SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

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## Final Project Report

Title: CONCEPTUAL DEVELOPMENT OF A METHOD TO DETERMINE THE PRINCIPAL STRESSES AROUND COAL MINE WORKINGS TO ENSURE SAFE MINE DESIGN

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CONFIDENTIAL

# *Conceptional Development of a Method to Determine the Principal Stress around Coal Mine Workings to Ensure Safe Mine Design*

COL 326
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# EXECUTIVE SUMMARY

The objective of this project is to identify or to develop methods or procedures for the determination of the principal stresses in coal mine workings, which in turn would provide improved criteria for mine design layouts in coal mines.

To address the objective a survey of 52 papers was carried out to identify methods which could be of use for the determination of in situ stresses in coal mines. This survey showed that the majority of methods used to measure stress in coal are based on stress meters which are installed in boreholes drilled into the coal seam and then over-cored by a larger diameter hole which results in the stresses acting on the sensor being relaxed. Measurement of the degree of relaxation allows an estimate to be made of the change in strain, which, in turn, can be used to evaluate the original state of stress.

The study has indicated that a new technique should be developed that is suitable for coal. Recommendations as to the requirements have been made and a step by step methodology has been proposed.

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## A. LIST OF TABLES

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## 1. INTRODUCTION

The basic principle of most stress measuring techniques has been dependent upon the measurement of deformation of the rock, from which rock stresses can be computed. A summary of various stress measuring techniques for a wide range of applications is given in Table 1 to Table 5 (Appendix A). A large number of instruments have been developed, some of which have enjoyed considerable success and popularity in many countries. Methods which can be used to determine the complete state of stress in coal mines include the following:

a) **Cells based on changes to electrical resistance**

- Glass stress meters.
- Vibrating wire stress meters.
- Bureau of Mines stress meter.
- Bureau of Mines deformation meters.
- CSIR mark I and II stress meters.
- CSIR Doorstopper.
- CSIR Triaxial cell.
- Strain cell (Slobody)
- Soft inclusion cell (Blackwood)

b) **Methods based on partial relief of stress; slot cutting**

- L.N.E.C flat jack (Lopes)
- Flat jack (Panek)
- Cylindrical jack (Jaeger and Cook)
- Under-coring (Duval and Hooker)
- Borehole deepening (De la Cruz and Goodman)
- Rubber pressure bag (Baar)
- Potts stress meter (Potts)

c) **Methods based on stress meters**

- Glass stress meter (Roberts and Hawkes)
- Vibrating wire stress meter (Hawkes)
- Encapsulated borehole stress meter (U.S. Bureau of Mines)

d) **Methods based on hydraulic fracturing**

- Hydraulic fracturing in a borehole (Fairhurst and Haimson)

e) **Methods based on rock fracturing**

- Core discing (Obert and Stephenson)
- Measure strain to fracture in a borehole with a borehole jack ( De la Cruz)

f) **Other stress measurement techniques**

- Correlation between physical rock properties and stress e.g. resistivity and rock noise( Kanagwa, Hyashi and Nakasha)
- Yield point detection (Dreyer and Borchart)

The above survey of available methods for measurement of the in situ stress in coal mines was taken from a review paper by Erer and Heidareich-zadeh (1984)[1]. The conclusion reached by these authors indicates that not all methods are suitable for use in all coal fields, a conclusion which is certainly true for South African coal fields. This report summarizes the available methods that can be used for stress measurements in coal but concentrates only on available methods which have the best chance of success in determining in situ stress in coal mines.

## 2. BOREHOLE DEFORMATION

In general borehole-based methods depend on the change in borehole dimensions, borehole surface strain and stress change. These instruments are probably the most popular method for measuring deformations, from which the stress change can be calculated using the theory of elasticity. In general the common methods used are based on stress relief, which is achieved by over-coring of the gauge which is installed in a central borehole.

### *2.1. General Description*

A diamond borehole (NX coring bit is the most popular) is drilled to the depth at which it is desired to measure the deformation/stress. If 'virgin' stress must be determined, the depth at which the measuring instrument is positioned should be outside the influence of stresses due to the surrounding excavations. The end of the borehole is then ground flat and a smaller borehole (EX size) is drilled concentrically into the end of the larger diameter borehole.

The instrument, for example a CSIR triaxial strain cell, is then installed into the smaller borehole using a suitable glue. When the glue has set, the initial measurements are taken. The instrument is then over-cored with a diamond drilling machine and the deformation of the smaller borehole is recorded during the over-coring process. The over-cored rock material is withdrawn from the hole and its deformation properties are determined in the laboratory.

The in situ stresses are then calculated from the over-core deformations, or strain changes, making use of the theory of elasticity. Measurements of strain change from a single borehole yield the secondary principal stress that acts on a plane normal to the axis of the borehole. To calculate the complete state of stress, three measurements must be made in three differently orientated boreholes. The procedure is illustrated in Figure 1 (Appendix B). Table 1 (Appendix A) gives a summary of the stress relieving methods available.

## 2.2. *Borehole Deformation Instruments*

The following borehole deformation instruments are available:

a. USBM. The United States Bureau of Mines deformation meter is the most popular strain meter in use and probably has the highest chance of success in coal, (Obert et al,1962 [2] ; Hooker et al, 1974[3]).

b. YOKE GAUGE CSIRO. The CSIRO yoke gauge (Walton & Worotnicki, 1986[4]) was designed to give the same information as the USBM [2,3] three component borehole deformation gauge. Three changes in the borehole diameter are measured, which enables calculation of both the vertical and secondary principal stress perpendicular to the axis. The gauge is commonly used for determining change in stresses.

c. CRIEP (Central Research Institute of the Electric Power Industry-Japan) This is a five element deformation gauge (Kanagawa, Hayashi & Kitahara 1978[5]).

d. Other instruments include the LNEC., MAIHAK VIBRATING CELL and SIBEK'S CELL. See Table 1 (Appendix A) for more details on the above techniques.

## 2.3. *Measurement of the strain at the end of a borehole*

This method is in principle the same as that described in paragraph 1. A borehole is drilled to a depth beyond the influence of the excavation. The end of the borehole is then flattened and polished with diamond drilling equipment and special diamond drill bits. After thorough cleaning of the borehole end, the strain measuring instrument, with strain gauges, is bonded on to the end of the borehole. Base readings are recorded and the borehole is extended over the instrument to relieve all stresses acting on the rock/coal material. The core with the strain cell attached is then removed from the borehole and strain relief readings are taken. The mechanical properties of the material, in which the measurements are taken, are determined in the laboratory and, using the theory of elasticity, the in situ secondary stresses in the plane of the borehole end are calculated.

### 2.3.1. Available instruments which are suitable for use in coal

a. DOORSTOPPER-CSIR: Figure 2 (Appendix A) illustrates the method/procedure. The Doorstopper (Leeman,1964[6.1,6.2,6.3,6.4]) is a four element strain gauge based instrument which is installed in a BX diameter diamond drilled hole. To determine the complete state of stress, strain changes from three differently orientated boreholes are required. The data are then combined to enable a complete three dimensional solution for the in situ stress state.

b. CONICAL STRAIN CELL, developed by Sugawara and Obara 1995[7]. The procedures used for this cell (Figure 3, Appendix A) are similar to the Doorstopper method, but with the following differences.
The bottom end of the borehole is deformed into a conical shape using special diamond drilling bits. After polishing and cleaning the conical portion of the borehole with a special diamond bit, a 16-element strain cell is bonded directly onto the rock surface. During over-coring of the strain cell, the strains are measured continuously and the complete state of stress can be computed from the results.

c. Other techniques are listed in Table 1. These include the PHOTO-ELASTIC BIAXIAL CELL (Hawkes & Moxon[8]) and WNIMI STRAIN CELL.

