



If a borehole is sunk in an unloaded rock body that is subsequently subjected to a load, the borehole will change its shape. Originally circular in form, it will become smaller and adopt an elliptical cross-section under the influence of irregular lateral pressures.

The change of diameter is a function inter alia of the stresses, the modulus of elasticity and Poisson's ratio.

The same applies in the reverse case:

If a borehole is sunk in a loaded rock area that is subsequently stress-relieved, the cross-section of the borehole will again change its shape but in the reverse direction. Complete stress-relief of a borehole's surroundings is most easily achieved by coaxial overcoring of the measuring borehole with a core drill bit. While doing so, care must be taken to protect the overcored hollow core from detectable disintegration or loosening of the rock structure and hence inelastic changes of volume.

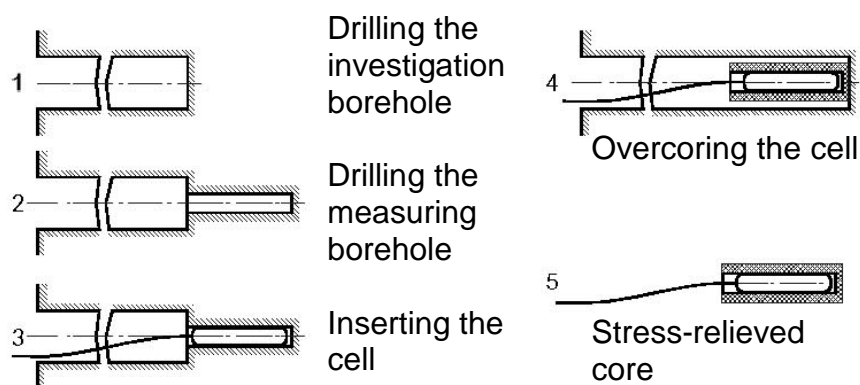
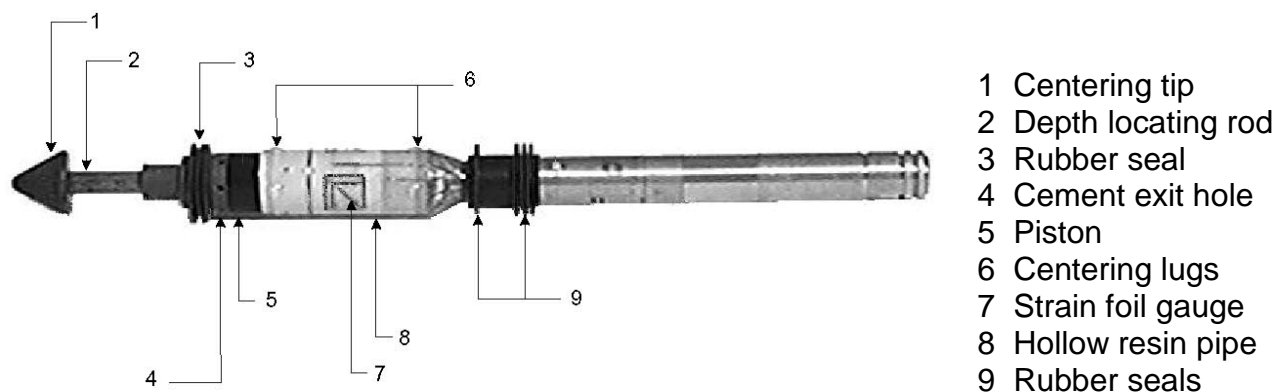


Fig. 1 Principle of the overcoring stress-relief method



Since 1972, measuring cells have been developed at several research institutes to measure the three-dimensional state of stress in rocks by the overcoring stress-relief method. One of these cells, the hollow inclusion stress cell from the Commonwealth Scientific and Industrial Research Organisation (CSIRO), is included in our instrument range. This triaxial cell (Austr. Patent No. 496712) is produced under licence by Environmental Systems & Services Pty Ltd, Victoria, Australia, and is used in Germany by us.

The HI cell consists of a plastic tube with nine embedded strain foil gauges (see Fig. 2). It is embedded in an EX borehole (diameter 39 mm, approximate length 600 - 700 mm) in an injected plastic compound. After the compound has hardened, the cell is overcored with an overcoring bit (146 mm diameter). Changes of the borehole diameter are measured continuously before, during and after the boring operation.



