Solutions in the Ground

Or perhaps – Sigra, your partner in the underworld?

Sigra is a company based in Brisbane, Australia and founded in 1994. It serves the mining, gas and civil engineering industries. It has also operated in 17 other countries. During this period it has build up a range of services to determine ground conditions. These have been used for coal and metalliferous mine design, tunnel investigations, pumped hydro, coal seam gas exploration and nuclear waste storage. Sigra has carried some of these investigations through to full mine or production designs. This level of involvement has required the company to have a comprehensive understanding of the issues that need to be addressed in such work. In addition, working in the civil, mining and petroleum industries has given the company a broad perspective.

Sigra employs geologists and engineers of the main disciplines including, chemical, civil, electronic, geotechnical, mechanical, mining and software. Other staff include specialist mathematicians, draftsmen, tradesmen and a commercial team.

Sigra also has a design and manufacturing capability that it principally uses to build its own unique equipment. This includes mechanical and electronic components. It has a 2000 square metres facility in Acacia Ridge for this purpose.

The key to being able to design an underground facility is to understand what is in the ground. This uses site geology supported by all of the means to conduct an investigation. These include field mapping, drilling surface and borehole geophysics. During this process a variety of tests need to be conducted to determine the geotechnical parameters. Sigra has specialised in developing efficient means to measure rock stress, rock properties and the hydraulic properties of the ground. These are described below.

Geology

Sigra has the ability to examine existing geological information, field map, conduct core logging, examine surface or borehole geophysics and arrive at a geological model of the area in question.

Our core logging follows rigorously the practice of:

- Determining the core position (depth) of cores including dealing with core loss.
- Logging the core lithologically
- Logging each structure precisely by taking three measurements, one at each side on the core and one in the middle of the core. This uniquely locates the structure orientation with respect to the core.
- Opening each defect and describing its features.
- Reconciling the structures and defects within the core with the acoustic televiewer image of the borehole wall. This ensures the correct orientation of each core section.

We integrate core information with borehole geophysics and build models that enable us to understand lithology, structure and stress.

Rock Stress Measurement

Rock stress may be one of the key parameters in underground design. Sigra has specialised in its measurement since 1996. The methods chosen must be appropriate for the condition of the rock mass. Essentially rock stress measurement may be divided into three categories these are:

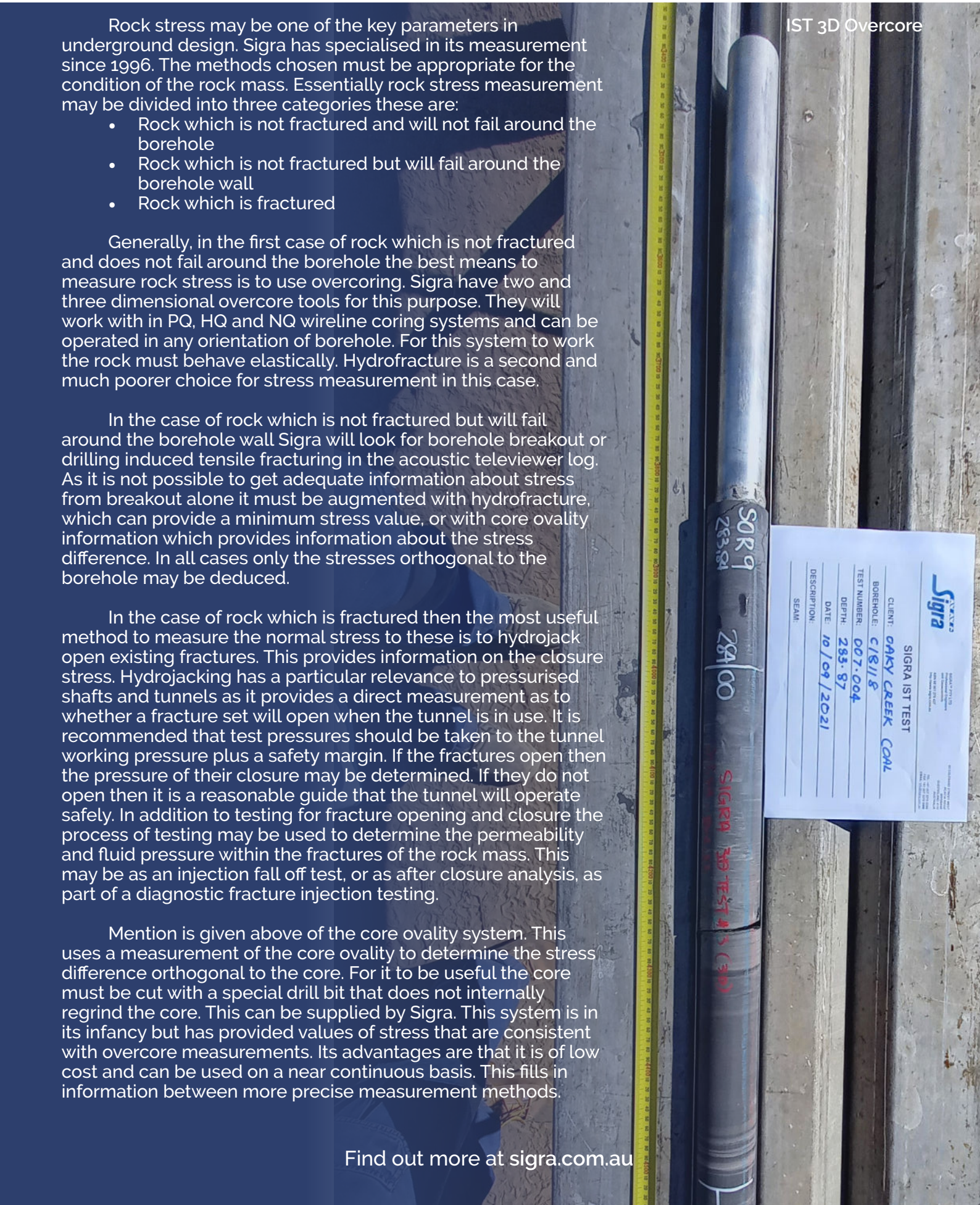
- Rock which is not fractured and will not fail around the borehole
- Rock which is not fractured but will fail around the borehole wall
- Rock which is fractured

