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DEVELOPMENT OF THE ANZI STRAIN CELL FOR THREE DIMENSIONAL IN SITU STRESS DETERMINATIONS IN DEEP EXPLORATION BOREHOLES

Ken Mills[1] and Jesse Puller

ABSTRACT: The Australia, New Zealand Inflatable (ANZI) strain cell is an instrument used to determine the three dimensional *in situ* stresses with a high level of confidence, through the overcoring method of stress relief. The ANZI cell has been used for over three decades at numerous sites around the world, typically in short inclined boreholes drilled from underground mines. Technical advances during the last decade have seen the ANZI cell deployed and overcored in increasingly deeper surface exploration boreholes. Recent development of a downhole electronic data logger, a wireline enabled drilling system and an instrument deployment system has greatly simplified the process of obtaining three dimensional overcore measurements at depth. This paper describes the ANZI strain cell, its operation and recent development for overcoring in exploration boreholes. The capability to deploy ANZI strain cells in exploration boreholes represents a significant breakthrough for the design of underground mines and underground excavations generally. Being able to obtain high confidence measurements of the *in situ* stresses at the planning stage of any underground construction activity provides the opportunity to take advantage of these stresses. Not only does it become possible to protect key infrastructure by locating it away from areas of stress concentration, advantage can be taken of the major stresses to promote caving through appropriate design.

INTRODUCTION

This paper describes the advances that have enabled overcoring of the Australia, New Zealand Inflatable (ANZI) cell in deep surface exploration boreholes and what a successful test can provide. An overview of the development of the overcoring method of stress relief and of the ANZI cell itself is provided for context. The operation of the instrument and the various stages of testing used to provide confidence in the integrity of each measurement is detailed. Recent developments including wireline enabled drilling techniques used to prepare the pilot hole and a newly developed downhole logger / strain cell assembly used to obtain the strain measurements from which the *in situ* stresses can be estimated at the point of measurement are described.

Before describing any process of "*in situ* stress measurement", the limitations of this terminology should be recognised. The concept of stress is a convenient engineering construct to link displacements and their derivative strain with forces through idealised models of material behaviour Stresses do not actually exist as something that can be measured. In a Continuous, Homogeneous, Isotropic, Linear Elastic (CHILE) material, six independent components of strain change are able to uniquely define a change in a three dimensional stress tensor. Strain change can only be measured by changing the loading conditions acting on a material.

To conduct an "*in situ* stress measurement" requires (1) a change in loading conditions, ideally from *in situ* conditions to conditions of zero stresses, (2) the measurement of sufficient independent strain changes during this process, and (3) an assumption about the material behaviour. To say that the stresses have been "measured" by this relatively involved process is somewhat misleading because the best that is possible is to "estimate" the *in situ* stresses based on imperfect measurements of strain change and an idealised model of the behaviour of rock material. Nevertheless, the term "stress

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measurement" has gained widespread usage in the lexicon and is, at times, more convenient to use, but the limitations of the terminology should be recognised.

OVERCORING METHOD OF STRESS RELIEF

The overcoring method of stress relief is a convenient method for changing the loading conditions from *in situ* stress conditions to conditions of zero stress. By measuring the strain changes during this process in six independent orientations and the full three dimensional *in situ* stress tensor can be determined based on a CHILE model of material behaviour. In practice, there are a variety of influences that are found to complicate this process including drilling induced effects (Mills, *et al.,* 2016), material behaviours that are not captured by the CHILE model (Mills and Gale 2016), and for some types of instrument, the presence of the instrument itself influences the final state of stress in the post-overcored rock.

The overcoring method of stress relief has its beginnings in a technique where rock on a tunnel wall is isolated from the stress field by drilling a series of interconnected holes and the resulting displacements are measured. Lieurance (1933) reports using this technique during investigations for the construction of the Boulder Dam. Olsen (1949) reports using the same technique but with the introduction of strain gauges for the purpose of measuring displacements. The overcoring method of stress relief in boreholes progressed during the 1950s with the development of a variety of different instruments (Leeman 1958, Hast 1958, Obert, *et al.,* 1962).