**Fig. 2** Triaxial cell HI for the measurement of primary stresses by the overcoring stress-relief method



In the HI cell, the three 45 °/90 ° strain gauge rosettes are aligned at exactly 120 ° to each other so that three gauges come to lie in annular direction, two in axial direction and four at  $\pm 45^\circ$  to the borehole axis (see Fig. 3). Each strain gauge is 10 mm long in order to be relatively large compared with the rock grain. The layout and size ensure that it is possible to take a realistic measurement of the complete stress tensor.

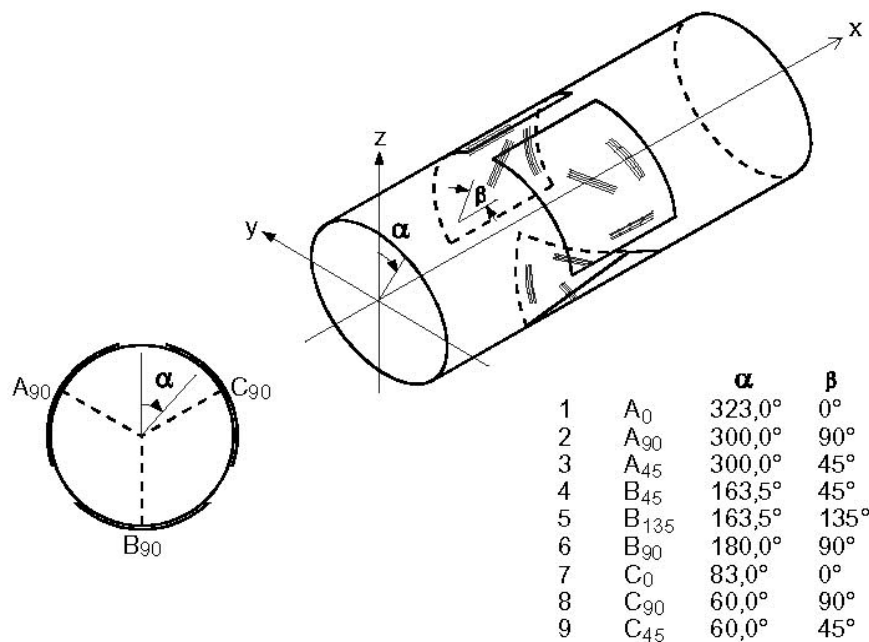


Fig. 3 Layout of the strain gauge rosettes in the HI cell

To inject the HI cell in the borehole, the cell is filled with a 2-component adhesive which a cylindrical ram pushes out through holes to completely fill the cavity between the measuring cell and the borehole wall. The filling normally has a wall thickness of 1.5 mm, but it is best measured by sawing open the overcored section because its value enters into the calculation of the stress tensor. The ram can be actuated either by pushing the measuring cell against the very bottom of the borehole or by means of a pull wire.



At present the use of this method is restricted to a maximum borehole depth of 150 m. Greater depths are fundamentally possible, but we advise against it because of the great difficulties involved in the installation and the limits set to the transmission of the measured values owing to the cross-section of the measuring lines.

Recently the transmission problem could be solved by using a borehole computer directly fixed above the measuring cell; but the potlife of the plastic adhesive still sets limits to the installation depth. Furthermore the borehole computer enables in a simple way a continuous measurement of the strains during the overcoring process. Up to now continuous measurements have only been possible by cable and by using a tube bit with single-core barrel. With this method the operative depth was limited to about 30 m and required a considerable additional effort from the drilling company. Consequently in most cases only a stress-relief measurement has been taken after having recovered the core. The borehole computer enables continuous measurements during the overcoring process until a maximum depth of 150 m working with double core barrel and modern standard drilling equipment without disrupting the drilling operation. Fig. 4 shows an example of measuring the strain as a function of the drilling progress.

