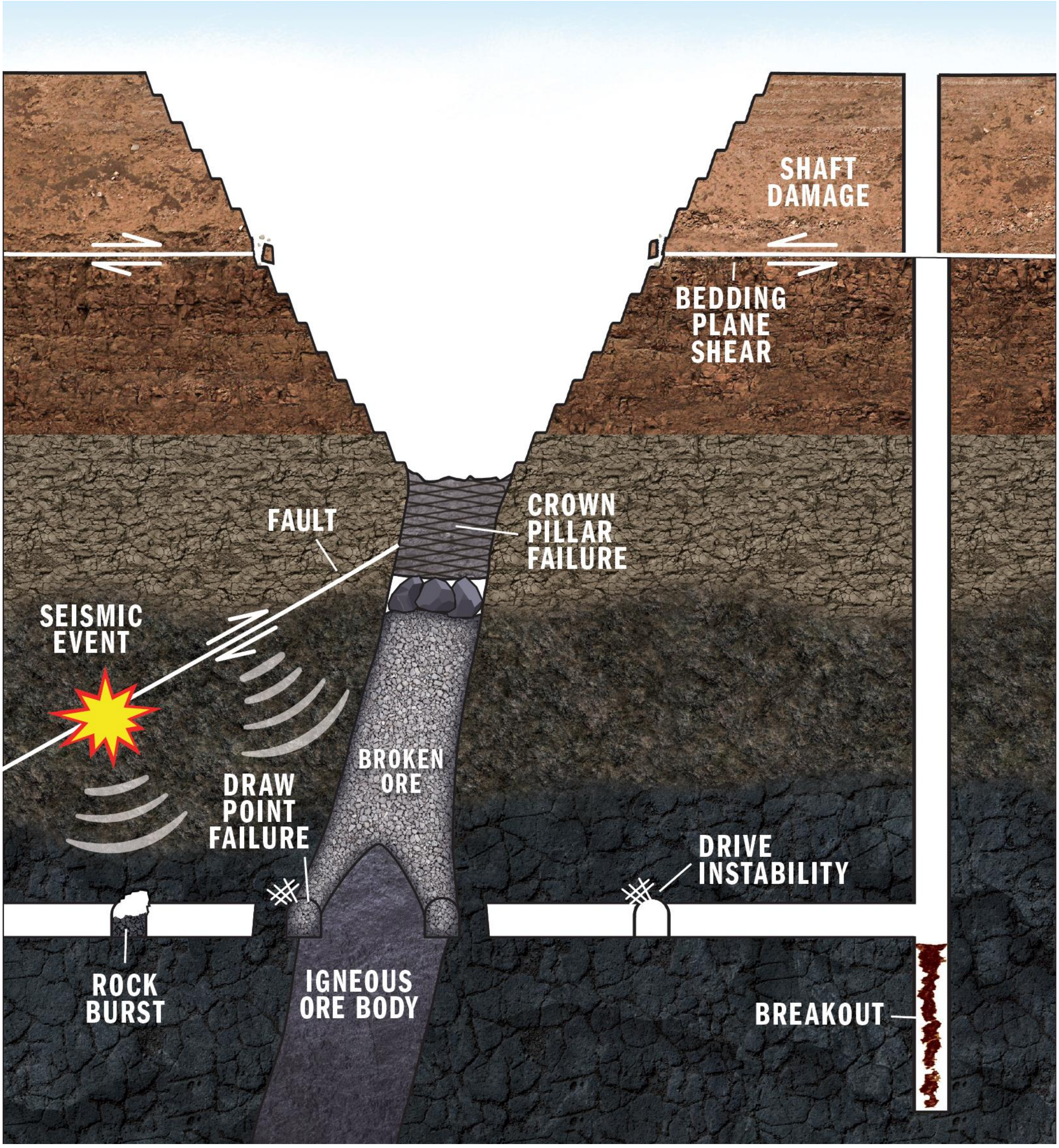

Figure 2: Various rock failure manifestations due to rock stress

Preconditioning of the rock mass may be achieved by the use of hydrofracture or explosives. Explosives have a short range while hydrofractures may extend significantly further. The use of hydrofracture is controlled by stress in the rock mass in two ways. Firstly, the hydrofracture pressure must be adequate to break the rock around the borehole, and secondly, in the direction in which the hydrofracture progresses. In a homogeneous rock mass the hydrofracture will progress normal to the minor stress. In the presence of joints the hydrofracture may be captured by these. This will depend on the relative difficulty the fracture meets in breaking rock and progressing in the direction of minimum stress compared to that required to progress up the joint at a higher minimum stress level.