In the 1960s, the technique developed further so that it became possible to measure *in situ* stresses in three dimensions from one borehole. An analysis presented initially by Leeman and Hayes (1966) and refined for solid inclusion devices by Duncan Fama and Pender (1980) provides a method for estimating the *in situ* stresses from elastic strains measured on the surface of a borehole, most generally using electrical resistance strain gauges bonded directly to the rock or included within a hollow inclusion bonded to the rock. The changes in strain that occur on the borehole wall during the overcoring are assumed to be caused entirely by the response to the change in stress of the rock material.

ANZI STRAIN CELL DEVELOPMENT HISTORY

The original Auckland New Zealand Soft Inclusion (ANZSI) strain cell (Mills and Pender 1986) was developed from 1980 to 1983 at the University of Auckland for the purpose of being able to estimate the three dimensional *in situ* stresses in coal. The primary goal was to reduce the tensile stresses generated at the borehole wall by the presence of the instrument. In soft rocks such as coal, the tensile stresses generated at the borehole wall during overcoring of hollow inclusion instruments can become high enough to cause tensile failure of the rock itself thereby compromising the test. A secondary goal was to develop an instrument where strain gauges bonded directly to the rock could be tested *in situ* prior to overcoring to confirm the behaviour of the rock material was tolerably consistent with a CHILE model.

From this start, the concepts of keeping the strain measurement system as unobtrusive as possible so that the presence of the instrument does not influence the strain measurements, coupled with providing as much redundancy of measurement of strains and material properties as is practical, have guided ongoing development of the instrument.

The ANZSI strain cell was 38 mm in diameter and carried nine strain gauges. The instrument was successfully used to measure *in situ* stresses in coal mines in New Zealand, Australia, and the United Kingdom as well as at several hard rock civil sites in New Zealand. In 1990, the instrument underwent a significant upgrade and a name change. The diameter was increased to 56 mm and manufactured on a hollow, tubular body. The number of strain gauges on each instrument was increased to 18, and the name was changed to ANZI (Australia New Zealand Inflatable) strain cell reflecting the instruments combined development history and essential mode of operation.

Since the first beginnings in 1980, the ANZI strain cell has continued to be developed through incremental improvements that have greatly increased its capability over time. Most recently, successful deployment and overcoring in a surface drilled exploration at 850 m depth below the ground surface was achieved.

The ANZI strain cell has been developed with focus on simplicity of operation and providing high levels of redundancy to give a sense of the confidence that can be placed in each individual point measurement. Available analysis techniques for converting measured strains to stresses are limited by assumptions that the material is linear, elastic, isotropic and homogeneous. However, many rocks in which overcore tests are conducted are not ideal materials. These rocks are commonly not linear, elastic, isotropic, or homogeneous. Furthermore, the material properties of some softer rocks are commonly observed to change with a change in stress.

Recognising that the calculation of stresses from strains is imperfect, the key to obtaining value from the measurement is gaining a sense of the confidence that can be placed in each measurement and how well the rock properties can be approximated as an ideal material. Experience show not all measurements aimed at determining the *in situ* stress field or changes in stress are reliable. However, having a basis to differentiate those that are high confidence from those that are not is invaluable when developing an overall understanding of the stress environment and the rock behaviour within that environment. The design of the ANZI strain cell is focused on providing systems to allow the confidence in each point measurement to be assessed.

OPERATION OF THE ANZI STRAIN CELL

The ANZI strain cell is a strain measuring instrument that uses the overcoring method of stress relief to allow the *in situ* stresses to be estimated from the strains measured on variously oriented strain gauges. The gauges are bonded directly to the rock on the wall of a borehole. Figure 1 shows a photograph of the 48 mm diameter version of the instrument. The instrument has an inflatable membrane of soft rubber-like material with multiple strain gauges exposed on its outer surface. Eighteen electrical resistance strain gauges at various orientations are mounted flush on the outside surface of the membrane. When the membrane is inflated during installation, the electrical resistance strain gauges become cemented to the borehole wall allowing direct measurement of strain changes in the rock. The wiring of the strain gauges is embedded in the membrane so that the instrument is waterproof. Reference gauges on the instrument that do not change, instrument orientation, inflation pressure, water pressure in the hole, and temperature are also now routinely monitored.

a) 48mm diameter ANZI strain cell.

b) Deployment assembly, downhole logger and ANZI strain cell immediately prior to installation.

c) Downhole logger, recovered overcore and compass module.

