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In situ stress measurement using the ANZI stress cell

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ABSTRACT: This paper describes the operation of the ANZI (Australia, New Zealand Inflatable) stress cell. Laboratory and field measurements are used to illustrate the instrument's operation. The ANZI stress cell has a pressuremeter design that enables 18 electrical resistance strain gauges to be pressure bonded directly to the rock of a borehole wall. The strain gauges are monitored during overcoring to obtain stress relief strains. An up hole pressure test is undertaken prior to overcoring to obtain the elastic properties of the rock in situ and to confirm the correct operation of all the strain gauges. The elastic properties of the rock are also obtained after overcoring in a biaxial test. The ANZI stress cell is widely used for routine three dimensional stress measurement in underground coal operations in Australia. It is being increasingly used in the United Kingdom, China, Japan and Vietnam in coal mining, civil and hard rock applications.

1 INTRODUCTION

The original ANZSI cell (Mills & Pender 1986) was developed in the early 1980's to allow measurement of three dimensional in situ stresses in coal. The instrument was primarily designed to overcome the tensile stresses generated in soft rocks at the borehole wall by more rigid hollow inclusion type cells.

The very soft pressuremeter design of the ANZSI cell provided various practical advantages that have since justified further development for use in a wide range of rock types. This further development was accompanied by a change of name to ANZI (Australia New Zealand Inflatable) stress cell reflecting the instruments combined development history and essential mode of operation.

This paper describes the operation of the ANZI stress cell with examples of laboratory and field test results that illustrate the instruments operation in a range of applications.

2 DESCRIPTION

The ANZI cell is a strain measuring instrument that uses the overcoring method of stress relief to determine in situ stress. The 56 mm diameter version of the instrument is shown in Figure 1. The instrument is essentially an inflatable membrane of low modulus polyurethane material with strain gauges on its outer surface.

Eighteen electrical resistance strain gauges of various orientations are mounted flush on the outside surface of the membrane. When the membrane is pneumatically inflated during installation, the electrical resistance strain gauges become cemented directly 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.

The mechanics of stress measurement are similar to other types of overcoring operations except that an additional in situ pressure test is conducted prior to overcoring to confirm the correct operation of the strain gauges, and to measure in situ modulus.

In situ stresses are determined from the measured strains using the technique described by Leeman & Hayes (1966). A minor correction can be made during analysis to include the effect of the 0.3-0.5 mm epoxy cement layer formed between the membrane and the rock using the analysis described by Duncan-Fama and Pender (1980).

The membrane material has a modulus of elasticity of less than 0.002 GPa and is therefore soft enough to be ignored in the analysis of the strains measured during overcoring. As a result of the low modulus, tensile stresses generated at the rock/instrument interface during overcoring are also low.

The pressurised length of the ANZI cell membrane is designed to be four times the diameter of the borehole in which the instrument is installed so as to generate near plane strain conditions during the up hole pressure test (Laier et al 1975). The increased