It is necessary to know the level of stress to determine whether an unassisted caving operation can work, and if preconditioning is required, it is also necessary to know the stresses to be able to design it.

Open pit mining also requires an understanding of the state of rock stress. This may be to decide that limit state analysis under gravitational loading is adequate for design. However, if the horizontal stresses are of adequate magnitude then rock failure may take place. For example, an excavation may release the lateral stress on a bedding plane and shear on that plane occurs. This sort of behaviour has caused major blocks to be ejected into the pit. Excessive stress may also cause the pit base to heave and while this may be regarded as free mining, it is too uncontrolled. It will not provide a suitable sizing of either ore or country rock for ease of transport or processing, and will cause personnel serious concerns about their safety. It also causes drilling and blasting problems.

While on average the vertical rock stress is determined by the gravitational load and increases linearly with depth, the horizontal stress distribution is generally much more complex. The quaint idea that some factor relates horizontal to vertical stress is generally incorrect and geotechnical engineers should stop making this assumption. It is wrong!

The lateral stress in rock is substantially controlled by rock strain. If we strain any solid it will develop stress depending on its mechanical properties. These mechanical properties are its Young's moduli, Poisson's ratios, plastic behaviour and the limiting factor of rock strength – yield or fracture. Let us take the simple example where we have three square section bars, one of steel, one of aluminium and one of wood. We can glue these together and squeeze them as a group in a very stiff vice so that they are all strained to the same extent. As a result the stress in the steel will be three times higher than that in the aluminium which will be higher than that in the wood. Rocks behave similarly; they have very different Young's moduli and stiff rocks will change their stress much more than soft rocks subject to the same strain change.

The processes within the rock mass that control lateral stress are the vertical stress and the lateral strain. In a zero lateral strain environment then the lateral stress is directly a function of the vertical stress and is governed by Poisson's ratio. However very little of the earth's crust lacks lateral strain. On the large scale this may come from tectonic plate movement, and may on the more local scale be affected by faulting, folding and temperature change. Erosion changes the vertical stress and may lead to failure of the rock mass through the development of reverse faults or multiple joints as confinement is removed. Rock stress is not a static phenomenon. As the earth's crust moves and erodes it changes. It is possible to have sudden swings in direction of principal stress due to stress relief caused by a fault movement. Faulting is generally not continuous; it occurs in the rock mass that is stressed to the extent that it fails. The loading is then shifted so that another rock group will carry more stress. Fault tips are zones of stress concentration and may cause mining problems.

The concept of a local tectonic strain is useful in analysing stress distribution. In this the rock mass self- weight is considered to provide the vertical stress. In a zero lateral strain environment the lateral rock stress due to gravity may then be calculated. If the stress is measured then this self-weight component of lateral stress may be subtracted from the total stress to arrive at the stress that is brought about by tectonic strain. The tectonic strain term here incorporates true tectonic strain, flexure in folds, the effects of faulting and cooling. Tectonic strain is frequently fairly constant while stress varies widely depending on the rock stiffness.

The task for mine design is to determine what the stress distribution actually is. This requires measurement. It also requires measurement where the mine will be, even if some mining has already taken place. It is no good measuring far field stress one or two kilometres from the mine so that the effects of stress concentration brought about by mining may be discounted.

This concept of a uniform far field stress is generally nonsense. There are many factors that may change the stresses between the measurement point and the mine. The more complex the geological situation then the more complex will be the stress distribution.

Stress measurement is conducted in boreholes and may be broken into two groups.

The first group is for rock that does not fail in the borehole. In this case examination of the borehole will yield no information on stress. The standard process is to measure the stress by the process of overcoring. Overcoring involves drilling a pilot hole or cone in advance of a core hole. Into this a cell is fitted that measures diameter or strain change of the rock. This is then cored over and the change in diameter or strain is measured.

The determination of stress from this requires the rock to behave elastically, though not necessarily linearly. The elastic properties and the change in diameter or strain are used to calculate the stress. This process can be achieved using a tool that measures the diameter change of the pilot hole. In this case the axial stress needs to be assumed and then the transverse major and minor stresses may be calculated. This process using Sigra's IST2D tool fits neatly into a wireline drilling operation using Boart Longyear's HQ-3 coring (96 mm hole and 60.9 mm core). In this case if the hole is vertical the axial stress is assumed to be that due to gravitational load. It is possible to measure stress at 400 m depth in two hours and at 800 m depth in 3 ½ hours. The tool is shown in Figure 1. If the hole is not vertical or there is no basis for assuming the stress in the axis of the hole then overcoring using a three dimensional tool may need to be undertaken. This tool is conical and is glued into a cone at the end of the hole. The process takes longer because the IST3D tool needs strain gauges to be glued in place. Each stress measurement will therefore take at least 12 hours and is normally spread over 24 hours, allowing the glue to set overnight.