Figure 1: Overcoring the 48mm ANZI strain cell in exploration boreholes.

There are six stages in the standard ANZI strain cell test procedure: preparation of the hole, installation, *in situ* pressure test, overcoring stress relief, biaxial pressure test, and laboratory testing of the core recovered from the pilot hole.

Borehole preparation

A borehole is drilled to the measurement location using standard drilling procedures. This borehole is now most commonly an HQ size (96mm diameter) borehole, but a range of other options are available and have been used. The end of the hole is prepared so that the core stub is removed and a centralising conical indentation is formed. A smaller diameter pilot hole is then drilled concentrically from the end of the larger diameter hole, typically for a distance of about 1m. The core from this pilot hole is inspected to determine an optimum test interval. The core is retained for material testing in the laboratory.

Installation

To install the ANZI strain cell, the outer surface of the instrument is coated with custom designed epoxy cement. The instrument is then installed into the pilot hole at the target depth. Pressure is applied internally to the membrane causing the strain gauges to be pressed directly against the borehole wall. Most of the epoxy cement coating is extruded away from the strain gauges and the membrane leaving only a very thin 0.3-0.5 mm thick layer between the gauges and the rock. When the cement has cured, typically 3-4 hours depending on rock temperature, the strain gauges are bonded directly to the rock.

***In situ* pressure test**

Once the cement has cured, the internal pressure is varied incrementally to conduct a pressure test using the instrument as a dilatometer or pressuremeter. The pressure changes in this test are kept relatively low to avoid disturbing the *in situ* stress field. The strain changes measured (typically 20-200 microstrain) are sufficient to confirm the correct operation of each individual stain gauge, provide a measure of the *in situ* properties of the host rock before it is disturbed by drilling, and, under some circumstances, provide independent confirmation of the *in situ* stress direction (Mills and Gale 2016).

The pressurised length of the ANZI strain cell membrane is designed to be four times the diameter of the borehole so as to generate near plane strain conditions during the *in situ* pressure test (Laier *et al* 1975). The increased length of the instrument also improves the length of overcore recovered in low strength or highly jointed rock.

Overcoring

The ANZI strain cell overcoring operation is conducted in much the same way as for other instruments that use the overcoring stress relief method. Direct bonding of the strain gauges onto the surface of the borehole means that the diameter of the overcore need only be slightly greater (10-20 mm) than the diameter of the pilot hole and instrument for the result to be valid. The zero stress state of the final overcore means the overcore does not need to remain completely intact or maintain a regular geometry for the result to be valid. These characteristics significantly extend the range of rock types and drilling environments in which the instrument can be used.

The configuration of strain gauges carried on the instrument can be varied to suit rock conditions. Typically, 5mm long gauges oriented in rosettes of three gauges each (0°, 45° and 90° to the axis of the borehole) are used. The 5mm long gauges minimise the strain averaging effect of longer gauges that can affect results in some stress fields. The gauges oriented at 0° and 90° orientations facilitate field interpretation of results.

The six rosettes of three gauges each are oriented at 60° intervals around the circumference of the cell to improve statistical confidence in the *in situ* stress measured (Gray and Toews 1974). Each rosette has one gauge oriented in a circumferential direction. Multiple gauges are oriented in an axial direction. Eighteen gauges gives 12 degrees of redundancy and two or more independent measurements of many of the individual strain components. For instance, the three sets of directly opposite circumferential gauges independently measure the same strain value.

With the downhole logging system, strain, pressure and temperature readings are recorded every few seconds commencing before the instrument is deployed until it is recovered, leading to a high data density. Figure 2 shows the strain changes associated with stress relief measured during overcoring for each of the eighteen strain gauges. The general form of the overcoring strain changes can be used as a basis to identify rosettes of strain gauges that may not be behaving in a manner consistent with a strong result.