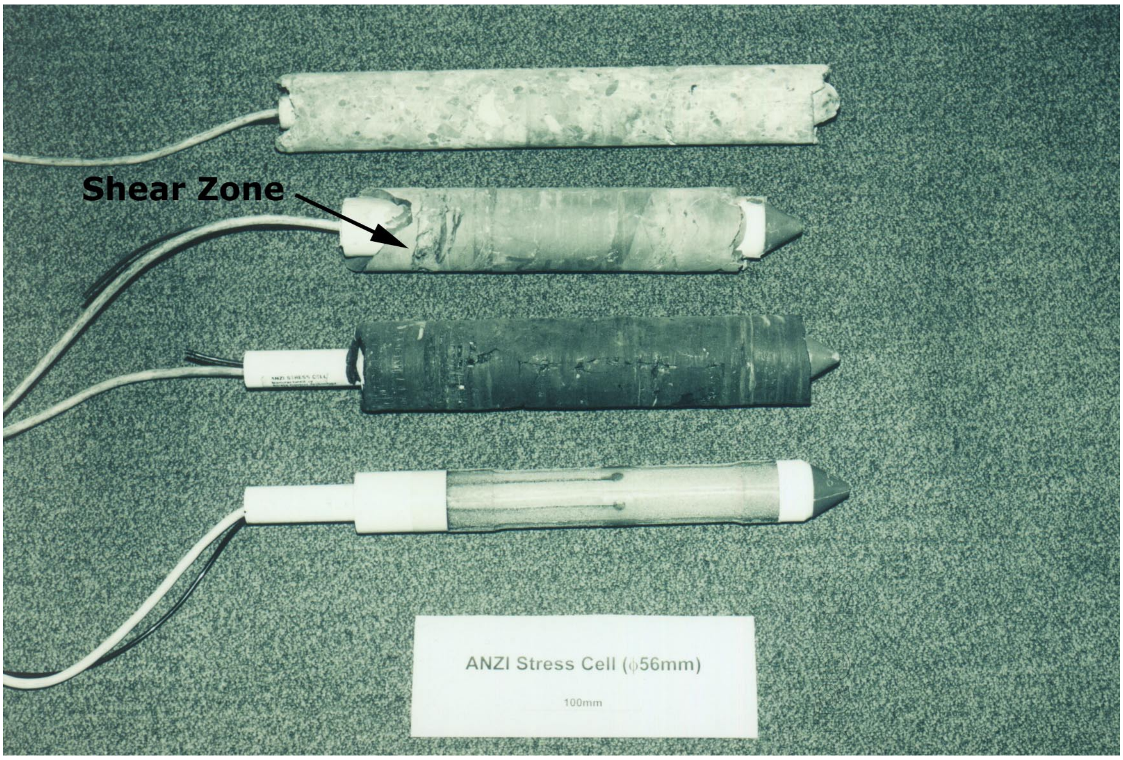

Figure 1. 56 mm diameter ANZI stress cell showing (from top to bottom) overcored instruments in conglomerate, mudstone and coal.

length of the instrument also improves the length of overcore recovered in weak rock.

2.1 *Strain gauge configuration*

The configuration of strain gauges carried on the instrument can be varied to suit rock conditions. Typically, 5 mm long gauges oriented in rosettes of three gauges each (0°, 45° and 90° to the axis of the borehole) are used. The 5 mm long gauges minimise the strain averaging effect of longer gauges that can affect results in some stress fields. The gauges 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 & Toews 1974). Each rosette has one gauge oriented in a circumferential direction. Every second rosette has one gauge oriented in an axial direction. This combination gives a high degree of redundancy and two or more independent measurements of many individual strain components. For instance, there are three gauges that independently measure the one value of axial strain, three sets of directly opposite circumferential gauges and three sets of directly opposite 45° gauges.

The advantages of having a large number of independent strain measurements include:

1. The consistency of the independent strain measurements provides a strong indication of the confidence that can be placed in the result.
2. Completely independent measurements of the stress field can be determined from the one overcore test if required.
3. If rock conditions are such that some rosettes are damaged during overcoring, strain readings from these rosettes can be ignored while still allowing redundancy in the result determined.

2.2 *Instrument configurations*

The ANZI cell is currently produced in two different sizes, a 56 mm diameter version (Figure 1) and a more recently developed 29 mm diameter version (Figure 2). The same strain gauges and rosette combinations are used on both sizes of instrument.

The 56 mm instrument is installed in an oversize TT56 diamond drilled hole and is typically overcored using an 82 mm internal diameter thin wall bit. Larger overcore diameters have also been used where there have been particular requirements for larger size drilling gear. The 56 mm instrument is now routinely used for stress measurements in the coal industry in Australia and has also been used in the United Kingdom, Japan, China and Vietnam.

A double cell configuration of the 56 mm instrument is shown in Figure 3 together with