## *2.4. Determination of the change of strain at the wall of a borehole*

The drilling technique is similar to that used with USBM[2,3] strain cell. Figure 4 (Appendix B) illustrates the procedures used for measuring the strains on the wall of the borehole. After drilling a concentric EX borehole, the hole is thoroughly cleaned and the strain gauge based instrument is installed and cemented in position. The cell is over-cored and the strain changes are measured, to calculate the in situ stress state.

### 2.4.1. Instruments to determine the complete state of stress in coal pillars

a. CSIR TRIAXIAL STRAIN CELL (Leeman 1969[9], Van Heerden 1976[10]). This cell consists of three four-element strain gauge rosettes that are orientated at

45 degrees and 90 degrees and are cemented directly onto the rock material. Base/zero readings are recorded before over-coring and the final strain relief readings are taken once the over-cored section has been removed. The complete in situ stress field can be computed from one measurement in a single borehole using this instrument, provided that the strength and elastic properties of the rock material are known and the applicability of the theory of elasticity is assumed.

b. CSIRO HI-CELL (Worotnicki & Walton 1976[4]). The CSIRO HI-CELL incorporates a total of 12 strain gauges with a length of 10 mm orientated at 90 degrees to each other in different directions. When installed, the cell forms a hollow epoxy inclusion casted on the borehole surface for a distance of about 100 mm. Core relaxation can be monitored during over-coring, by means of a cable permanently attached to the strain cell. The complete state of stress can be computed from the results of one test in a borehole.

c. LUH-TECHNIQUE (Leijon 1983[11]). This technique is similar to the above two methods but, contrary to these, is recoverable and is re-usable after laboratory reconditioning.

Some of the advantages and disadvantages of borehole-based methods have been reported by Cooling, Hudson & Tunbridge 1988[12]; Leijon & Stillborg 1986[11]. The most important disadvantages and advantages are listed below:

### 2.4.2. Advantages of over-coring techniques

a. Complete stress tensor can be obtained with most strain gauge devices.
b. Some instruments have extra gauges that can be used for checking, such as the CSIR triaxial strain cell.
c. Elastic properties of the actual over-core material are used for calculation of results.
d. Temperature affects are accounted for by compensation with strain gauge

bridge configuration.

### 2.4.3. Disadvantages of over-coring techniques

a. Epoxy based adhesives are not suitable for use in dirty, wet or humid environments such as encountered in coal mines.

b. Some corrections may have to be made for strain gauges that are not in direct contact with the rock (e.g. because of thick cement).

c. Surface mounted strain gauges can be damaged easily during installation and removal.

d. Specialized installation techniques are needed when working with strain gauges.

e. Most strain gauge instruments can not be used in a wet environment.

f. The contact between the strain gauges and the rock may give errors owing to the presence of surface crystals and the micro scale of the strain gauges, which are usually not longer than 10 to 15 mm and less than 5 mm in width.

g. Specialized, high quality drilling with suitable drilling equipment is needed.

h. Owing to the need to ensure that the strain gauges are directly bonded to the rock surface and are not easily damaged, only one measurement can be made in a single borehole in one mining shift.

i. Micro cracking can occur, damaging the strain gauge, and also the grain size of rock used may be too large or too small to give reliable strain relief measurements.

j. Good rock material is required.

# 3. INTERFELS BOREHOLE SLOTTER

This technique falls under the group of partial stress relief methods. The instrument is based on the measurement of strain changes on the inside wall of a diamond drilled borehole by means of a special transducer. With the borehole slotter, the strain relief is created by cutting a slot in the wall of a borehole (Bock & Foruria 1983[14] ; Bock 1986[15]). The strain change is then measured next to the slot during the cutting process. Three boreholes of 100 mm diameter are required to determine the complete state of stress. In order to obtain measurements, the borehole slotter is installed in the borehole and clamped in position. Figure 5 shows the basic layout and measuring principle of the instrument. A half-moon shaped radial slot is cut into the side of the borehole by means of a small diamond impregnated saw. The slot is about 1 mm wide and 25 mm deep. The saw is pneumatically driven and is activated hydraulically for the cutting operation. Before, during and after the slotting operation tangential strain is measured, with a contact strain sensor, at the borehole wall in the immediate vicinity of the slot where stress relief occurs. At the testing point where stress measurements are to be made, a number of successive slots are cut in different orientations; three slots 120 degrees apart are the minimum requirement for a single two-dimensional stress measurement. Normally, additional slots are cut until a sufficiently consistent trend is observed. These trends are then used to calculate the state of stress, using the Kirsch solution in conjunction with laboratory values for the properties of the rock material. The complete state of stress can only be calculated if the three boreholes are orientated in three different directions.

## *3.1. Advantages of the Borehole Slotter*

a. The method is attractive as many slots can be cut in one borehole and during one mining shift.
b. The boreholes can be drilled before the time and it is not necessary for the drilling equipment to be available during the slotting process.
c. The strain is measured next to the slot during the cutting process.
d. Measurements are possible in jointed rock material.

### 3.2. *Disadvantages*

a. The borehole slotter is based on a mechanical strain gauge based principle, which is subject to temperature variations. This could have a detrimental effect on results.

b. The boreholes need to be drilled carefully since the condition of the wall of the borehole is critical as the measuring device is pushed against the borehole surface.

c. Measurements in fractured rock conditions are not possible.

d. At least three slots are required to calculate the secondary principal stress in a plane normal to the borehole.

## 4. LARGE DIAMETER OVER-CORING

This over-coring method is similar to that of the CSIR instrument but on a larger scale. The method[16] consists of the fixing of rosette gauges, mechanical or electrical, at three positions on the periphery of a tunnel or bored raise. The gauge length is usually about of 150 to 300 mm. The rosettes are over-cored using a large diameter coring bit. In practice a 360 mm diameter, thin wall diamond drill is usually used. Checking of results is done by measuring outside the over-core, yielding results from under coring. The complete state of stress can be calculated using the elastic theory.

### *4.1. Advantages*

The advantage of this method is the large scale of material that is used for the measurement;

a. Gauges of 150 mm to 300 mm long are used for the measurements and thus the strains are likely to be more accurate.
b. Over-coring with the 360 mm bit ensures less breakage of core in weak material
c. Rock surfaces can be inspected and suitable sites can be selected to ensure that the best location for gauges and over-coring is obtained.
d. In situ stresses are calculated from the measured strain relief using elastic theory. The complete state of stress can be determined if three boreholes are used.

### *4.2. Disadvantages*

a. The method requires a bored raise or tunnel; special sites should be developed and planned for, which is not always possible.
b. This method is very expensive.
c. Special safety requirements are needed in order for personnel to gain access to testing positions.
d. It is rarely possible to develop a testing site at the position where stresses need to be determined.
e. Special drilling equipment is needed for the bigger than usual diameter required.

## 5. PARTIAL RELIEF OF STRESS

### *5.1. Flat Jack Measurement Technique*

This is a direct method of measuring stresses on the surface of an excavation. Deformation of rock is measured by cutting a slot, placing a jack into the slot and then inserting a pressure bag that is inflated to equalize the pressure in the bag with the load. This is an old method, suggested by Tencelin in 1952[17]. Six tests in six different orientations are required to determine the complete state of stress. Virgin stresses can be calculated using the theory of elasticity and numerical modelling.

According to Rocha, Lopes & Da Silva 1956[18], a summary of the technique is as follows:

> Measuring or reference pins are installed into the rock surface on either side of the slot to be cut with the aid of a special jig. See Figure 6 (Appendix B) for the layout of a flat jack test. A slot is then cut into the rock surface with a diamond saw in a frame specially designed to control the sawing operation. As an alternative to the slot cutting, a series of overlapping holes can also be drilled. After the slot has been cut a flat jack is grouted into the slot and pressurized. Deformation measurements on the measuring pins are recorded during the pressurization of the jack. When the distance between measuring pins is the same as it was before the slotting operation, the pressure in the small flat jack is equal to the stress.The pressure in the jack represents the stress magnitude on the surface of the excavation, normal to the plane of the slot.