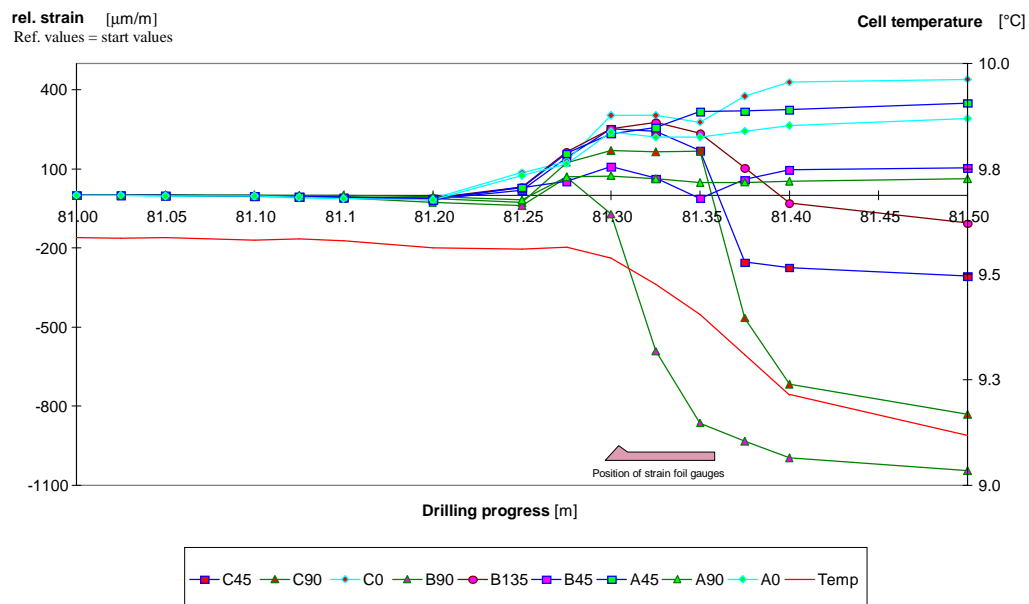


Fig. 4 Signals during the overcoring process



Underwater applications of the HI cell are possible since the injected plastic compound can also harden in the presence of water. To receive satisfactory results, the fissure clearance at the measuring point must be bigger than 250 mm and the measuring cell must lie with all probability within a larger fissure body.

The elastic parameters of the rock must be known to calculate the primary stress. It makes sense to determine these parameters by a biaxial test directly at the overcored section. To do so the overcored section with the sticked in HI cell is radially loaded in the biaxial chamber and the thus arising deformations are measured. The core sheathed by neoprene is loaded with a hydraulic pump. The recording of the measured strains is made in loading steps of 0.25 - 0.5 MPa. From the stress/deformation diagram you can also infer to the bonding quality of the HI cell.

The following input parameters must be known to calculate the complete stress tensor from the measurement results obtained with the CSIRO cell:

- Magnitudes of deformation of the cell due to rock relief.
- The spatial orientation of the measuring cell.
- Elastic properties of the rock.

The strain foil gauges of the CSIRO cell are separated from the wall of the EX borehole by a gap around 1.5 mm wide filled with araldite. Consequently, the strains measured in annular direction and in directions of 45 ° and 135 ° differ from the actual values. WOROTNICKI and WALTON (1976) have therefore established four coefficients of correction that can be used to calculate the deformations arising in the borehole wall from the measured values. These coefficients of correction are taken into account in the evaluation program. Formulas suitable for calculating the state of stress due to the measured deformations of the borehole wall caused by overcoring have been published by LEEMANN (1971). Six mutually independent strain measurements are generally required to determine the complete stress tensor. The CSIRO cell, however, supplies nine strain values in eight different directions. Through this redundancy of measured values it is possible to select results using a regression calculation based on the principle of the smallest squares. The first step entails determining and eliminating the most prominent strain measurement from the overall profile. A further iteration step can be performed with the remaining eight measured values. Altogether three iterations are possible be-



cause at least six strain measurements have to be evaluated. Furthermore, it is possible to assess the quality of a data-set in the light of statistical characteristic values that are calculated by the computer program.

It should be remembered, however, that the multiple regression calculation includes certain assumptions - concerning the data - and that it supplies a solution which is severely optimised in statistical terms. A final assessment of the relevance of individual measured values should be undertaken, therefore, on the basis of empirical values. An important role in this is played not only by statistical characteristic values but also by such factors as result from individual conditions during the test.

The state of stress in rock is calculated with the help of STRESS91, a program that was developed by MILLER (1983) in Australia and which uses the above described iteration method. In each iteration step the strain value with the biggest deviation is eliminated to obtain the smallest square solution. It is also possible for individual measured values to be sorted out by the operator if they appear unusable for any reason.

The program needs to receive the following input data:

- General information to identify the test.
- Orientation of the borehole.
- Modulus of elasticity and Poisson's ratio of the rock.
- Strain values and spatial position of the strain foil gauges.

The program output (see the following evaluation example) consists of:

- The three main directions and magnitudes of stress.
- Three orthogonal and three shear components relative to the reference system.
- The characteristic statistical values for evaluating the reliability of the measurement results.