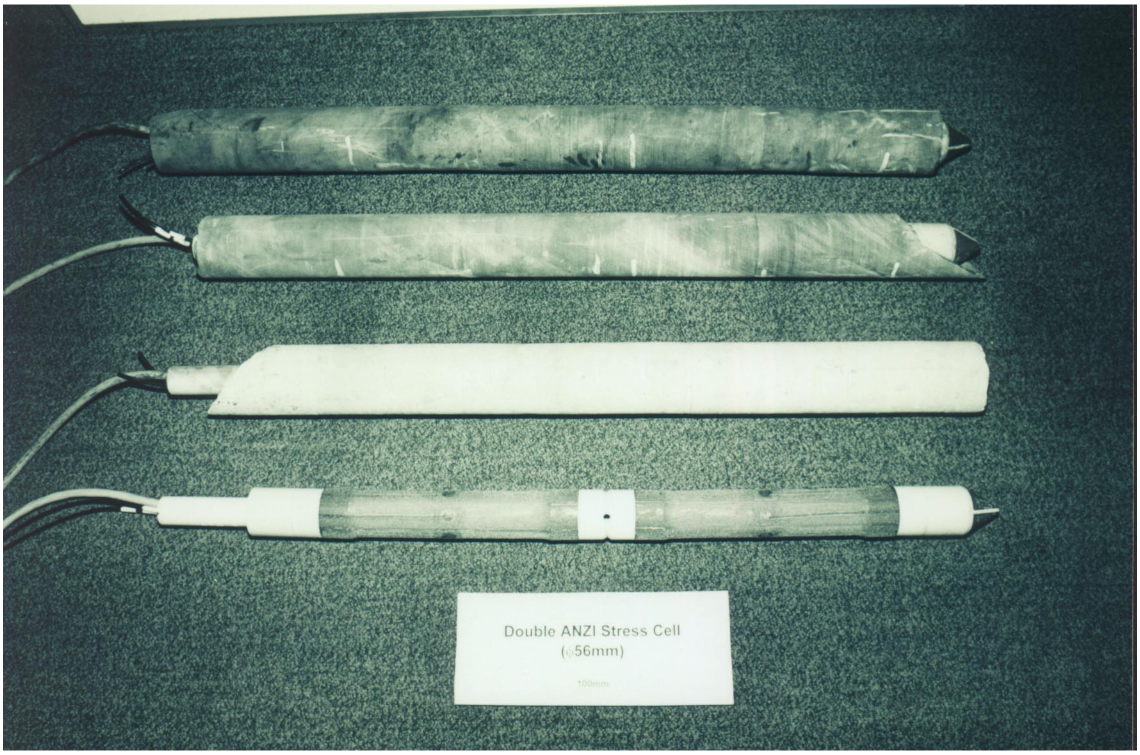

Figure 2. Double ANZI configuration showing instrument and overcores in various coal measure strata