Variations of the method exists such as:

a. CYLINDRICAL JACK - Jaeger & Cook 1963[19],

b. FLAT JACK and

c. PRESSURE BAG - West Germany 1960.

See Table 2 for more details on the three methods.

### 5.2. *Advantages*

a. Direct measurement of stresses on the surface of the excavation is determined by pressurizing of the pressure bag.

b. A flat jack in a given orientation will give one component of the stress field.

### 5.3. *Disadvantages*

a. For determination of virgin in situ stresses the theory of elasticity, or numerical modelling must be used.

b. Special sawing and drilling equipment is required.

c. Good rock quality is needed on the surface of the pillar or the rock.

d. Six measurements, at different orientations, have to be made using the flat jacks to determine the complete state of stress.

# 6. BOREHOLE DEEPENING

This technique allows the radial deformation of a borehole to be monitored, while deepening/extending the borehole. It has been used successfully for stress measurement in large caverns and excavations.

A diamond borehole is drilled to the required depth for measurements. Instrumentation to measure the diameter of the borehole at several positions, is then installed as close as possible to the bottom of the borehole. Specially designed drilling bits and drill string are then used to deepen the borehole. During the deepening of the borehole the deformation of the borehole is measured at several positions, by means of a hollow borehole deformation transducer. The complete state of stress can be calculated from differently orientated boreholes using numerical analysis. Large scale tests (Wittke, W. 1990[22]) have been performed in Waldeck II Cavern Germany (Jagsch, D. 1974[21]). A large diameter borehole 920 mm was used.

## 6.1. Advantages

a. As a result of the large scale of the method, the rock mass behaviour and not the rock material behaviour is monitored for the calculation of stresses.
b. Measurements of deformation over a large gauge length are possible, which will improve the accuracy of measurements.
c. The method is not dependent on the recovery of core and therefore the drilling is somewhat easier.
d. Measurements are be possible in jointed and weaker / softer material.

## 6.2. Disadvantages

a. The method requires special drilling equipment and a bigger than usual borehole.
b. A special measuring technique must be used to determine the deformation of the borehole during deepening of the borehole operation.

c. Boreholes with different orientations are needed to determine the complete state of stress.
d. Numerical modelling is required to interpret the results.

## 7. STRESS METERS IN BOREHOLES

This technique is used to measure changes in stress with time, and can also be used to determine in situ stresses. The method depends on the deformation of the borehole. As a result of the gauge being rigid and the rock mass resistance to deformation, change in stress is induced in the stress meter. Stress meters are generally used in the mining industry to monitor the stress change.

Examples of stress meter instruments that have been used or are still in use are listed below. In Table 3 (Appendix A) more details are given on the following instruments:

a. Potts stress meter.
b. Glass stress meter.
c. Vibrating wire stress meter and
d. USBM encapsulated hydraulic stress meter.

### *7.1. Advantages*

a. With some of the stress meters, such as the solid inclusion gauge, the complete state of stress can be determined in one borehole.
b. Stress meters have a high rigidity and a long term stability.
c. The instruments are in contact with the wall of the borehole through the entire body of the instrument.
d. Some types of vibrating wire instruments may be recovered and reused.

### *7.2. Disadvantages*

a. The stress measurements have to be calibrated against a rigid instrument.
b. The tolerance [23] in diameters between the borehole and the cell is important.
c. For most of the instruments, differently orientated boreholes, with at least three different orientated cells in each of the boreholes, are needed for stress calculations.

d. Some stress meters need to be grouted in position; if the contact between the stress meter and the borehole is not controlled, crucial deformation or loading of the instrument at the beginning of a test is lost and large errors can be made.

## 8. HYDRAULIC ROCK FRACTURING OF A BOREHOLE

Hydraulic fracturing (Fairhurst, C: 1964[20]; Haimson, BC: 1976[25]), also called hydrofracturing, is a method that gives a direct estimate of stress without calibrations being necessary. The method is in common use and generally is used to determine stress at great depth.

In this method, fluid pressure is applied to a test section of a borehole isolated by borehole packers in a series of pressurisation cycles. Figure 8 (Appendix B) illustrates the packer equipment and the pressurisation cycles. The pressures, which are required to generate, propagate, sustain and reopen the fractures, are related to the stress field.

### *8.1. Advantages*

a. Minimum principal stress is measured from the shut-in pressure. The complete state of stress is determined by hydraulically fracturing the rock in three non-parallel boreholes.
b. HTPF[26] method, hydraulic tests on pre-existing fractures will provide data normal to the plane of the existing fractures.

### *8.2. Disadvantages*

a. Not suitable for use in fractured and jointed material such as coal. This is because it would be very difficult to build up enough pressure to fracture the material and very high natural flow rates will make the results difficult to interpret.
b. Results do not give distinct trends and are difficult to interpret.
c. To determine the orientation of principal stresses, the boreholes must be drilled in the exact direction of at least one of the principal stresses.
d. Large logistical support is required, for example: packers, hoses and instrumentation, to ensure results that are reliable.
e. Careful mapping of boreholes using down the hole logging is required if HTPF [26] methods are used.

## 9. SUMMARY

a. Borehole over-coring methods suffer from poor reliability, and specialized services and equipment. Successful application of this technique for stress measurements in coal mines are few.

b. Unlike boreholes in rock, the inner wall of a borehole drilled in coal has a rough surface and is easily disturbed during the installation of instrumentation. Therefore accurate measurement of the changes in borehole dimension is difficult to obtain.

c. The presence of water in boreholes, and the influence on strain readings in over-coring methods, makes these methods suspect in coal.

d. With most of the borehole stress measurement techniques, only a small portion of the coal material is monitored (typically 10 mm). The ideal would be to monitor behaviour on a much larger scale and to look at the coal mass.

e. It is difficult to bond strain gauges to coal, special techniques are needed and successful strain measurements are difficult to obtain on coal material in a mining environment.

f. Intact over-cored coal material is very difficult to obtain as a result of the nature of the coal itself.

g. The borehole slotter technique suffers from the same disadvantages as the strain gauge techniques. Mechanical measuring devices, on a very small scale, can only be used and 10 mm is typical for gauge length.

h. Large diameter over-coring is more reliable but dependent on a specific site.

i. Flat jack equipment is not suitable for stress measurements in poor rock material conditions such as the exposed surface of a coal pillar or working face.

j. With the borehole deepening method, deformation measurements can be taken on a much larger scale. In this method the response of the rock/coal mass is measured.

k. Owing to the mechanical contact between stress meters and the coal surface inside a borehole, large measuring errors can be made.

l. Specialized equipment is required for the hydrofracturing; the technique is also operator sensitive and the results are difficult to interpret.

m. As a result of the porous and jointed nature of coal, the hydro-fracture method is unlikely to be effective.

## 10. REQUIREMENTS FOR A RELIABLE METHOD THAT CAN BE USED IN COAL MINES.

This study of stress measurement techniques, their advantages and disadvantages, has indicated a number of important requirements as follows:

a. The technique should:

- be developed to work in South African coal fields.
- take into account the overall rock/coal mass and not the coal material only.
- allow many measurements to be made during a test.
- be sensitive to small changes in stress.
- provide checks on the data obtained during the test.
- be practical.

b. In addition data reduction software should be developed that is user friendly.

# 11. RECOMMENDATIONS

It is suggested that a project be undertaken to further develop ***large scale borehole deepening*** as a stress measurement technique. This is because the currently used stress measuring techniques for rock/coal are strain gauge based and no further development of this technology is possible and feasible.

It is clear that most of the problems associated with the existing small scale techniques can be eliminated if measurements are aimed at measuring the reaction of stresses in the coal on a much larger scale.

The development of a larger scale (minimum borehole diameter of 300 mm) stress measuring technique is suggested. Stresses can then be calculated from the deformations/strains measured inside the borehole. Making use of mechanical/optical measuring techniques to determine the size and shape of the borehole is recommended.