### Sales Information

- 13.1.1 CSIRO HI-triaxial cell (modified version system GIF) with 9 measuring points and integrated thermistor for temperature measurement
- 13.1.2 Epoxy adhesive resin for cementing the CSIRO HI-triaxial cells, quantity matched for one cell, for rock temperature ranges of + 4 to + 10°C, + 10 to + 18°C, + 18 to + 25°C, + 25 to + 32°C, + 32 to + 45°C, + 45 to + 60°C (please indicate)
- 13.1.3 Setting and centre device for test holes of 146 mm and pilot holes of 39 mm in diameter (horizontal or vertical version)
- 13.1.4 Setting rods made of aluminium with torsion-proof couplings made of rust-proof steel, length 2 m
- 13.1.5 Borehole computer for registration of the strains during overcoring (wireless version) with compass probe for determining the installation direction of the triaxial cell
- 13.1.6 Biaxial chamber for determining the material properties at the overcored section with manual pump and precision manometer for core diameter of  $101 \pm 2$  mm (other diameters on demand)
- 13.1.7 Installation manual CSIRO
- 13.1.8 Evaluation program STRESS 91



This method is based on inducing an artificial condition of stress-relief in the rock with a saw cut and taking simultaneous measurements of the resulting deformation. This deformation is then reversed again by applying compensation pressure with suitable loading devices. As a rule, the stresses needing to be induced in this process are equivalent to the original stresses. Unlike test methods based purely on stress-relief, this method requires no knowledge of the elastic constants of the rock at the measuring point.

The compensation method with flat jacks was first used by MAYER et al. (1951) and later simplified and refined by ROCHA et al. (1966). Its principle and procedures are illustrated in Fig. 1. As the first step, measuring pins are cemented on the surface of the component in an appropriate arrangement on both sides of the planned cut. The distances between the pins are recorded by electric displacement sensors or set strain transducers (reading accuracy  $\pm 1 \mu\text{m}$ ).

Following the zero measurement, a slot normally measuring 400 mm wide and 5 mm high is cut with a diamond-tipped circular saw. A crescent-shaped hydraulic pressure cell is inserted exactly into the slot and connected with an hydraulic pump fitted to a precision manometer (class 1.0). Finally, the pressure cell is loaded until the relief-induced deformations are compensated.

The method has a number of advantages:

- It does not assume a linearly elastic rock
- It does not require knowledge of the rock's deformation characteristics
- The large test dimensions minimise the significance of rock inhomogeneities

This method fails, however, when confronted with tensile stresses. This rarely occurs in practice, however.



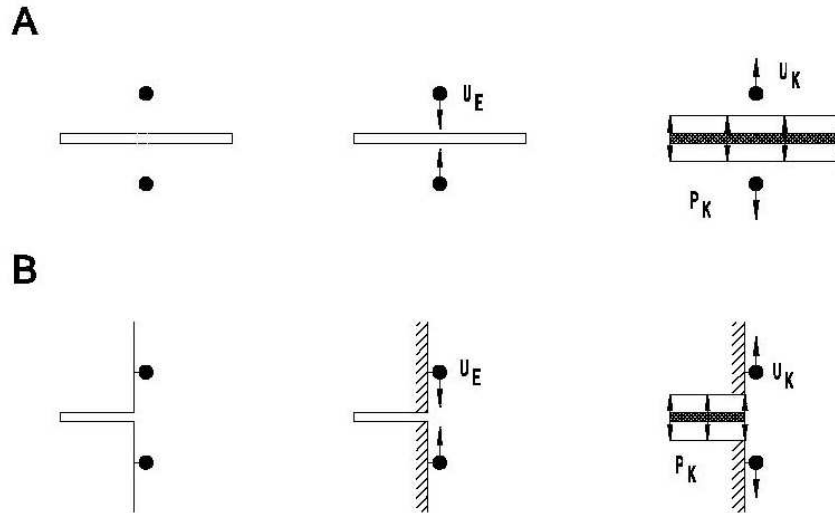


Fig. 1 Measuring principle compensation method

A = Front view, B = Cross section

$U_E$  = relief-induced deformation

$U_K$  = Compensation of relief-induced deformation

$P_K$  = Compensation pressure

The evaluation of test results obtained by the compensation method with flat jacks is based on the following equation:

$$\sigma_n = p \cdot K_m \cdot K_a$$

$p$  = Oil pressure in the cell at full compensation

$K_m$  = Form constant of the pressure cell used

$K_a$  = Ratio of cell area to cut area

The stresses determined with this equation correspond to the tangential stresses at a distance of 5 cm from the outer edge of the rock surface.