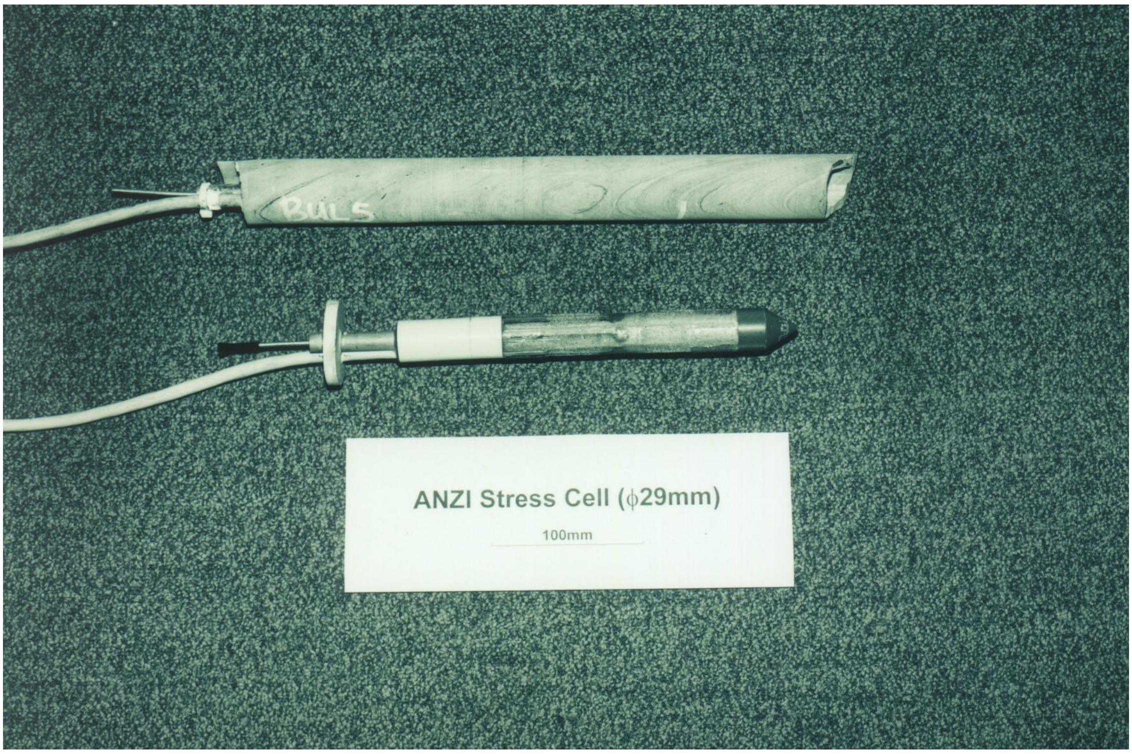

Figure 3. 29 mm diameter version of the ANZI with a 42 mm diameter overcore in sandstone

several overcores in various coal measure rocks. The two instruments share the same cable but can be independently inflated.

The double cell configuration allows two tests to be conducted in only slightly longer time than it would normally take to conduct a single test. The first instrument is monitored until it is completely overcored. The second instrument is then monitored as drilling continues until it too is completely overcored.

The 29 mm version of the ANZI cell is still being fully developed. The smaller instrument has been used to successfully measure in situ stresses in a range of rock types. It is quicker to install than the

56 mm instrument and requires lighter weight drilling equipment. An installation at 10-15 m from an underground roadway typically takes less than 2 hours from the start of drilling the hole.

3 OPERATION

There are four stages in the ANZI cell test procedure: installation, in situ pressure test, overcoring stress relief and biaxial pressure test. The overcoring and biaxial tests are essentially similar to procedures used for other types of stress relief instrument.

3.1 *Installation*

To install the ANZI cell, the access hole and pilot hole are drilled to the location of the test. The instrument is coated with low slump epoxy cement and installed into the pilot hole to the required depth. There is no requirement for the instrument to be installed near the end of the pilot hole as it can be inflated at any location. The pilot hole is typically drilled well beyond the measurement site and a suitable target horizon chosen on the basis of the core recovered.

When the cement has cured, typically 8-36 hours depending on temperature, the strain gauges are bonded directly to the rock.

In coal mine investigations, tests are typically conducted in holes 10-15 m long drilled up at an angle from underground roadways. There has been no additional difficulty in installing instruments at depths in excess of 40 m or in down holes when required.

3.2 *Pressure test*

Once the cement has cured, a pressure test is conducted using the ANZI cell as a pressuremeter or dilatometer. The pressures used in this test are kept relatively low to avoid disturbing the in situ stress field. The strain changes measured (typically 50-200 μS) are sufficient to confirm the correct operation of all the gauges and provide a measure of the in situ properties of the host rock before it is disturbed by overcoring.

3.3 *Overcoring*

The ANZI 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 instrument and the overcore does not need to remain intact for a valid result to be obtained. These characteristics extend the range of rock types and drilling environments in which the instrument can be used.

3.4 *Biaxial pressure test*

A biaxial pressure test is conducted after the core is recovered to measure elastic modulus and Poisson's ratio. If the core is damaged and a biaxial test cannot be completed, the elastic modulus can be estimated from the pressure test conducted prior to overcoring.

4 LABORATORY CALIBRATION TESTS

Figure 4 shows the results of laboratory calibration tests conducted on an ANZI cell installed in an aluminium cylinder of known elastic properties (Elastic modulus 71 GPa and Poisson's ratio 0.34).

4.1 *Internal pressure test*

The internal pressure of the ANZI cell was incremented to simulate an up hole pressure test. The strain changes observed are shown in Figure 4a together with the strain changes that would be expected for the geometry and elastic properties of the cylinder.

The strain changes observed for a 2000 kPa internal pressure change in the cell are relatively small compared to the precision of the strain reading system. The results are nevertheless sufficient to determine the elastic properties of the aluminium and confirm the correct operation of the gauges.

The strain changes registered by the three different orientations of strain gauge can be seen. The circumferential gauges register the largest strains. The axial gauges register very little strain, confirming near plane strain conditions exist during the pressure test. The 45° and 135° gauges register strains midway between the circumferential and axial strains.