Software to calculate the stresses from the measured strains must also be developed

**To develop the technique and instrumentation the following steps are envisaged:**

## 11.1. Development of electronic measuring equipment.

a. Define design parameters and accuracy and identify suitable electronic components for measuring devices to be incorporated in a measuring trolley.
b. Detail design and electronic diagrams of electronic components.
c. Manufacture of electronic components.

## *11.2. Development of mechanical equipment*

a. Define design parameters and accuracy and identify suitable components for measuring device/trolley.

b. Detail design and mechanical drawings of measuring device / trolley.

c. Manufacture mechanical measuring device / trolley.

### 11.3. Development of method for analysis of data

a. Develop theory for analysis of results.

b. Write computer program.

c. Test program with theoretical results.

### 11.4. Laboratory testing of electronic measuring equipment

a. Conduct laboratory tests on electronic components.

b. Modify equipment.

### 11.5. Laboratory testing of mechanical equipment

a. Conduct laboratory tests on mechanical measuring device / trolley.

b. Modify components.

### 11.6. Integration of measuring system

a. Integrate mechanical and electronic components into one unit.

b. Obtain SABS intrinsically safe certification of equipment.

### 11.7. Modifications to system

Modify mechanical, electronic and control software.

### 11.8. Field trials

a. Integrate measuring device and drilling equipment for underground use in a coal mine.

b. Carry out trials in coal mine.

c. Analyse results and compare with actual stress conditions.

### 11.9. Modifications to system as appropriate

### 11.10. Further field trials

a. Conduct further field trials underground in a coal mine.

b. Analyse field data and test for acceptance.

### 11.11. Stress calculations of field data

a. Stress calculations with field data.

b. Complete data reduction software.

### 11.12. Preparation of report and instruction manual

a. Complete manual on operational procedures.

b. Complete report on stress technique measurement.

### 11.13. Technology transfer to industry.

a. Hold workshop, on new stress measurement technique, with mining industry.

b. Training of technicians in application technique.

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# APPENDIX A

## Tables 1 - 5

# APPENDIX A

## Tables 1 - 5

# Table 1
# In situ stress relieving measurement techniques

| Stress Measurement | Measuring Principle | Procedure | Name of Instrument | Transducer | Measurable Stress Components | | | Nature of Stress Measurement | | Author Manufacturer | Country Year | Application to coal mining | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 | 2 | 3 | absolute | relative | | | | |
| Stress reliving | Measurement of changes in the diameter (s) of a borehole deformation gauge | Over-core the gauge within a central borehole | U.S B M. * Deformation | Bonded strain gauges | x (Year 1961) | | X (year 1963) | x | | Merril, Peterson | USA (1961) | Coal pillars | Soft inclusion currently available |
| | | Over-core a cylinder with strain gauges | L.N E C * | Bonded strain gauge rosettes | x | | X | x | | Rocha and Silverio (L.N E C ) | Portugal , (1974) | | Currently used Araldite is used in the borehole |
| | | Overcoring opperation is carried out | Maihak * vibrating wire cell | Vibrating wire transducer | x | | X | x | | Maihak company | W Germany (1960) | | |
| | | | Griswolds cell | Strain gauges attached to cantilevers or rings | | | | x | | Griswold | USA (1962-63) | Not applicable | Out of date |
| | | | CSIR Mark I & II | I electrical res strain<br>II.L V D T. | | x | | x | | Leeman (CSIR) | S Africa (1960) | Coal pillars, not reliable | Out of date |
| | | | Sibek's cell | Strain gauges | | x | | x | | Sibek | Czechoslovakia (1960) | Rib pillars and face | Out of date |
| | | | University of Liege cell | L V D.T | | x | | x | | Bonnechere | France (1975) | | |
| | | | Four-comp deformation gauge | Strain gauges | | | X | x | | Crouch Fairhurst (U.S.B M.) | USA (1967) | | Variation of U S B.M triaxial cell |

# Table 1 (cont.)
# In situ stress relieving measurement techniques

| Stress Measurement | Measuring Principle | Procedure | Name of Instrument | Transducer | Measurable Stress Components | | | Nature of Stress Measurement | | Author Manufacturer | Country Year | Application to coal mining | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 | 2 | 3 | absolute | relative | | | | |
| | | | Photo-elastic soft inclusion cell | Strain gauges | x | | | x | | Riley<br>Goodman<br>Nolting | USA (1976-77) | | Variation of U S B M triaxial cell |
| | Measurments of strain at the bottom face of a borehole | Overcore a rosette gauge bonded on the bottom of a borehole | Doorstopper | Bonded strain gauges | | | X | x | | Leeman (CSIR) | S Africa (1971) | Applicable to coal | Very popular in many countries |
| | | Overcore a borehole with strain gauges on it's walls | CSIR Triaxial cell | Bonded strain gauges | | | | x | | Leeman (CSIR) | S Africa (1971) | Overcoring is difficult on coal | Determination of complete stress tensor in a single borehole |
| | Strains at the bottom of a borehole | Overcoring operation | Photo-elastic biaxial cell | Photoelasticity | | x | | x | | Hawkes and Moxon | USA (1964) | Intrinsically safe for use in a coal mine | Borehole should not exeed 5m |
| | | | W N I M I strain cell | Bonded strain gauges | x | | | x | | Slobody | USSR (1965) | It was used in longwall mining | Modified versions are being used |
| | Change in magnetic permeability with stress | Over-core a rectangular solid incusion | Hast's cell | Magnetostriction | x | | | x | | Hast | Sweden (1958) | | The first reliable gauge employed |
| | Observation of photo-elastic stress fringes | Over-core a hard inclusion with down hole polariscope | C S I R O * Hollow inclusion cell | Strain guages bonded to the gauge body | | | | x | | Wortnicki and Walton | Australia (1976) | | |
| | | | Photo-elastic glass stress meter | Photo-elastic stress fringes | | x | | | | Roberts and Hawkes | UK (1964-65) | Applicable to longwall mining | Observation of fringes are difficult in deep boreholes |
| | | Strain gauges encapsulated in an epoxy resin cylinder | Soft inclusion cell | Electrical resistance strain gauges | | | X | x | | Blackwood | Australia (1976) | Rib pillars of longwall panels | Similar to LNEC gauge developed |

# Table 2
# In situ partial stress relieving techniques

| Stress Measurement | Measuring Principle | Procedure | Name of Instrument | Transducer | Measurable Stress Components | | | Nature of Stress Measurement | | Author Manufacturer | Country Year | Application to coal mining | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 | 2 | 3 | absolute | relative | | | | |
| Partial relieving of stress | Measurement of displacement caused by a slot cut wall<br>Stress compensation | | L N E C<br>Flat-jack | | x | | | | | Rocha, Lopes and Silva<br>(L N E C ) | Portugal (1965) | Simply and effectivly used | No grouting Semi-cirlce sltos Reusable at increasing depths of same slot |
| | | | U S B M<br>Flat-jack | Electrical resistance strain guages | x | | | x | | Panek<br>(U S B M ) | USA (1961) | Applicable to coal | |
| | | | Cylindrical Jack | Hydraulic oil within a core | x | | | | | Jaeger and Cook | USA (1966-69) | In coal pillars up to a depth of 14-15cm | Supplementry method |
| | Measurement of displacement of strain due to undercoring | Undercore the strain guage rosette on the surface of a rock face | | Three pairs of strain guages | x | | | x | | Duvall and Hooker | USA (1974) | | Variant of the "Doorstopper installation is a difficult supplem-entary method |
| | Cast inclusion method | Overcore a hard inclusion to freeze stresses into it | Soft inclusion guage | | x | | | x | | Riley<br>Goodman | USA<br>(1977) | | Stresses are measured in the laboratory |
| | Borehole deepening method | Monitor the ratial deformation of deepening boreholes | | Detection of bending cantilever beams with bonded strain guages | x | | | x | | De La Cruz and Goodman | USA (1970) | | Measurements should be preformed as close as possible to the bottom |
| | Pressurebag method | Locating the rubber pressure bag in the bottom end of a borehole drilled in a pillar | The rubber pressure bag | Displacement of a hydraulic fluid | x | | | x | | Baar | W Germany<br>(1960) | Easily installed in coal | |
| | | | Potts' stressmeter | Electrical resistance strain guages | x | | | x | | Potts | UK (1960) | Widely used in coal mines | Not currently available |
| Measurement of stress changes by hard inclusions | Borehole inclusion stressmeter | Measurement of changes in transducing element due to rock stress variations | Grid stressmeter | Strain guages in the form of a wheatstone bridge | x | | | x | | Salamon | UK (1960) | | |