Assuming that displacement transducers are incorporated in the pressure cells or that the volume of hydraulic liquid injected to inflate the pressure cell can be measured to an accuracy of 1 cm<sup>3</sup>, compensation tests with flat jacks may also be used to determine a rock's modulus of deformation. However, to comply with Recommendation No. 7 of Working Committee 3.3 - Rock Testing Technology - of the Deutsche Gesellschaft für Geotechnik e. V. (1984) and Suggested Method for Deformability Determination using a Large Flat jack Technique of ISRM (1986), it is generally necessary in this case to use large slots with large flat pressure jacks of 1000 x 1250 mm (LFJ) (see page no. 4). According to the theory of elasticity, a homogeneous isotropic semi-infinite mass that is subjected to a uniformly distributed load is governed by the following equation:

$$E = (1 - \nu^2) \frac{K}{\Delta s} \Delta p$$

$\nu$  = Poisson's ratio

$K$  = Form coefficient with the dimension of a length

$p$  = Oil pressure in the flat jack

$s$  = Displacement

It is possible, therefore, to determine the modulus of rock deformation if the coefficient  $K$  is known.  $K$ -values for cells of 1000 mm width and 1250 mm overall length are shown in Fig. 2. Attention is also drawn to publications by LOUREIRO-PINTO (1981) listing further possibilities for the calculation of  $K$ -values.





Pressure cell arrangement	Position	K[cm]	Position	K[cm]
	A, B C, D	131 136		
	A, F B, E	150 191	C, I D, G	160 215
	A, L B, J C, N	155 202 167	D, M E, F G, I	231 216 249
	A, P B, O C, R D, Q	157 206 170 237	E, L F, J G, N I, M	223 228 259 267

Fig. 2 K-values for various pressure cell combinations from DGGT (1984)

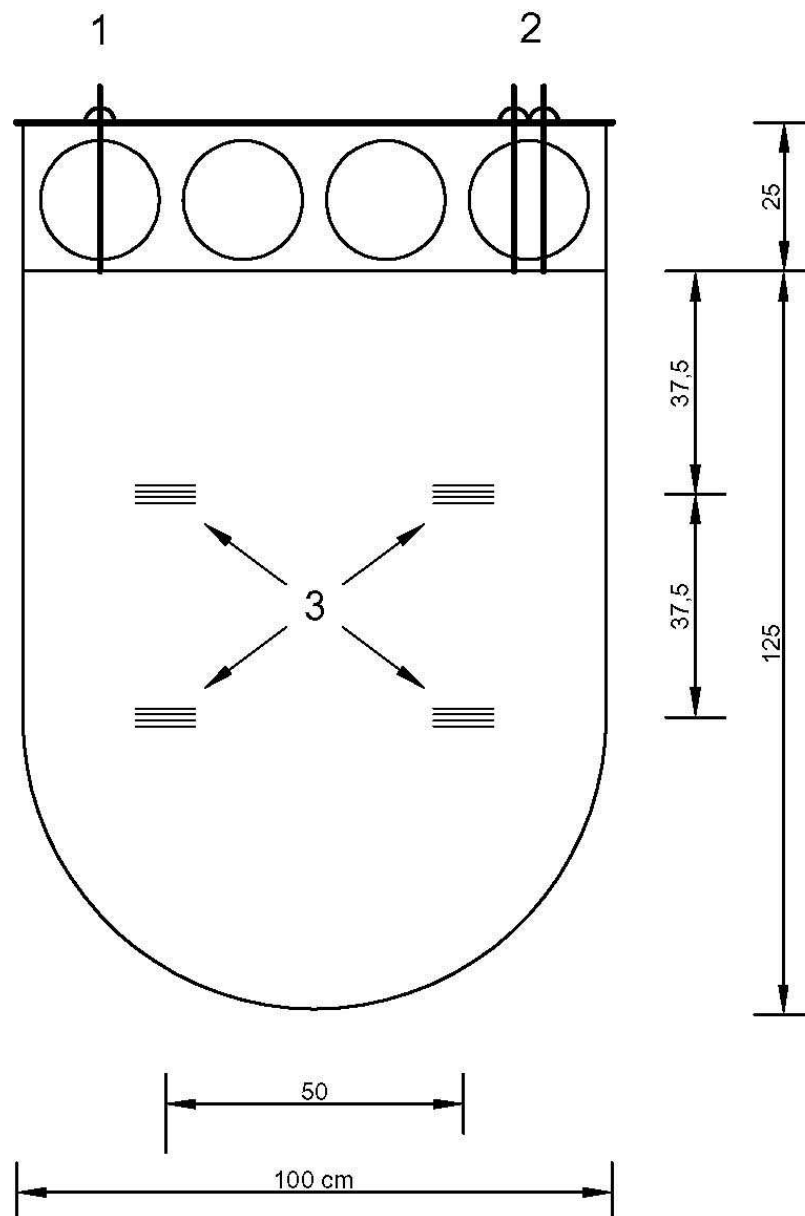


Fig. 3 Dimensions of Large Flat Jack (LFJ)  
 1 Oil inlet, 2 Strain gauge wiring, 3 Deformeters