Generally, in the first case of rock which is not fractured and does not fail around the borehole the best means to measure rock stress is to use overcoring. Sigra have two and three dimensional overcore tools for this purpose. They will work with in PQ, HQ and NQ wireline coring systems and can be operated in any orientation of borehole. For this system to work the rock must behave elastically. Hydrofracture is a second and much poorer choice for stress measurement in this case.

In the case of rock which is not fractured but will fail around the borehole wall Sigra will look for borehole breakout or drilling induced tensile fracturing in the acoustic televiewer log. As it is not possible to get adequate information about stress from breakout alone it must be augmented with hydrofracture, which can provide a minimum stress value, or with core ovality information which provides information about the stress difference. In all cases only the stresses orthogonal to the borehole may be deduced.

In the case of rock which is fractured then the most useful method to measure the normal stress to these is to hydrojack open existing fractures. This provides information on the closure stress. Hydrojacking has a particular relevance to pressurised shafts and tunnels as it provides a direct measurement as to whether a fracture set will open when the tunnel is in use. It is recommended that test pressures should be taken to the tunnel working pressure plus a safety margin. If the fractures open then the pressure of their closure may be determined. If they do not open then it is a reasonable guide that the tunnel will operate safely. In addition to testing for fracture opening and closure the process of testing may be used to determine the permeability and fluid pressure within the fractures of the rock mass. This may be as an injection fall off test, or as after closure analysis, as part of a diagnostic fracture injection testing.

Mention is given above of the core ovality system. This uses a measurement of the core ovality to determine the stress difference orthogonal to the core. For it to be useful the core must be cut with a special drill bit that does not internally regrind the core. This can be supplied by Sigra. This system is in its infancy but has provided values of stress that are consistent with overcore measurements. Its advantages are that it is of low cost and can be used on a near continuous basis. This fills in information between more precise measurement methods.



IST 3D Overcore

Ground Fluid Behaviour

The purpose of such measurement is generally to find the water make into openings or the fluid loss from them. This requires the measurement of permeability and fluid pressure. The fluid pressure is also of significant importance to the stability of the ground as it changes the effective stress within it.

Many of the techniques used in the civil engineering and mining industries are really quite inappropriate for the determination of the required parameters. This particularly applies to packer testing which provides neither information on pressure nor permeability. The commonly used slug test where a hole is filled or bailed and then allowed to recover is somewhat better, but is difficult to analyse properly and therefore provides poor repeatability. The prime reason for this is that the ground around a borehole is generally disturbed. This may be caused by drilling muds, stress concentrations or a simple lack of intersecting fractures.