# Table 3
# In situ measurement hard inclusion techniques

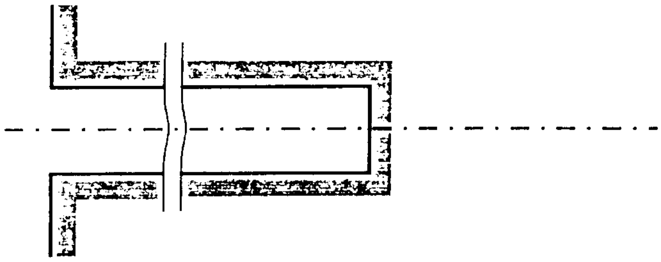
| Stress Measurement | Measuring Principle | Procedure | Name of Instrument | Transducer | Measurable Stress Components | | | Nature of Stress Measurement | | Author Manufacturer | Country Year | Application to coal mining | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 | 2 | 3 | absolute | relative | | | | |
| Measurement of stress changes by hard inclusions | Borehole inclusion stressmeter | Measurement of changes in transducing element due to rock stress variations | Grid stressmeter | Strain guages in the form of a wheatstone bridge | x | | | x | | Salamon | UK (1960) | | |
| | | | M R D E borehole plug | Foil resistance strain guages | x | | | x | | Wilson | UK (1960) | | |
| | | | Hast's rigid inclusion | Electrical res strain guages | x | | | x | | Hast | Sweden (1958) | | |
| | | | Glass Stressmeter | Photo-elastic fringes | | x | | | x | Roberts and Hawkes | UK (1964) | Suitable for coal mines | Illumination difficulties may arise |
| | | | Spherical rigid inclusion | Three strain guage rosettes | | | x | | x | The US Geological Survey | USA (1968) | | Cell is grouted in the borehole |
| | | | Vibrating * wire stressmeter | Vibrating wire | | | x | | x | Hawkes | USA (1973) | Applicable to coal mines | Favourable guages at present |
| | | | U S B M * Encapsulated borehole hydraulic stressmeter | Close hydraulic circuit | x | | | | x | US Bureau of Mines | USA (1962) | Favourable for coal mines | |

# Table 4
# In situ stress measurements by rock fracture

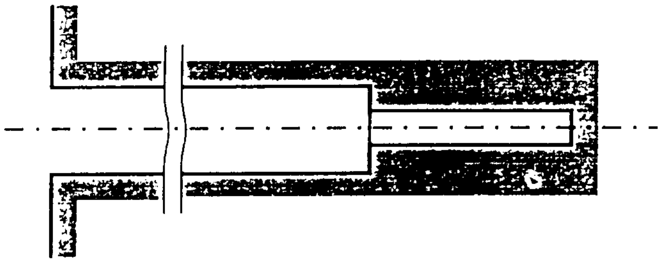
| Stress Measurement | Measuring Principle | Procedure | Name of Instrument | Transducer | Measurable Stress Components | | | Nature of Stress Measurement | | Author Manufacturer | Country Year | Application to coal mining | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 | 2 | 3 | absolute | relative | | | | |
| Rock fracture | Rock fracture | Hydraulic fracturing in a borehole | | | | x | | x | | Fairhurst Haimson | USA (1965) and (1978) | | Current stress measuring method |
| | | Core discing | | | x | | | x | | Obert and Stephenson | USA (1965) | | |
| | | Measure strain to fracture a borehole with a borehole jack | | | x | | | x | | De La Cruz | USA (1978) | | |

# APPENDIX B

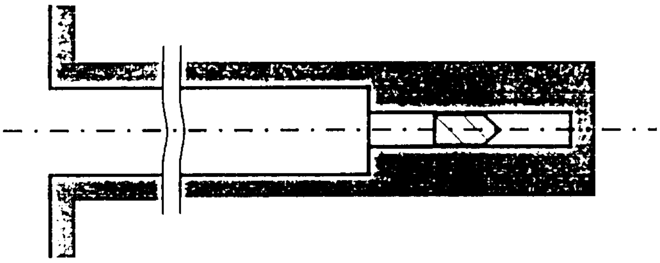
## Figures 1 - 8



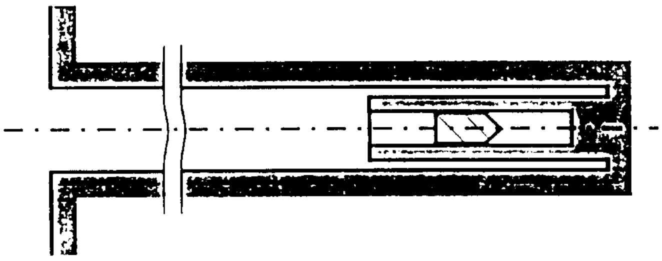
a) Borehole drilled to the depth at which the stress is to be determined



b) Pilot borehole drilled into the end of the borehole

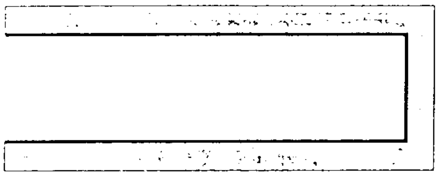


c) Deformation meter placed in the pilot borehole

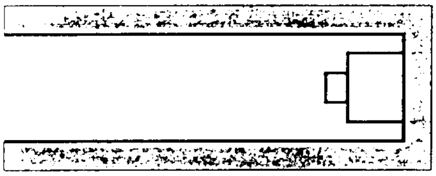


d) Pilot borehole overcored and strain relief monitored

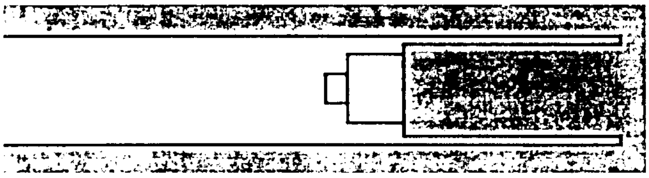
Figure 1. Borehole deformation procedure



a) BX borehole drilled to the required depth and end flattened and polished with diamond



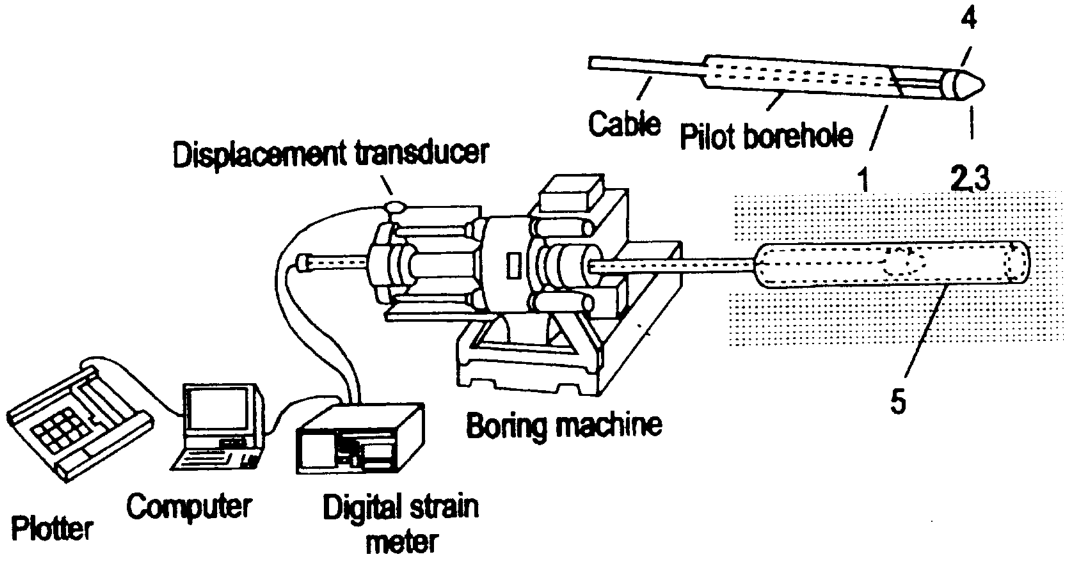
b) Strain cell bonded on to end of borehole and strain readings recorded