4.2 *Biaxial pressure test*

A second calibration test was conducted by applying pressure to the outside of the aluminium cylinder. This test is effectively a post-overcoring biaxial pressure test. The measured strains are shown in Figure 4b.

The strain changes registered in this test form three groups representing each of the three gauge orientations. The strain changes are linear and hysteresis if negligible.

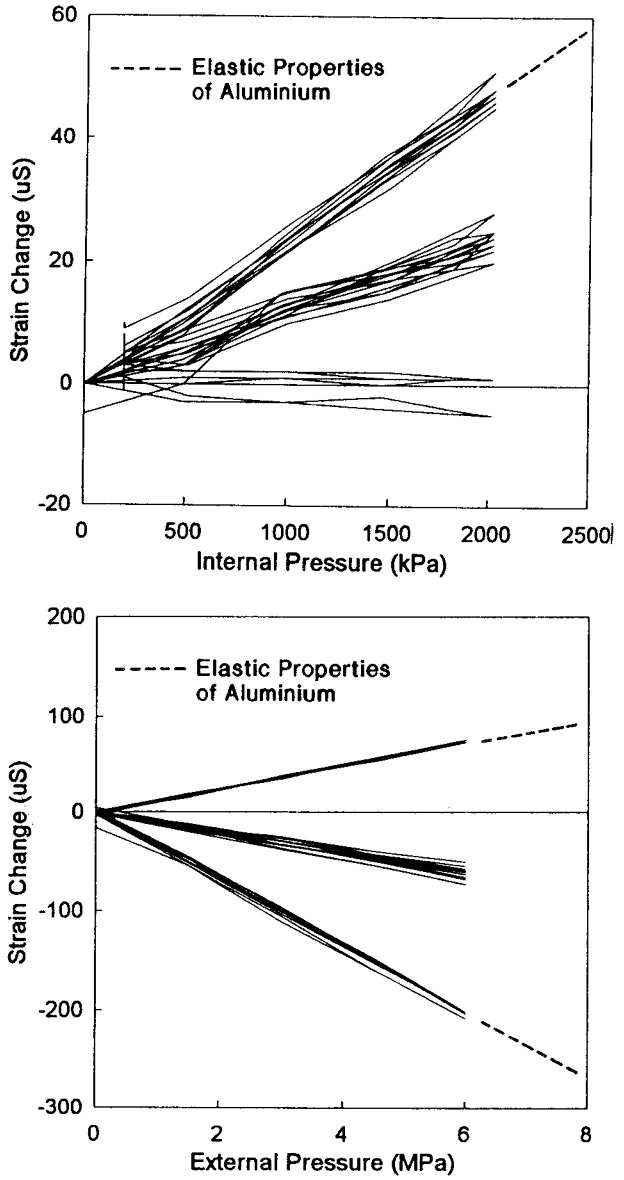

Figure 4. Calibration pressure tests in aluminium cylinder: a) internal and b) external pressure tests.

The elastic modulus and Poisson's ratio of the aluminium determined from the biaxial test equal the known modulus of the material. The 45° gauges register strains midway between strains registered on the circumferential and axial gauges.

This biaxial calibration test confirms the correct operation of the instrument. Furthermore it indicates that useful strain levels can be measured in a stiff material.

5 FIELD MEASUREMENTS

Figure 5 shows the results from a stress measurement test in coal measure strata using the ANZI stress cell. For clarity, the strains measured on the nine 45° gauges are not shown.