In situ stresses are calculated from the measured strains using the technique described by Leeman and Hayes (1996) and variously enhanced by others. A minor correction can be made during analysis to include the effect of the 0.3-0.5 mm thick epoxy cement layer formed between the membrane and the rock using the analysis described by Duncan-Fama and Pender (1980), but the effects of this correction are slight. For all practical purposes, the strain gauges can be considered bonded directly to the borehole wall.

The membrane material has a modulus of elasticity of only a few mega Pascals and so is soft enough to be ignored in the analyses. Significantly, the tensile stresses generated at the rock/instrument interface during overcoring are too low to overload either the epoxy cement bond strength or the tensile strength of the rock for most rock materials ensuring the integrity of the overcore measurements is maintained in a broad range of difficult drilling conditions.

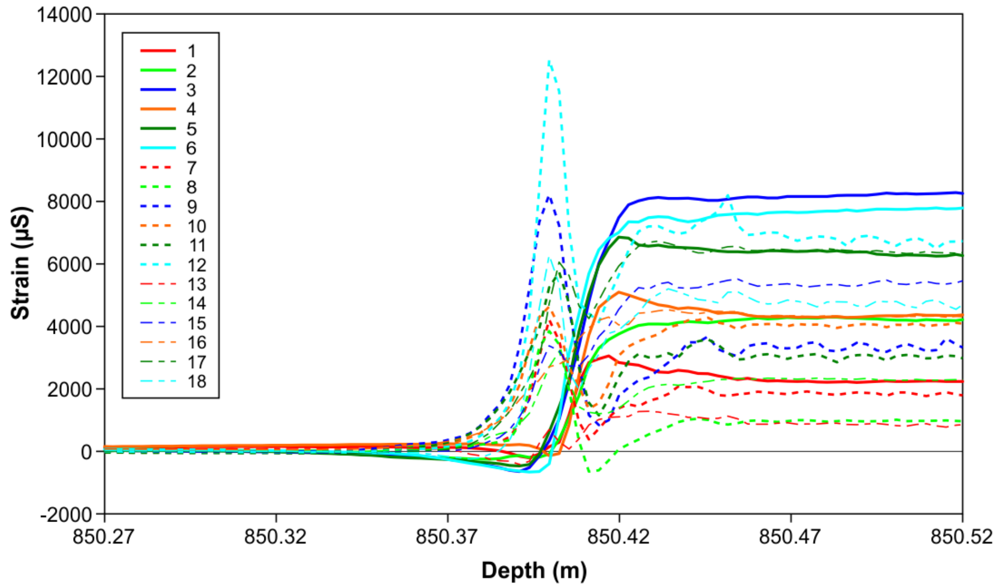

Figure 2: Strain changes during stress relief from overcoring measured at 3 second logging intervals, at 850m depth in an exploration borehole.

Biaxial pressure test

A biaxial pressure test is conducted after the overcore is recovered. In this test external pressure is applied to the rock cylinder so the elastic modulus and Poisson's ratio of the rock material can be estimated. The overcored rock annulus is incrementally pressurised in a biaxial cell that applies radial pressure to the outside of the overcore. The biaxial test provides measurement of the elastic modulus and Poisson's ratio at a range of different pressures and is useful as an indicator of the sensitivity of the rock to modulus variations with pressure.

Laboratory testing

A laboratory test of the core recovered from the location of the measurement is tested in a multi-stage uniaxial compression test. Axial and circumferential strain gauges and the load/displacement records of the compression test all the elastic properties of the rock to be estimated during three or more load/unload cycles up to failure in uniaxial compression.

Assessment of elastic properties

The elastic properties of the rock mass are determined in three separate tests;

1. the *in situ* pressure test conducted prior to overcoring
2. the biaxial pressure test conducted after overcoring, and
3. laboratory tests on core recovered from the pilot hole.

These three essentially independent measurements are conducted on the rock in various stages of the overcoring process and therefore at various levels of stress.

