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.

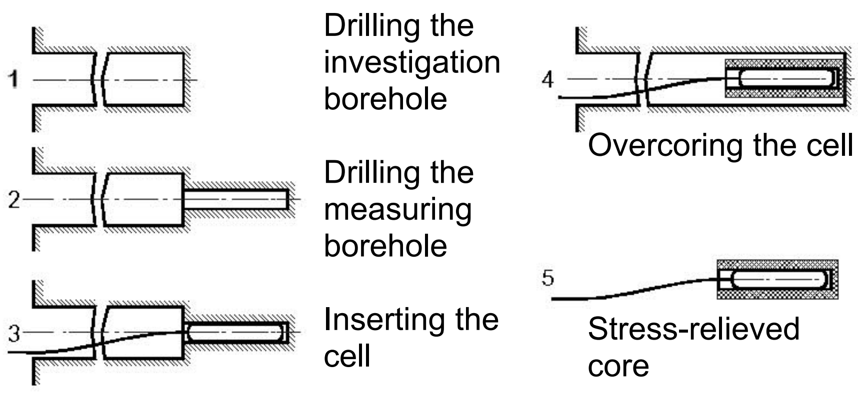

Fig. 1 Principle of the overcoring stress-relief method

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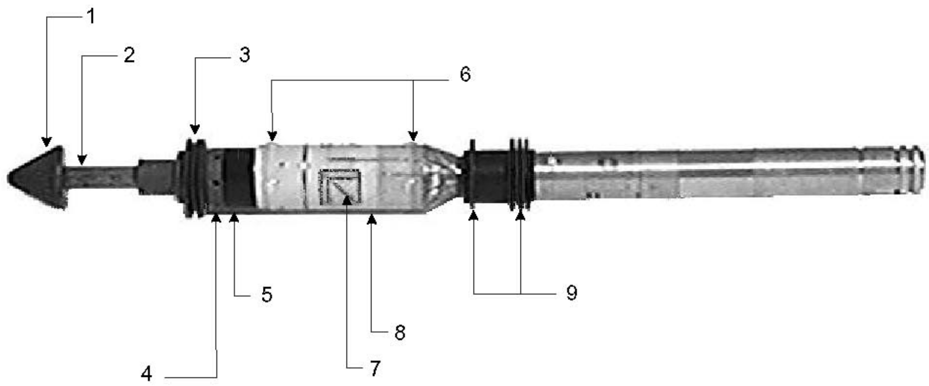
Since 1972, measuring cells have been developed at several research institutes to measure the three-dimensional state of stress in rocks by the overcoring stress-relief method. One of these cells, the hollow inclusion stress cell from the Commonwealth Scientific and Industrial Research Organisation (CSIRO), 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.



1 Centering tip
2 Depth locating rod
3 Rubber seal
4 Cement exit hole
5 Piston
6 Centering lugs
7 Strain foil gauge
8 Hollow resin pipe
9 Rubber seals

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

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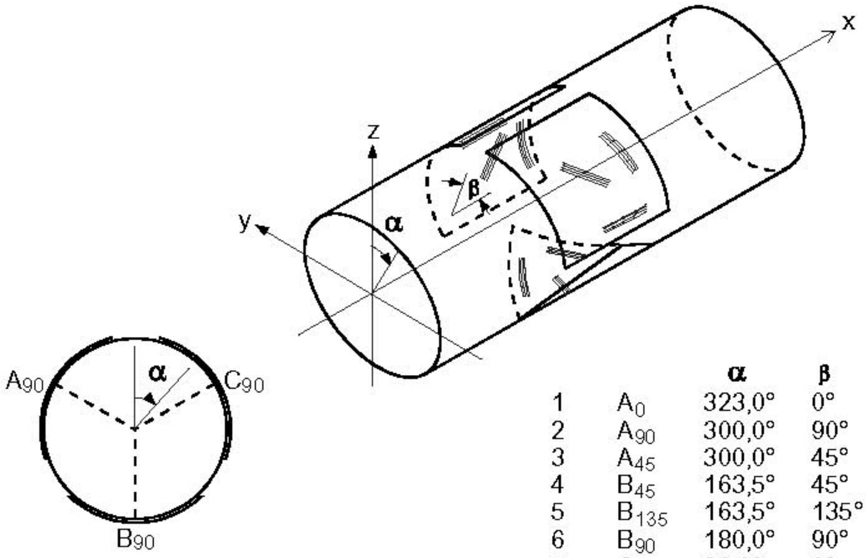
In the HI cell, the three 45 °/90 ° strain gauge rosettes are aligned at exactly 120 ° to each other so that three gauges come to lie in annular direction, two in axial direction and four at ± 45 ° to the borehole axis (see Fig. 3). Each strain gauge is 10 mm long in order to be relatively large compared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



		α	β
1	A_0	323,0°	0°
2	A_{90}	300,0°	90°
3	A_{45}	300,0°	45°
4	B_{45}	163,5°	45°
5	B_{135}	163,5°	135°
6	B_{90}	180,0°	90°
7	C_0	83,0°	0°
8	C_{90}	60,0°	90°
9	C_{45}	60,0°	45°

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.

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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.

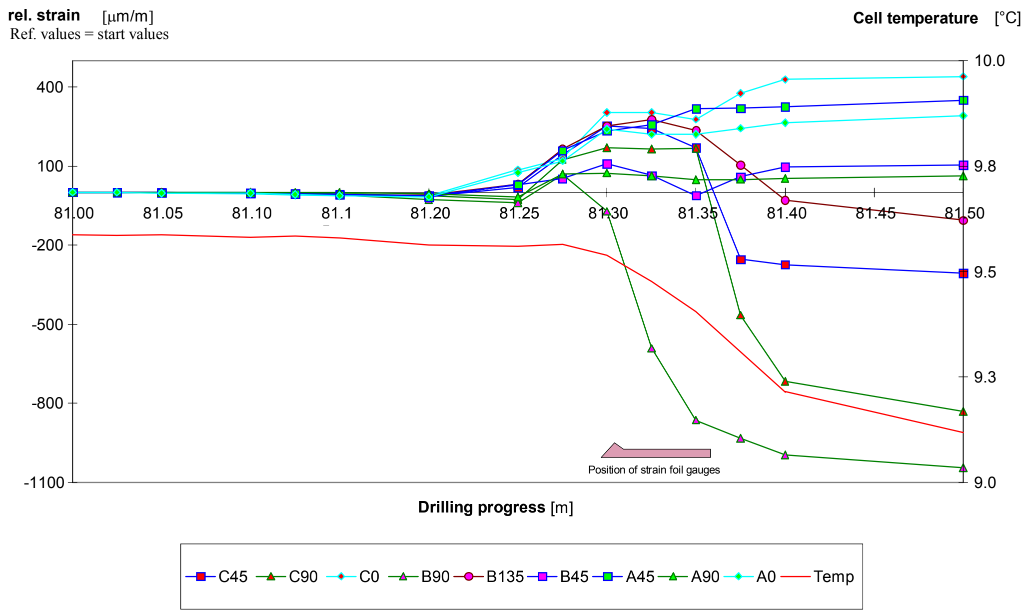

Fig. 4 Signals during the overcoring process

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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-

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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.

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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 ± 2 mm (other diameters on demand)
13.1.7	Installation manual CSIRO
13.1.8	Evaluation program STRESS 91

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