With the hard inclusion method, stress sensors of generally high rigidity are inserted in a borehole in order to record changes of stress. This method uses transducers whose modulus of elasticity is higher than that of the rock at the measuring point. The procedure is based on the following theoretical relationships:

If a transducer with modulus of elasticity  $E_G$  is friction-locked in an elastically loaded rock body with modulus of elasticity  $E_M > E_G$ , the stress in the transducer will differ from that in the surrounding rock; stress concentrations will arise in the transducer. If the modulus ratio  $E_M/E_G$  is known, the stresses measured in the transducer can be corrected.

It is possible to distinguish between a number of methods according to their principle of measured value conversion or measured value transmission:

- Hydraulic measuring principle
- Electrical measuring principle
- Mechanical measuring principles
- Optical measuring principle

Flat pressure pads of standard rigidity have proven particularly successful as stress sensors. The pressure transducers (Fig. 1) are installed properly orientated in measurement boreholes. Stress components are measured in orthogonal direction to the pressure pads.

To produce the friction-locked connection between the pressure pads and the rock, the boreholes are filled with a mortar that matches the rock's characteristics. Prestressing by high-pressure injection of epoxy resins can take place once the mortar has hardened.

This method is also suitable for measuring small changes of stress. In viscous or plastically strained rock areas the transducer can be expected to "grow into place" through rock flowage, i. e. the stresses inside the rock gradually build up in the transducer, too. Under such rock conditions and with the right choice of mortar it is also possible to determine the actual magnitudes of the orthogonal stress components in addition to stress changes.



The standard rock stress sensor consists of:

Three directionally orientated, flat steel pressure pads with three valve transducers type BB 10/20 KF 50 each turned through 120 °. Load capacity 0 - 50 bar (higher possible if necessary). Injection line around the pressure pads and square rod connection. Connection lines for measurement of the valve transducers and injection lines for subsequent injections.

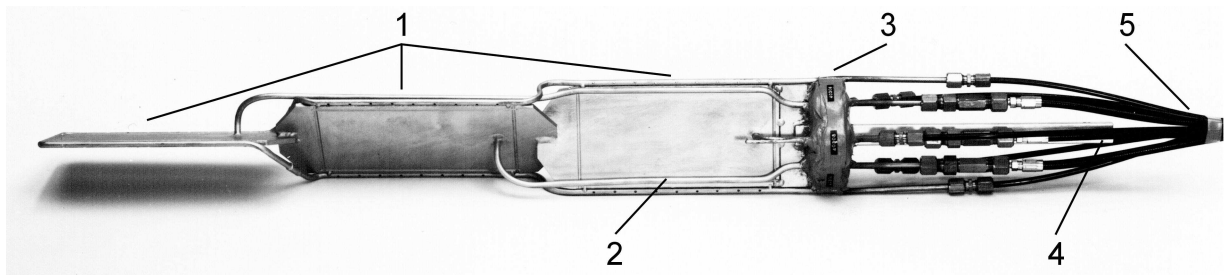


Fig. 1 Pressure transducer with three hydraulic pressure pads

- |                     |                         |
|---------------------|-------------------------|
| 1 Pressure pads     | 2 Injection line        |
| 3 Valve transducers | 4 Square rod connection |
| 5 Connection lines  |                         |

Pressure in the pressure pads is measured either hydraulically by means of valve transducers system Glötzl or electrically by pressure sensors. The stress inside the pressure pads can be read off the instrument directly in bar.

The perforated high-pressure injection lines arranged around the edge of the pressure pads are closed with adhesive tape in order to prevent mortar getting in during installation. Once the filler mortar has hardened, artificial resins or similar can be pressed through these injection lines to prestress the filler and the embedded stress sensors.



Borehole stress relief with the borehole slotter is a 2-dimensional stress measurement method based on the principle of local stress relief in a borehole. By means of a small, pneumatically driven diamond saw relief slots are sawn parallel to the borehole axis (Fig. 1). The slots are about 1.0 mm wide and up to 20 mm deep.