These different conditions provide insight into the rock behaviour and the impact of drilling on the rock as it is unloaded and recovered from the hole. In an ideal, homogeneous, linear, elastic, isotropic material, all three tests would indicate the same values of elastic properties. However, variations are commonly observed, and these variations have provided useful insights into a range of factors that affect the material behaviour of these rocks.

OVERCORING IN EXPLORATION BOREHOLES

The ANZI strain cell was first used in a surface exploration hole in 2009. The instrument is now routinely overcored at depths ranging 200-400 m, with two successful results achieved recently beyond 800 m depth. The benefits of understanding the *in situ* stress field during exploration and the design phase of an underground excavation are significant. With relatively little effort once the *in situ* stress orientations are known, underground excavations can be laid out to minimise stress concentrations on key infrastructure, reduce the investment in reinforcement, and yet still take advantage of elevated *in situ* stresses to fracture rock and induce caving without the need for blasting. The potential to realise these benefits by being able to obtain high confidence estimates of the three dimensional *in situ* stresses has driven the development of the ANZI strain cell for use in exploration holes. A number of key challenges were overcome to enable successful stress measurements at depths beyond 800 m. These were met incrementally as the ANZI strain cell was deployed at progressively greater depths over the past eight years.

Overview of key developments

Initially the same drilling equipment and installation techniques used in underground overcoring were used in surface boreholes. Installation rods routinely used underground were used in shallow installations down to about 150 m but were found to be difficult to use at depths greater than about 50 m. Solid installation rods were replaced with a two cable system deployed on a mechanised cable drum through the drill rods. The first cable was connected to the instrument and monitored at the surface for the duration of the overcoring. The second cable was used to pressurise the instrument during installation and the pressure test.

The 56 mm diameter version of the ANZI strain cell was used initially but this required specialist core barrels because the standard HQ core size is 61 mm in diameter. Several core barrel configurations were developed and trialled but the challenges of swapping out core barrels became a significant impediment to the ease of conducting measurements. A new 48 mm diameter version of the ANZI strain cell was developed to allow overcoring with standard HQ3 equipment to streamline the process.

In order to eliminate rod tripping, a wireline deployed downhole drilling system was implemented. This system is based on a standard casing advancer system that provides for a wireline deployable downhole drive. The end of the hole is able to be shaped and a 48 mm diameter pilot hole drilled using an LTK48 core barrel without needing to trip the rods and replace the HQ barrel. A self-contained downhole logger module and new deployment system were designed to eliminate the need to run a data cable from the instrument to the surface. This final piece of the system enables the ANZI strain cell to be deployed routinely to much greater depths than was previously possible.

Overcoring using custom coring barrels

In 2009, several ANZI strain cells were overcored in HQ surface exploration boreholes at depths of generally less than 30 m. Multiple rod trips were required to change the drilling bit/core barrel to prepare the pilot hole. A 58 mm diameter ANZI cell was installed using PVC conduit, with the data cable and inflation line running through the centre. After the epoxy glue used to bond the strain cell to the pilot hole had cured, the PVC conduit and inflation line were removed and a custom built single tube core barrel with a 76 mm ID shoe bit was run in. The process required manually feeding the data cable through each additional drill rod added. The data cable was run through a modified water swivel on the drilling rig rotation drive unit. Once the stresscell had been overcored and the core had detached, the instrument with the overcored rock attached was recovered through the HQ rods via the data cable.

For a two year period during 2010-2011, approximately 12 overcores were conducted at depths ranging 30-50 m using this system. The internal diameter of the core barrel was increased, to aid drilling circulation and reduce the fluid pressure acting on the stresscell during overcoring. A rotation sensor with an audible alarm was fitted to the ANZI strain cell to indicate when the overcore had detached, so rotation could be immediately stopped to prevent cable twist. In 2012, a similar system using PVC installation conduit was employed to achieve a successful measurement at 150 m. Due to the depth increase and inability to confirm a correct landing from surface using standard technique, a mechanical stopper was fixed to the back of the instrument assembly to land at the top of the pilot hole. The stopper was adjustable and fixed at a position that placed the strain gauges at an optimum location in the pilot hole. From this time, the custom overcore barrel and drill string were run to the bottom of the hole prior to the installation of the instrument. This approach eliminated the requirement to feed the data cable through each drill rod as it was added. The complete drill, install, and overcore operation at this depth took nearly two days owing mainly to the rod tripping time required to prepare the pilot hole.