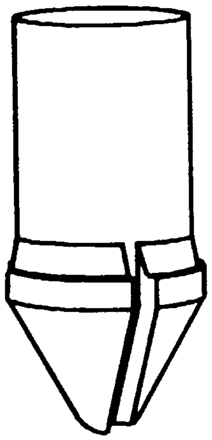
c) Borehole extended with BX diamond coring crown thereby stress relieving the core

d) BX core, with strain cell attached, removed and strain readings taken

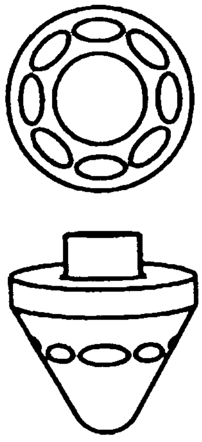
Figure 2. Doorstopper procedures



1 Pilot core boring of 76 mm
2 Bottom reforming by conical bit
3 Bottom cleaning
4 Conical strain cell
5 Compact overcoring and strain monitoring

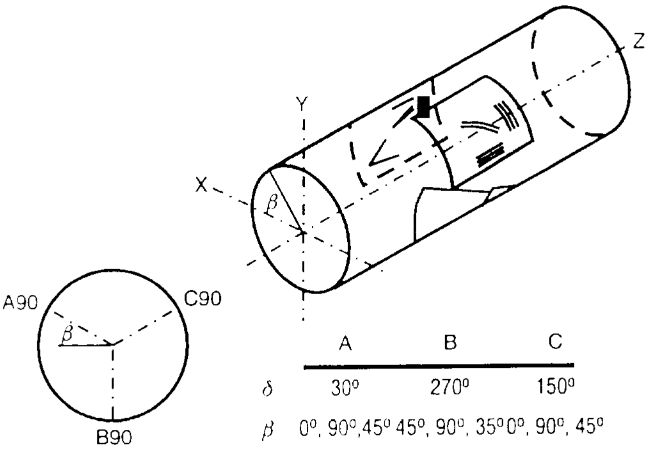


Conical Diamond impregnated Drill Bit

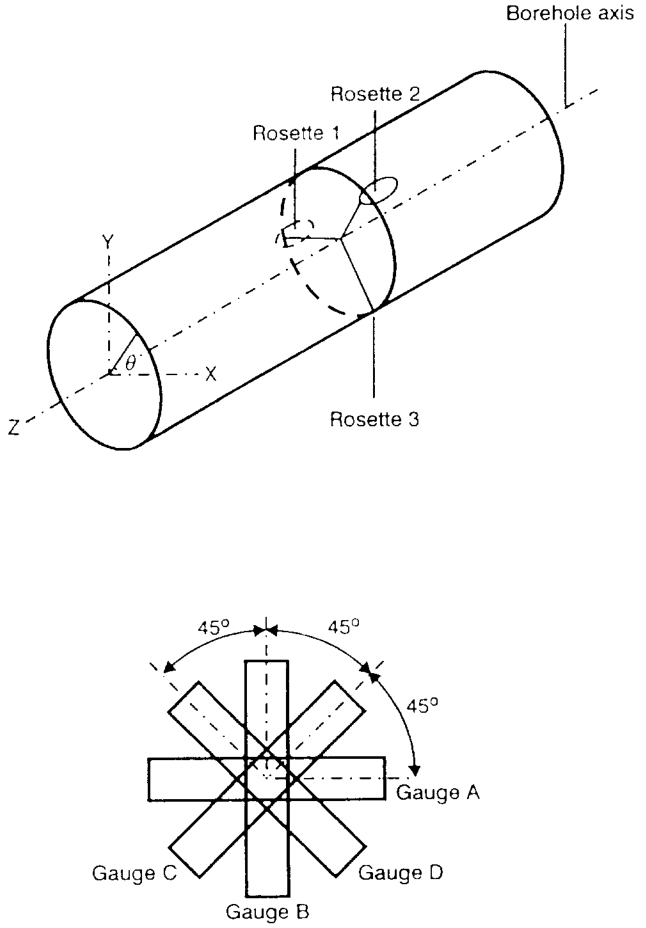


16 Element Conical Strain Cell

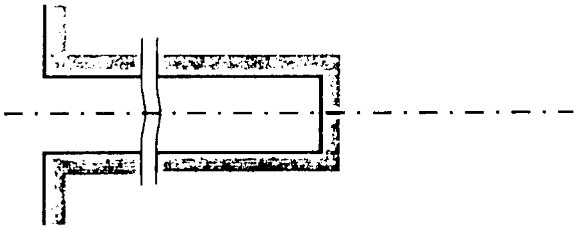
Figure 3. In Situ Continuos Strain Measurement System and Procedure



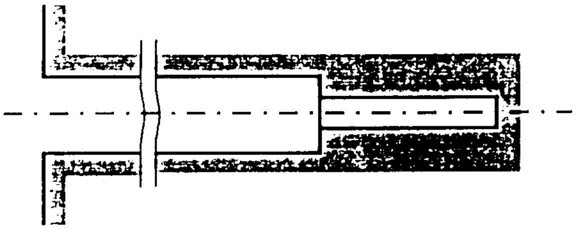
Strain gauges in the CSIRO H1 cell



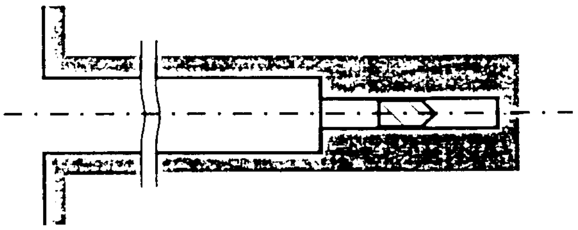
Strain gauges in the CSIR cell



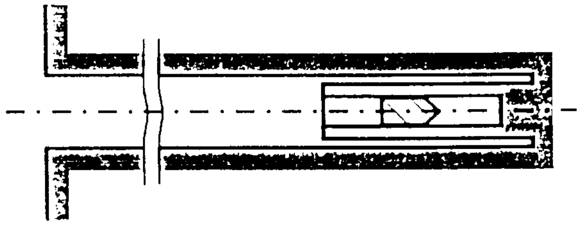
a) Borehole drilled to the depth at which the stress is to be determined