Fig. 1 Borehole slotter at the end of the borehole

Directly next to the slot a specifically developed contact strain sensor is pressed with a specific force to the borehole wall (Fig. 2) during the slotting. The function of the sensor is to measure the tangential strain of the borehole wall during the slotting. At the scheme shown in Fig. 3 there is a complete local stress relief along the slot in the borehole wall followed by a proportionally tangential strain.

Normally the boreholes are monitored with a camera to eliminate unsuitable borehole sections.



At the selected test location slots are successively sawn in different directions. At least three slots, 120 ° apart from each other, enable the determination of the 2-dimensional state of stress. But normally three additional slotting tests are made for a stress measurement at another borehole location 10 cm deeper or higher of the first point (Fig. 4) to verify the results by redundant dimensioning.



Fig. 2 Strain sensor besides the diamond saw blade

The resulting redundancy of the measured data allows a quantification of the data quality, f. e. in the form of a correlation coefficient. This possibility of internal control of the measured data has turned out to be extremely advantageous when performing and interpreting the borehole slotting tests. If f. e. the inner consistency of the measuring results seems to be insufficiently low during the test performance, additional slots can be directly sawn until an adequately consistent trend becomes apparent.





For evaluation the tested area is taken as linear elastic, homogeneous and isotropic. By means of the perforated disc model the primary stress state is re-calculated with the equations of KIRSCH from the relief of the secondary state of stress when slotting in the borehole. As input values the modulus of elasticity and the Poisson's ratio must be determined from uniaxial compression tests out of cores taken from the borehole.