Cable winch

A project was commissioned in 2013 to conduct an overcore at 300 m depth. Installation using PVC conduit was not possible at this depth due to the weight of the system. A hydraulically powered cable drum winch was designed and built specifically for the purpose of installing the instrument. The instrument could be deployed on the data cable via a pulley system on the drill rig mast and the inflation line could spool into the hole in parallel from a separate cable drum. An electronic compass was added to the strain cell to provide orientation. Tripping the rods in and out of the hole to change out the core barrels was found to introduce fines into the pilot hole. A longer pilot hole was used to accommodate the fines and a landing sensor was added to the stresscell stopper to provide confirmation the instrument has fully entered the pilot hole, prior to applying inflation pressure from surface. These strategies were only partly successful and the rod tripping was still excessively time consuming.

Small diameter instrument

A new pilot hole preparation technique was required to allow the pilot hole to be drilled without the need to trip rods and at the same time allow drill rods to act as effective casing to prevent fines entering the pilot hole. For this system to be truly effective, the drilling system would be capable of being integrated into routine drilling operations using the 61 mm ID HQ core bit for the overcoring, to eliminate the need for a single rod trip. A 48 mm diameter ANZI strain cell was developed to work in a pilot hole that could be prepared using an LTK48 core barrel and then overcored using a standard HQ3 bit. A 48 mm ANZI strain cell was successfully installed through the rods into the 48 mm diameter pilot hole using the two cable mechanical winch deployment system and then overcored with the conventional HQ bit without the inner tube in place. The overcore was recovered after overcoring using the stresscell data cable by pulling it up through the rods.

Wireline deployed drilling system

In 2014, a wireline deployed downhole drilling system was used successfully to prepare a 48 mm pilot hole for an overcore measurement at 160 m depth. The system requires the addition of a short casing advancer driver sub located between the locking coupling of the core barrel and the first drill rod. The driver sub can be installed at any time because it does not interfere with routine drilling operations. The downhole drilling assembly is pumped down the rods in a fashion similar to the inner tube, landing in the driver sub and protruding out through the HQ bit. The HQ rod string is raised off bottom prior to deploying the downhole drilling assembly sufficiently that the protruding bit does not contact the end of the hole. The downhole drive drilling assembly rotates with the HQ drill string and a series of seals and stabilisers direct drilling fluid to the downhole drive bit face. Two deployments of the downhole drive are required to prepare the pilot hole. The first is to grind out the HQ core stub leaving a conical indentation in the centre of the HQ hole to centralise the barrel. The second is to drill the pilot hole using the LTK48 core barrel. The downhole drilling assembly is retrieved on the overshot. In 2014/15 six successful overcore stress measurements using the downhole drive drilling system to prepare the pilot holes and 48 mm ANZI strain cells were conducted at depths between 250 m and 350 m.

Development of a downhole logger system

A decrease in gauge sensitivity owing to increasing cable lengths and the challenges of handling long cables provided the impetus to investigate the feasibility of a self-contained data logger that could be fixed to the back of the stresscell. The data logger presented a technical challenge but significantly increases the capability of the stress measurement system. The downhole logger has the following benefits over a cable system with measurement at the surface:

- increases accuracy, stability and frequency of strain readings achievable because of shorter data cable lengths
- permits internal and external pressure and temperature readings without adding to cable weight
- eliminates the need to use the hydraulic cable winch system for deployment
- reduces amount of equipment required thus allowing air-freighting of gear
- reduces labour requirements from a two person operation to a one person operation
- reduction in manual handling and elimination of all significant hazards
- overall reduction in drilling rig downtime and associated cost savings to the client

In December 2015 a prototype logger housing was constructed. This housing is designed to withstand a maximum working pressure of 10 MPa (or a 1000 m deployment). The downhole logger electronics were ready for use in June 2016 after approximately six months of design, manufacture, and testing.