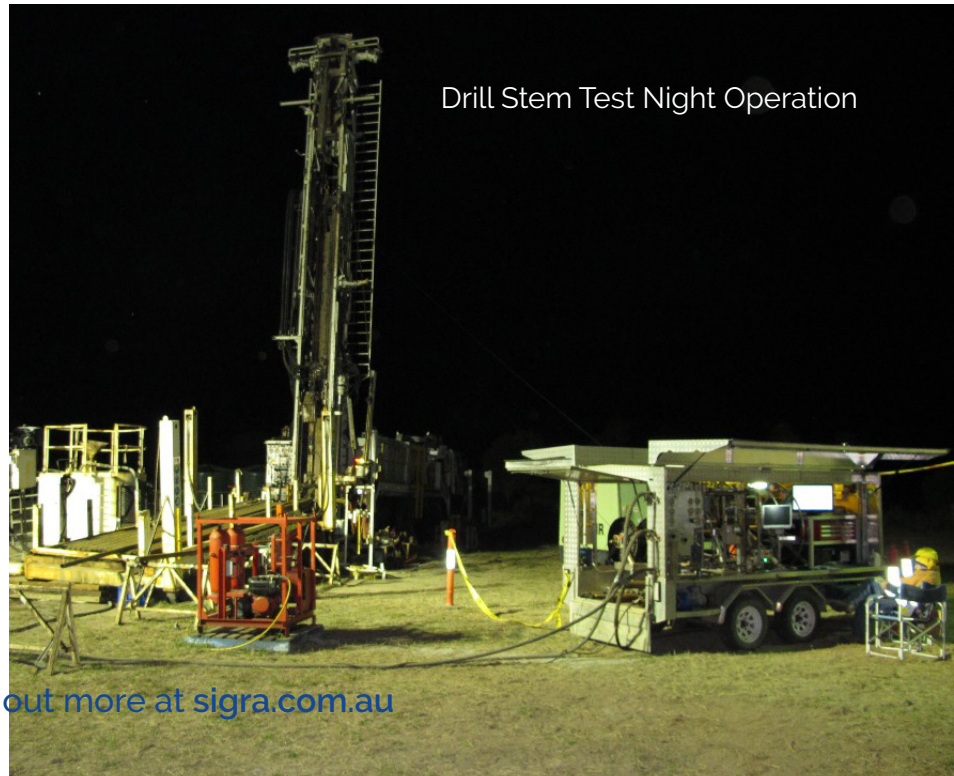
The only way to avoid problems associated with pressure loss around a borehole during flow is to measure during the recovery period when there is no flow or to measure away from the borehole using piezometers.

Sigra uses a variety of techniques to measure fluid behaviour. These are a mix of what can be drawn from hydrogeological practice and what has been gleaned from the petroleum industry. Thus, Sigra will still recommend a pumping test with surrounding piezometers in some instances. It may however recommend a process of testing using drill stem test or injection fall off techniques combined with the installation of piezometers in each hole following testing. Once the piezometer has been installed another drill stem or injection test is conducted in an adjacent hole and the pulse from this test measured in the piezometer. This process may be repeated to get a good areal distribution of directional permeability and the storage behaviour of the ground.

Sigra's drills stem test tools are developed for use in HQ core holes using wireline equipment. It can also operate in other size holes. Sigra has taken its analysis of such tests to that are used in the petroleum industry and in some cases beyond that industry's best practice including the determination of:

- Permeability
- Fluid pressure
- Well bore loss including pressure dependent well bore behaviour
- Radius of investigation
- Fracture or barrier locations

One of Sigra's developments which is a packer system which may be used to conduct measurements in horizontal or sub horizontal holes. This is of particular importance where fractures need to be tested in holes drilled along tunnel alignments.



Drill Stem Test Night Operation

Ground Fluid Behaviour

Sigra has also developed its own piezometer installation techniques to suit the various ground conditions. Much of current deep piezometer installation has deteriorated to cementing pressure transducers in place and then measuring their output without any check on what they are measuring nor any ability to do so. Sigra does cement-in pressure transducers but these are connected to the ground by a process of cement displacement.

This is akin to hydrofracturing the cement grout to ensure connectivity to the formation being monitored. This system may be checked for connection by pumping water through the system and watching the pressure decay. It may also be used to check for the existence of intraconnection within the borehole. Up to six pressure transducers have been successfully installed at differing depths in a number of 600 m deep HQ sized boreholes using these techniques.

While these cemented transducers have significant uses, they are not suitable for all situations. In highly fractured rock, traditional gravel pack installations are likely to be appropriate. Where there are isolated fractures in rock the use of swell packers that grow to seal a particular zone are likely to be most suitable.

Sigra also supply and maintain the logging equipment to collect piezometer and other data remotely and place it on the web.

Cement displacement piezometer installation

Gas in the Ground

Dealing with gas in the ground has always been a significant part of Sigra's work. Most of this has been in relation to coal and other sedimentary rocks but has also extended to evaporites. This involvement has had three essential elements – dealing with outburst phenomena, mine gas drainage and commercial gas extraction.

Sigra has contributed considerably to the understanding of outbursts of gas and coal from the working face. This has been an extension of work started by the company's founder in 1979. The culmination of this is a coherent explanation of the phenomena and sensible procedures to deal with outburst risk. Of recent, the company has dealt with similar problems in sandstones and in evaporites. This has been augmented by recent work on rockbursts. A major part of controlling outbursts is gas drainage. Gas drainage is also essential in controlling gas in ventilation without which a lot of mining would be impossible. This has led Sigra into the investigation and design of gas drainage systems for mining purposes. These have included both virgin and goaf drainage. They involve a significant amount of reservoir engineering and drilling technology.