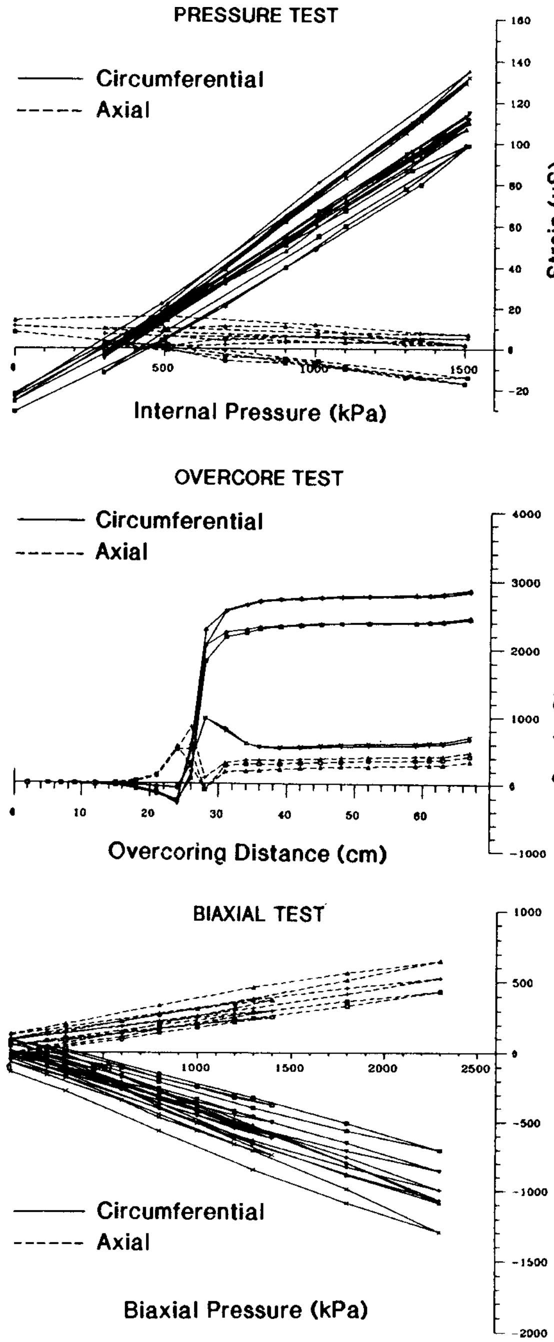

Figure 5. Typical overcoring test in coal measure strata using the ANZI stress cell. a) up hole pressure test b) overcoring test c) biaxial test.

The pressure test indicates the gauges are operating correctly prior to overcoring and the elastic modulus of the sandstone material in situ is approximately 16 GPa.

The overcoring test indicates that the instrument has registered the stress relief correctly. The form of the stress relief is smooth and consistent with expected behaviour. Independent strain gauges on opposite sides of the instrument register almost identical strain changes giving confidence in the result. The three axial gauges also indicate similar strain magnitudes.

The biaxial test shows generally linear behaviour and indicates an elastic modulus of 8 GPa and a Poisson's ratio of 0.43. The variation in the modulus indicated by the biaxial test is partly associated with eccentricity of the pilot hole and partly with drilling induced microfracturing.

The ratio of the elastic modulus determined in the up hole pressure test and that determined in the biaxial test typically ranges 1.8 to 2.0 for coal measure strata. This difference is attributed to stress-relief microfracturing that occurs during drilling.

5.1 *Other field measurement experience*

The ANZI cell has been used to successfully measure in situ stresses in a wide range of strata types. Figure 1 shows some typical overcore specimens recovered from tests in conglomerate, mudstone and coal.

The top core shows an example of a test in conglomerate strata. A large number of redundant gauges is necessary to establish the validity of the measurement because of the obvious inhomogeneous nature of the conglomerate material.

Overcore tests conducted in a mass concrete footing below a loaded column have indicated 1 MPa stresses can be resolved to better than 0.2 MPa in concrete given sufficient gauge redundancy.

The mudstone core in Figure 1 shows an example of a 2 cm wide semi-open shear zone preserved intact in the core. Open fractures have also been "captured" in this way during tests in other heavily deformed strata.

The lower core shows an example of an overcore measurement obtained in a jointed coal material. Individual gauges are often affected by jointing and/or drilling damage, but, with a sufficiently large number of gauges, enough usually remain cemented to intact material and allow the stresses to be determined.

6 CONCLUSIONS

The ANZI stress cell has various analytical and operational advantages that have enabled in situ stresses to be successfully determined in a wide range of rock types and conditions.

Laboratory calibration tests in an aluminium cylinder confirm that the instrument correctly measures the elastic properties of a stiff material in both the pressure test and biaxial test.

Direct bonding of the strain gauges to the rock simplifies analysis and reduces tensile bond stresses at the rock/instrument interface.

The large number of redundant strain measurements on the instrument provides a strong indication of the confidence that can be placed in the result.

The double version of the instrument enables two tests to be conducted in only slightly longer than it normally takes to complete one.

The 29mm diameter version of the instrument allows quicker installation using lighter weight drilling equipment.

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