b) Pilot borehole drilled into the end of the borehole

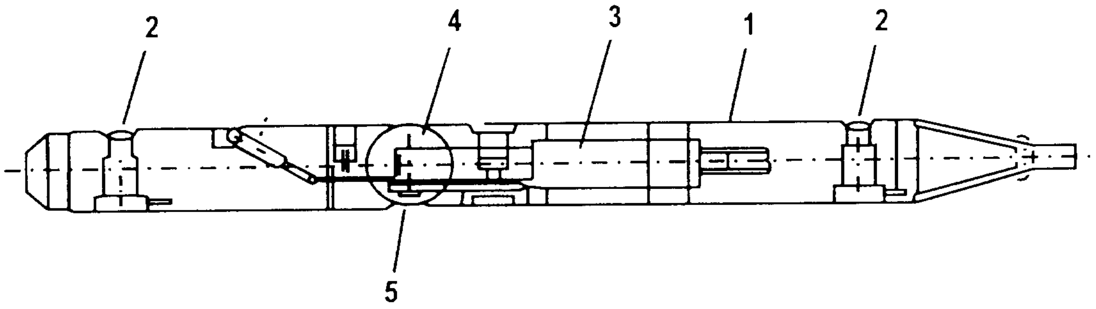


c) Deformation meter placed in the pilot borehole



d) Pilot borehole overcored and strain relief monitored

Figure 4. Triaxial strain cell procedures



1 Borehole slotter
2 Hydraulic cylinders
3 Pneumatic motor
4 Diamond saw blade
5 Strain sensor

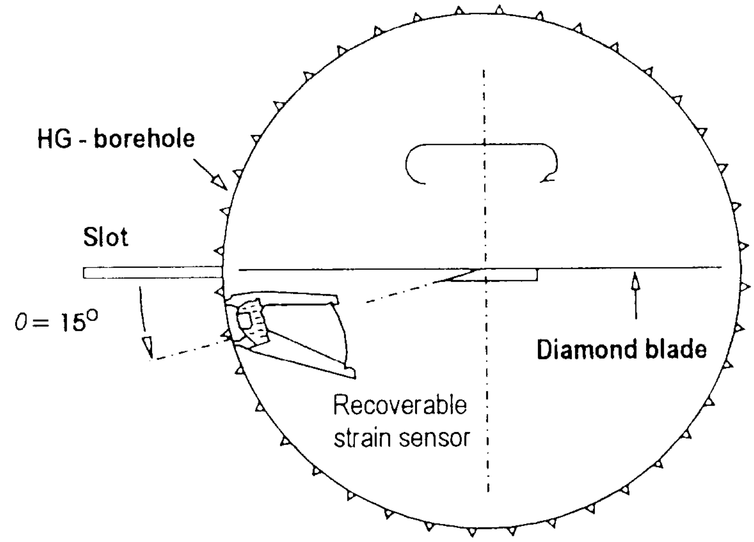
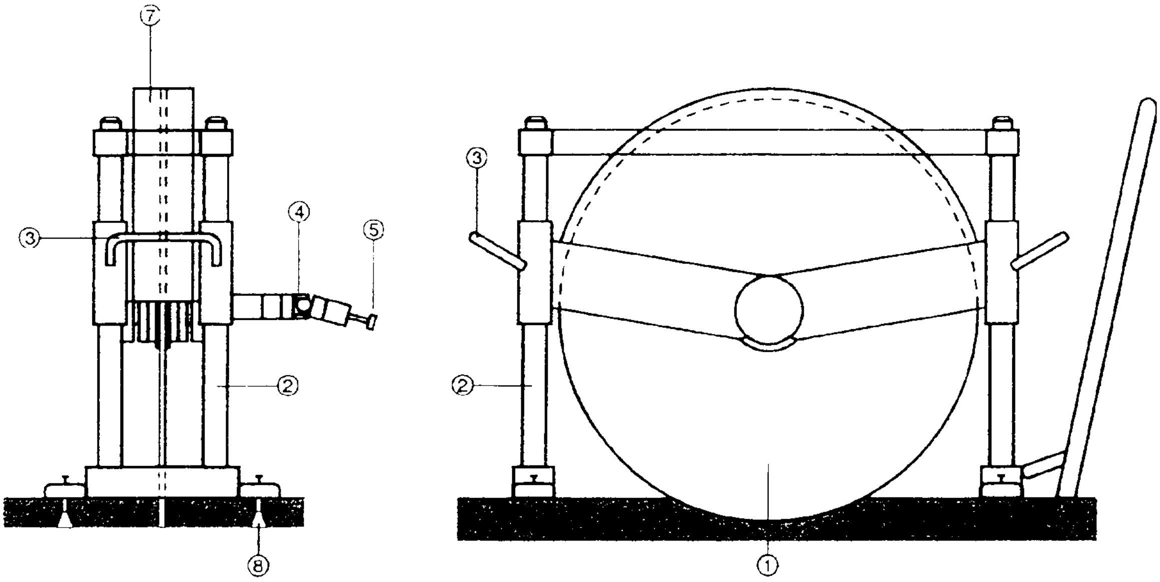


Figure 5. Principle Configuration of Borehole Slotting



1 Diamond disk
2 Guiding columns
3 Holders for operation
4 Cardan joint
5 Sliding
6 Lever for alternate movement
7 Protecting case
8 Bolts