The second group of stress measurement is in rock where the borehole wall fails. Here the first indication of stress is the degree of borehole breakout as shown in Figure 3. This occurs due to the concentration of stress around the hole which causes opposite sides of the hole to fail compressively. Occasionally high ratios of major to minor stress lead to a tensile failure in the borehole wall. Borehole breakout is an indication of the ratio of the tangential stress at the hole wall to the compressive strength of the rock in that direction. It is a direct indicator of whether failure around an opening may be expected. The complete analysis of stress around a hole wall from breakout is not possible as the stress at the hole wall is a combination of the major and minor stress, the rock strength and the fluid pressure. It is a good indicator of stress direction and it is easy to measure using an acoustic televiewer image. Similarly, larger breakout failures may occur in shafts.

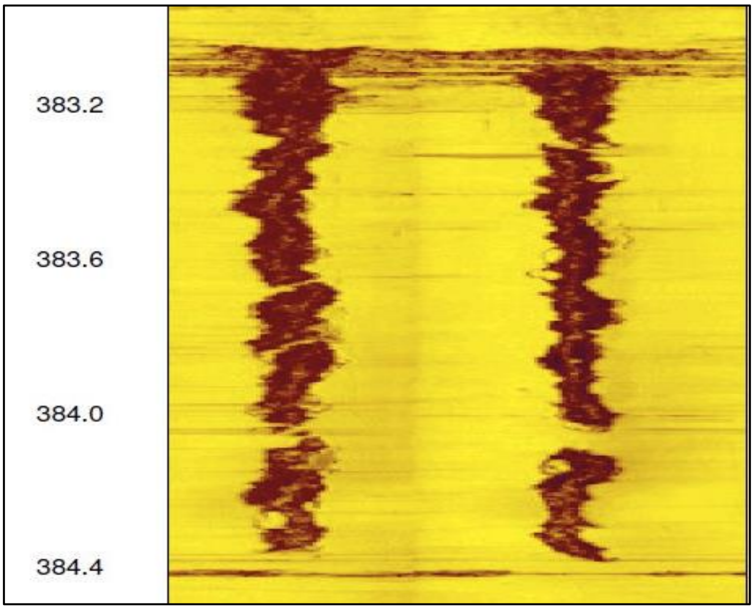

Figure 3: View of borehole breakout from acoustic televiewer scan

The usual process to complete the measurement of stress with borehole breakout is to also undertake hydrofracture. This usually involves pressurising a zone between packers until it fractures. Pumping is continued to develop the fracture and is then stopped. As fluid leaks from the fracture it closes and the closure pressure is detected from the pressure decline. This pressure is the minor stress. An example of the analysis of the pressure decline for closure pressure is shown in Figure 4. Getting the major stress from hydrofracture requires re-opening the borehole and making a large number of assumptions that are usually not justified. These include linear elasticity of the rock mass and the assumption that the plane of minimum stress passes through the axis of the hole. Great care must also be exercised to ensure that the packers used as seals do not push so hard on the hole wall that they induce failure. The use of the minor stress and borehole breakout information is the process most generally used by the petroleum industry to estimate stress. It can be used to advantage in mining too.