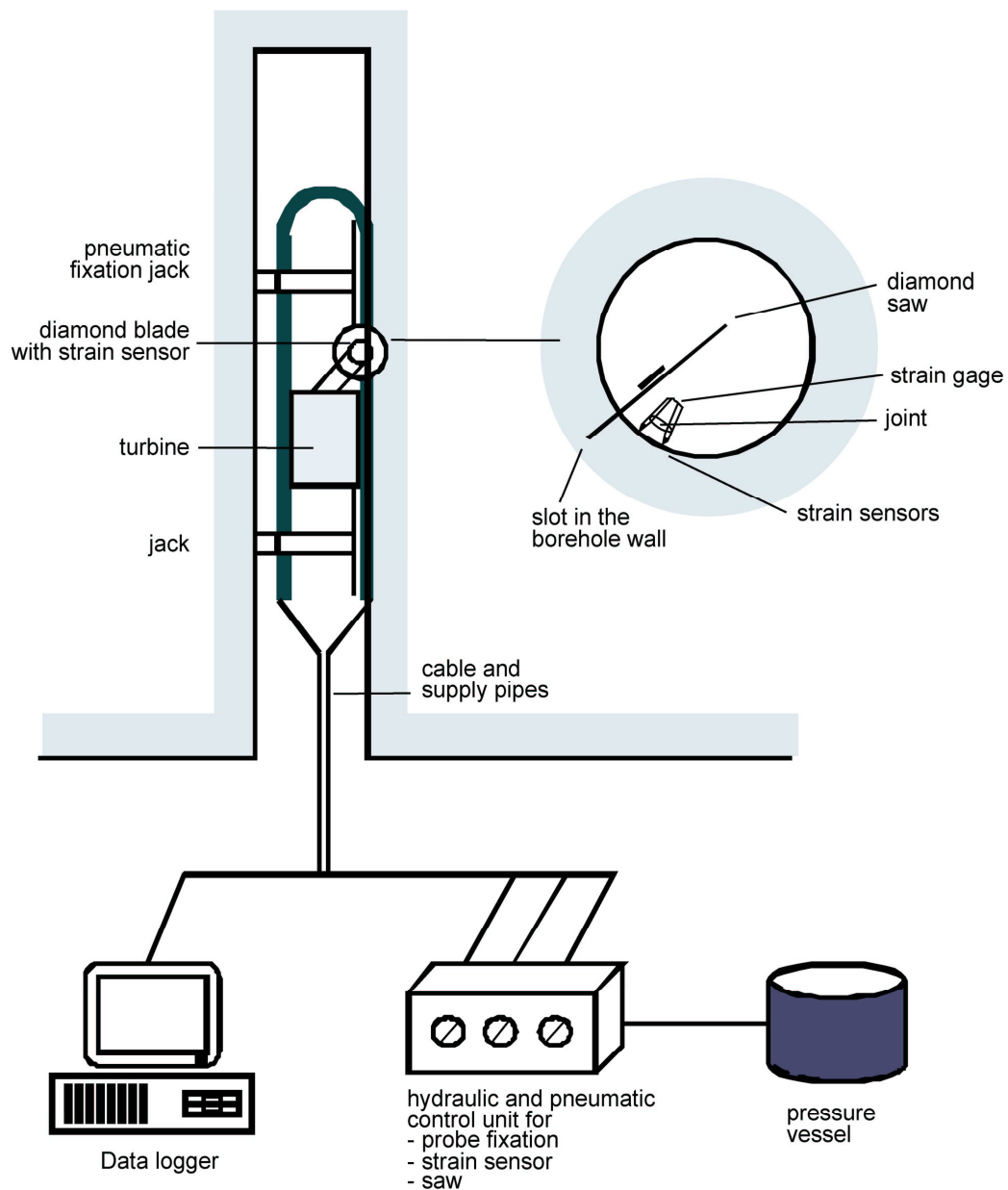


Fig. 3 Scheme of a borehole slotting equipment





The accuracy of the primary stress measurement with the borehole slotter depends on the magnitude of the rock modulus and on the sensitivity of the contact strain sensor. For a rock with a modulus of elasticity of 40 GPa the accuracy is about  $\pm 0.5$  MPa. Usually the resolution of the sensor is about 1 microstrain.

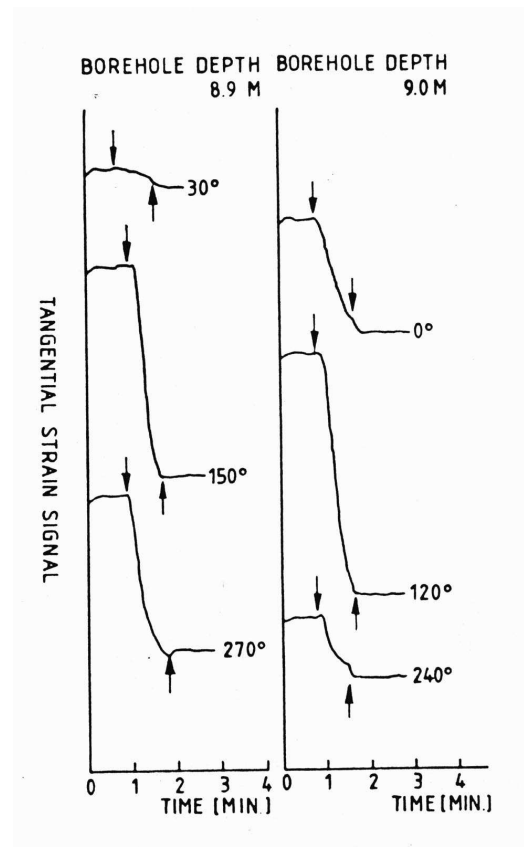


Fig. 4 Time-strain curves of 6 slotting tests, together resulting in a single, redundant 2-D stress measurement

To determine the 3-D stress state in rock the procedure must be conducted in three boreholes with different azimuth and dip angle. The dip directions and inclinations of the boreholes which should be as near as possible are to be exactly measured, as these values enter into the calculation of the stress tensor.

As drillings core drillings are necessary because the modulus of elasticity and the Poisson's ratio of the rock must be determined by laboratory tests at each measuring point to evaluate the stress state.



## Technical Data

### Application conditions

- The exploration of geological boreholes is possible up to max. 30 m depth
- The method is not applicable underwater, it is therefore recommended that the boreholes are orientated either slightly upwards or vertical. A typical orientation of the boreholes to determine the 3-D in-situ stress state would be:  
Borehole 1: Subhorizontal about 5 ° up (perpend. to borehole 2 if possible)  
Borehole 2: Subhorizontal about 5 ° up (perpend. to borehole 1 if possible)  
Borehole 3: Vertical up
- Borehole diameter of core drillings: 96 – 103 mm. The borehole should be drilled with a diamond core bit.
- When measuring out of a tunnel or gallery the measurements should only be conducted in a depth deeper than 1.5 – 2 times of the cavity diameter.
- The borehole should always be at least 1 m deeper as the biggest desired measuring depth.
- The work space in front of the borehole should be at least 2 x 2 m due to the slide rods.

### Dimensions

Borehole Slotter	L = 1300 mm, dia = 90 mm
Slide rods	LxWxH 1500x20x20 mm
Hydraulic / Pneumatic Control unit	LxWxH 660x390x650

### Weight

Borehole Slotter	13.5 kg
Slide rods	1.0 kg / shot
Hydraulic / Pneumatic Control unit	28.0 kg