The downhole logger system also required a complete re-design of the instrument deployment system. This process took some three months to complete. The deployment system consists of two separate modules that are deployed together but recovered separately at two different stages in the stress measurement process. The full assembly consists of an upper landing module and a lower logger module. The complete assembly is lowered on the overshot with the dry-release in place. Once the assembly reaches the water level in the hole, it is released and allowed to float down the inside of the drill pipe. The assembly seats in the core barrel landing ring and cell inflation is achieved through pressurisation of the drill pipe from surface through a series of downhole valves and seals.

Once the epoxy cement has cured and the *in situ* pressure test has been conducted, the upper module detaches from the lower module and the upper assembly is recovered using the overshot on the wireline. The inner tube is then run in and seated with the downhole logger inside. The ANZI strain cell is then ready to be overcored. In June 2016, after six months of laboratory and field trials, the downhole logger and deployment systems were used for the first time. Three successful overcore stress measurements were conducted at depths between 200 m and 300 m using the wireline drilling system and the modular deployment system and downhole logger.

Cement cure time optimisation

Testing of the cement cure times allowed the total elapsed time between installation and the commencement of the pressure test to be reduced to about 4-5 hrs depending on ambient rock temperature in the hole. This discovery makes same day overcoring possible. One of the three overcores described above was conducted on the same day the instrument was installed.

Overcores to 850 m

In November 2016, an opportunity came up to undertake overcore stress measurements at depths greater than 400 m in an inclined borehole. Two main challenges needed to be overcore:

- increased descent rate to prevent the epoxy cement from curing prematurely
- centralising of the deployment system in HQ rods to facilitate landing in inclined boreholes.

Laboratory tests to confirm the epoxy cement curing time indicated that the stresscell would need to descend at a rate of twice normal descent rates to be effective at 500 m+ depth. A rapid descent back-end containing a series of valves was developed to increase descent rate and reduce travel time. A field test was conducted and confirmed a two-fold increase in descent rate was confirmed as was the operation of the internal valving system. After some challenges with getting the assembly to land properly and some redesign of the deployment system to include a centralising tube and release mechanism, successful overcore measurements were made at 547 m deep in one orebody and again at 811 m and 850 m in a second orebody. Each stress measurement was able to be conducted in a single 10 hr shift with a return to normal drilling operations immediately after.

Capability improvements

The capability to deploy ANZI strain cells in exploration boreholes represents a significant breakthrough for the design of underground mines and underground excavations generally. Being able to obtain high confidence measurements of the *in situ* stresses at the planning stage provides the opportunity to take advantage of these stresses. Not only does it become possible to protect key infrastructure by locating it away from areas of stress concentration, advantage can be taken of the major stresses to promote caving.

CONCLUSION

The capability to deploy ANZI strain cells in exploration boreholes represents a significant breakthrough for the design of underground mines and underground excavations generally. Being able to obtain high confidence measurements of the three dimensional *in situ* stresses at the planning stage of any underground construction activity provides the opportunity to take advantage of these stresses. Not only does it become possible to protect key infrastructure by locating it away from areas of stress concentration, advantage can be taken of the major stresses to promote caving through appropriate design.

The ANZI strain cell has a range of operational features and analytical simplicities that have enabled *in situ* stresses to be successfully determined and stress changes to be successfully monitored in a wide range of rock types and applications over the last three decades.

The high levels of redundancy in both the instrument and the measurement technique are designed to provide an indication of the confidence that can be placed in each result and to enhance the understanding of material behaviour at the point of measurement and ground behaviour at the site more generally.

The development history of the instrument has been described in this paper together with the key steps that enable high confidence measurements to now be made in exploration boreholes at depths in excess of 800m. These measurements are possible to conduct within a few hours allowing overcore measurements for the determination of the full three dimensional *in situ* stress field to be made a routine component of exploration activities.

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