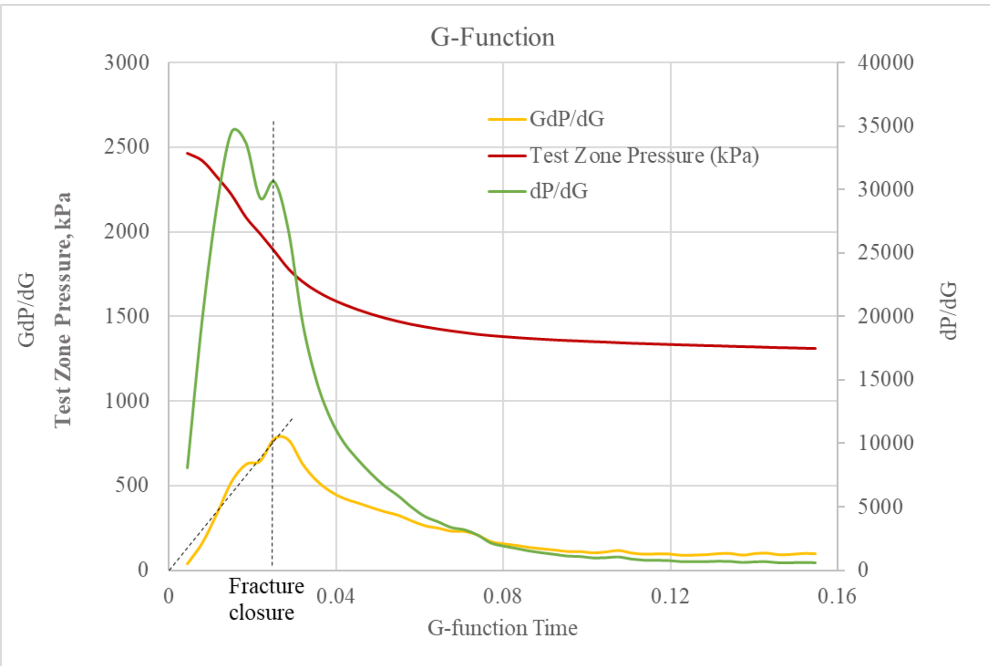

Figure 4: G-function time hydrofracture closure analysis

Another variant of hydrofracture is hydrojacking. Here, a rock joint is isolated by a straddle packer system and the joint is opened by fluid pressure. The normal stress across the joint is assessed by the closure pressure after the cessation of pumping. It is frequently the only option where the rock is jointed.

In all cases of rock stress measurement there is a need to interpolate value of stress between points of measurement. In the case of breakout there is a pattern that can be seen from the acoustic televiewer image.

Another newly developed process to gain a near continuous assessment of rock stress differences is by the measurement of core ovality. This requires drilling with a core bit that does not regrind outside of the core by the internal action of the bit. Once retrieved the core is placed in a tool that rotates it and measures its diameter to micron accuracy. The difference in the major and minor diameters of the core can be used, with an estimate of the Young's modulus and Poisson's ratio of the rock, to arrive at the difference in major and minor stress perpendicular to the core. It may be economically used to measure every metre of core and serve as an indicator of where another overcore measurement should be made. The equipment to do this is shown in Figure 5.

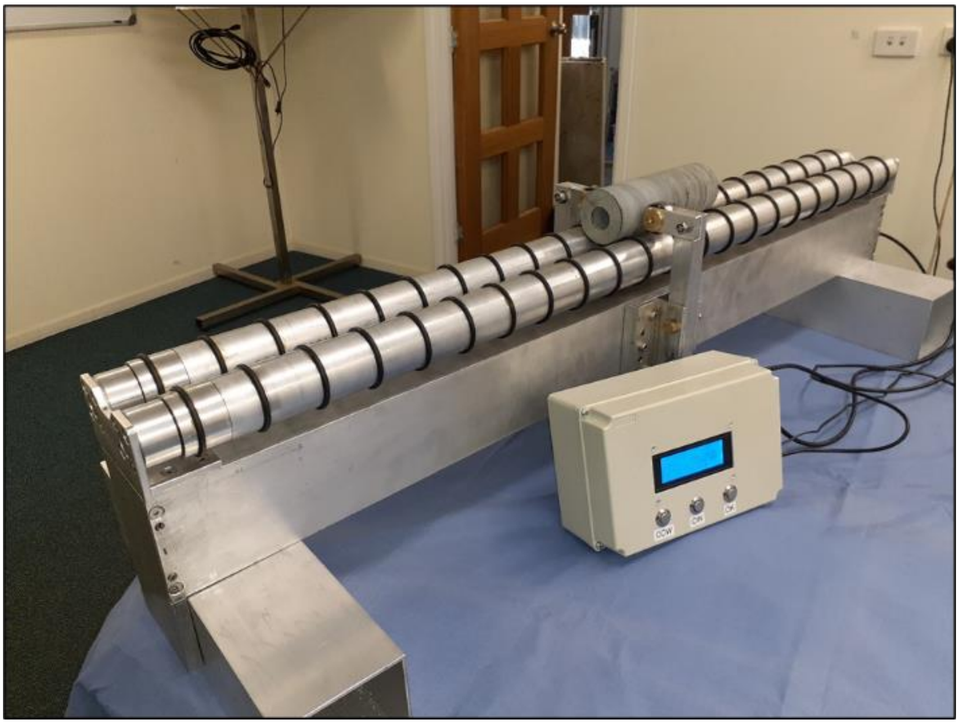

Figure 5: Core ovality testing equipment

Finally it is just as important to develop a model of the stress distribution in the mining area prior to mining as it is to model the stresses brought about by mining. The latter must follow the former.