The advent of the extraction of commercial gas from coals led Sigra down the path of the petroleum industry and Sigra developed a range of services to serve the growing market. These included methods to measure gas content, the sorption isotherms of carbonaceous rock, permeability and reservoir pressures on a continuous basis.

The methods to measure gas content include core desorption, no gas loss core barrels and a method which measures gas content in open hole drilling. In the latter drilling is conducted in an overbalanced hole so that no gas escapes from the formation. All gas that is released comes from the rock being cut. This has proven itself in coal sequences and is ideal for shale investigations where thick sequences of low permeability gas bearing rock exist.

Sigra measures gas isotherms on samples in the laboratory. By experimental necessity these are single gas isotherms from which combined gas isotherms may be generated theoretically. Sigra has also developed a process to measure native isotherms. These are the isotherms of the naturally occurring gas mixture. They are derived by measuring the isotherm on initial desorption.

One important phenomenon in the drainage of coals is their changing permeability. This is a function of the stress within these, the shrinkage that occurs with gas and water loss and sorption behaviour. From this information Sigra can calculate the change in stress that occurs with production and therefore the likely change in permeability. This is extremely important in determining how a reservoir will perform or a longwall block will drain. Sigra measure all of the input parameters for this modelling exercise.

Sigra has also developed some useful production hardware to separate solids from water from gas, both in the well and on surface. It also manufactures blow out prevention control devices.

Rock Properties

Sigra has a rock mechanics laboratory that is about the best in world for what it does. It is not a general commercial laboratory that runs routine tests in and spits out proforma reports. Our lab serves our purposes and generally those of our clients more appropriately. We think about what we test and how we test it.

The first purpose of our lab is to measure the properties of the rocks that have come from our overcore stress measurement operations. The focus here is on determining the anisotropic, elastic linear or nonlinear behaviour of the rock. We do this in multi-stage servo controlled triaxial cells that we have designed and manufactured. This equipment enables the measurement of poroelastic rock behaviour where the effect of fluids must be taken into consideration.

Sigra undertake cyclic uniaxial testing. This is particularly useful in determining the stress at which the rock behaves plastically.

Because of the importance of tensile strength in rock mass behaviour we have developed true tensile tests that are used to measure core axially or transversely. These are far more appropriate than Brazilian tests which indirectly induce tensile stress by the shape of the test sample. These rely on perfectly elastic behaviour to failure and induce a complex compressive, tensile and shear loading.

We also test shear behaviour of rock by several techniques. One is a simple shear test that is rapid. The second is borrowed from the Russian standards and enables shear across a core at varying normal stresses far more rapidly than the conventional shear box.

The Sigra laboratory also undertakes index tests such as point loading, Brazilian and slake behaviour. We also have the capability to undertake petrological examination of rock specimens. This can be important in determining the presence of minerals such as zeolites which may cause failures.

Trying to explain to NATA why we use some nonstandard tests and have some accreditation for that test approved is likely to take many years, something we do not have. All of our measurements are made by instruments that are kept in calibration.

Core sample prepared for the Triaxial Test

Find out more at sigra.com.au

Borehole Geophysics

Sigra can log boreholes with its acoustic televiewer and its full wave sonic tool both of which are used for geotechnical purposes. This logging can not only be conducted in vertical holes but also in near horizontal holes. The latter have particular uses in tunnelling or cavern investigations. Sigra can add other sondes to its suite.

Dams

Sigra have been involved in a number of studies to evaluate the state of existing dams. Many of these have been in providing stress measurements within the foundations of or within concrete dams themselves. The work has also involved site investigations for pumped hydroelectric schemes. Here Sigra's ability to measure real permeability and provide permanent monitoring is especially important.

Tailings Dams and Soft Soils

Sigra are also active in the area of tailings dams. Its newest innovation here is in the use of wick drains which utilise air lift pumping to lower the fluid pressure within the tailings to far below hydrostatic and thus increase the effective stress and induce over-consolidation of soft materials. This technology is also applicable to naturally occurring soft soils. The air lift process can be far more effective and energy efficient than preloading which requires the movement of the preload material on to, and frequently, off the site. The technology is readily solar powered, making it more energy efficient.

Conclusion

Sigra are geared up to provide the technologies required for any structure in the ground. These may be mines, caverns, tunnels or the new range of energy storage projects. These include pumped hydroelectric, compressed air cavern or hydrogen storage investigation and design. Sigra can provide the in the ground keys to these technologies and help the world become carbon neutral.

Sigra's capability to innovate and develop solutions is a key to its success and that of our clients.