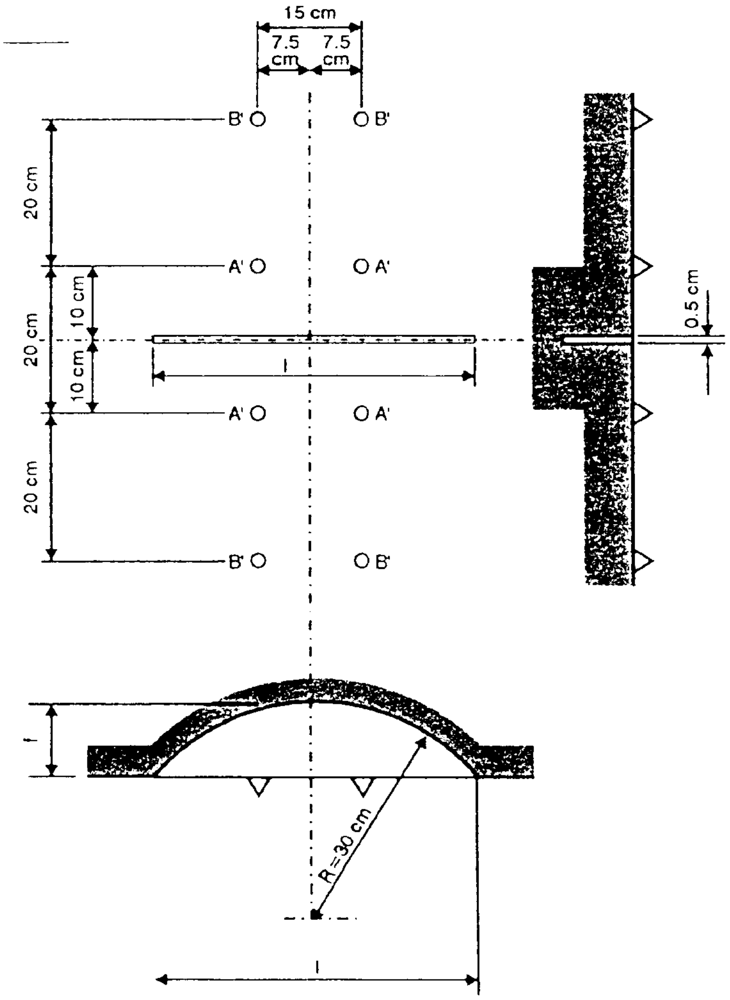


Figure 6. Flat jack method of stress measurement

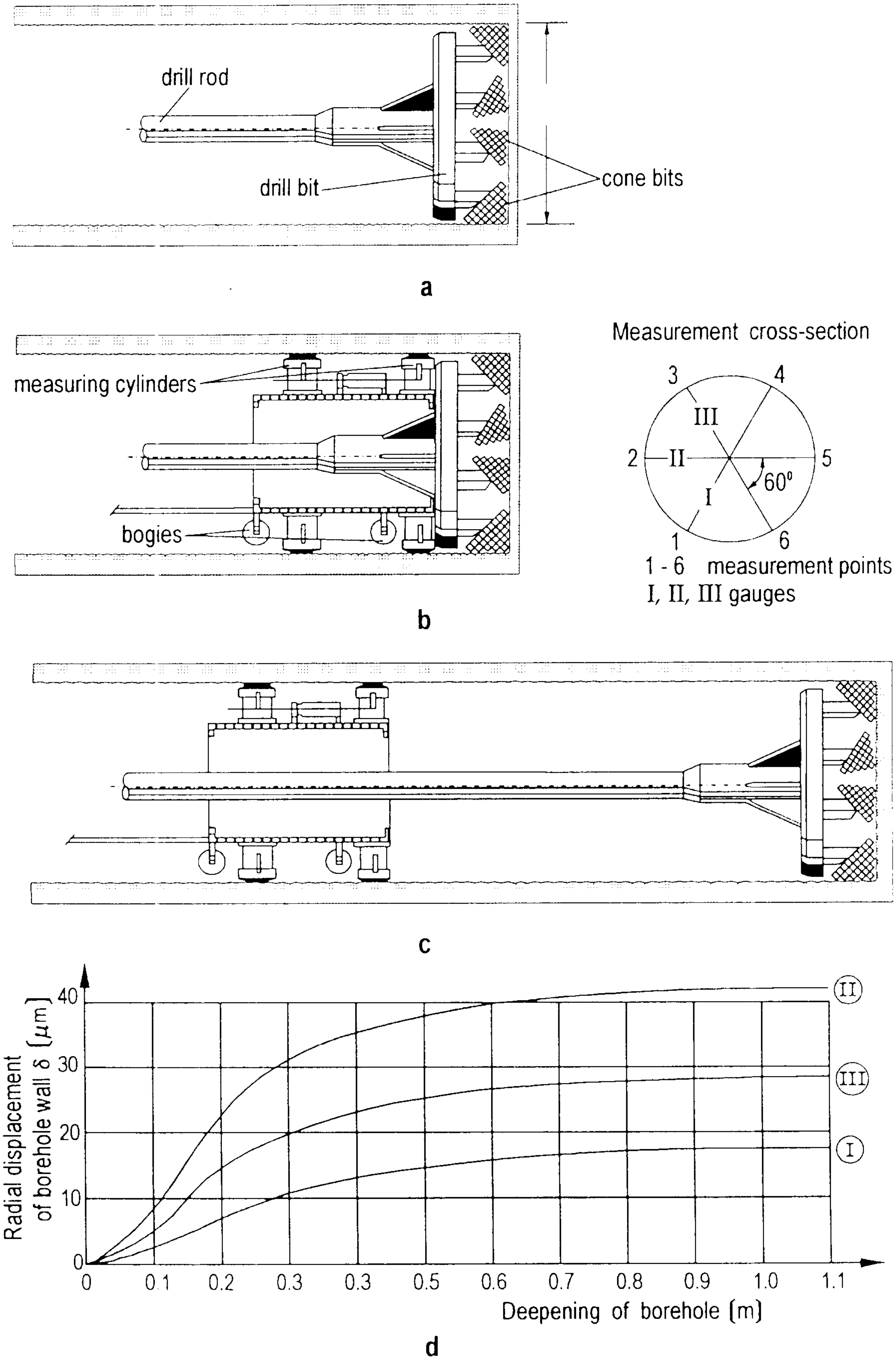
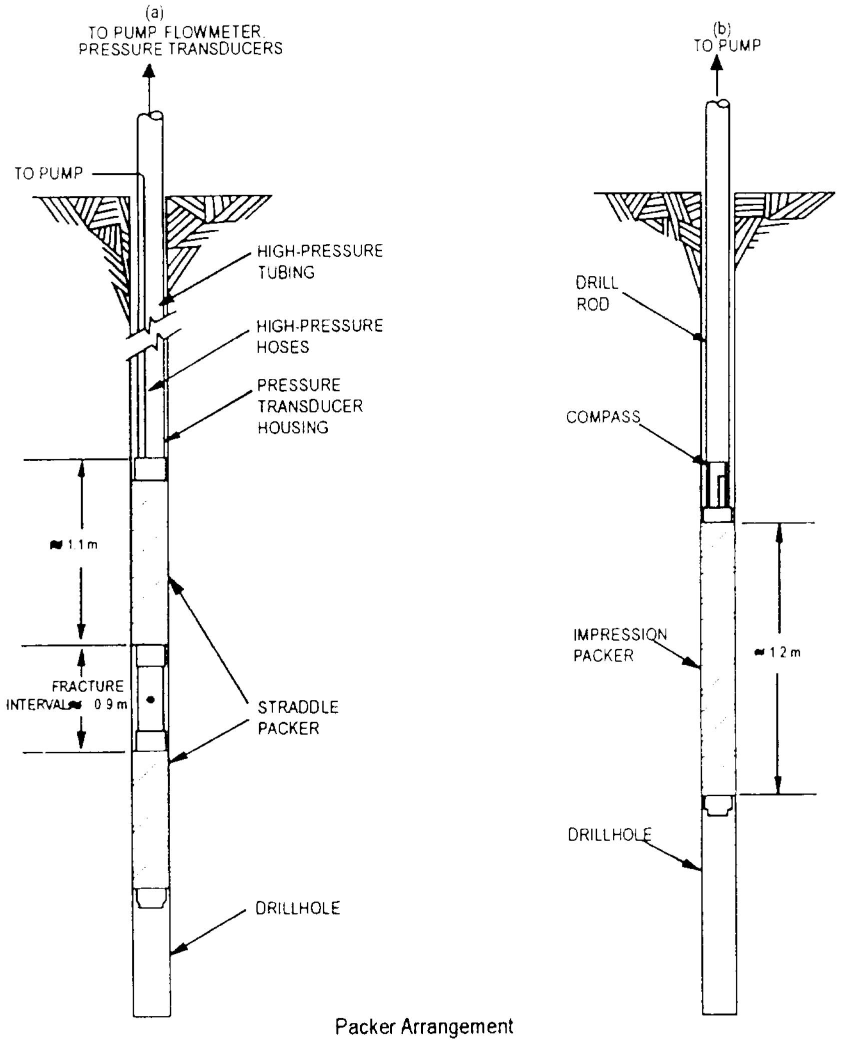
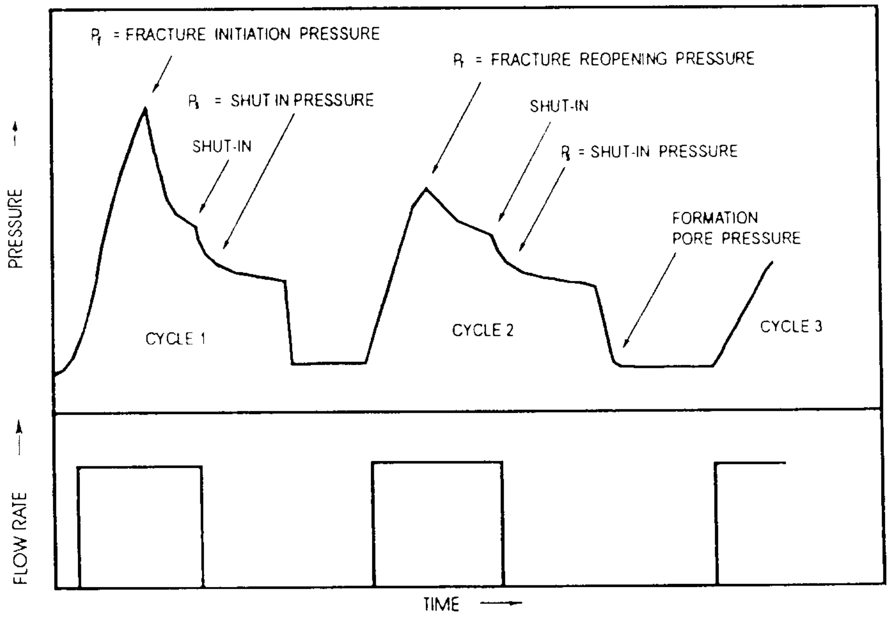


Figure 7. Large Diameter Borehole Deepening



Packer Arrangement



Idealized Hydraulic Fracturing Pressure Record

Figure 8. Schematic Representation of Hydrofracture