Unit 4	Pre-Mining State: Notation and Specifications of Pre-Mining Stress, In-Situ Stress and Factors Influencing In-Situ Stress. Methods of In-Situ Stress Determination and Presentations	5

In-situ stress and methods to determine in-situ stresses

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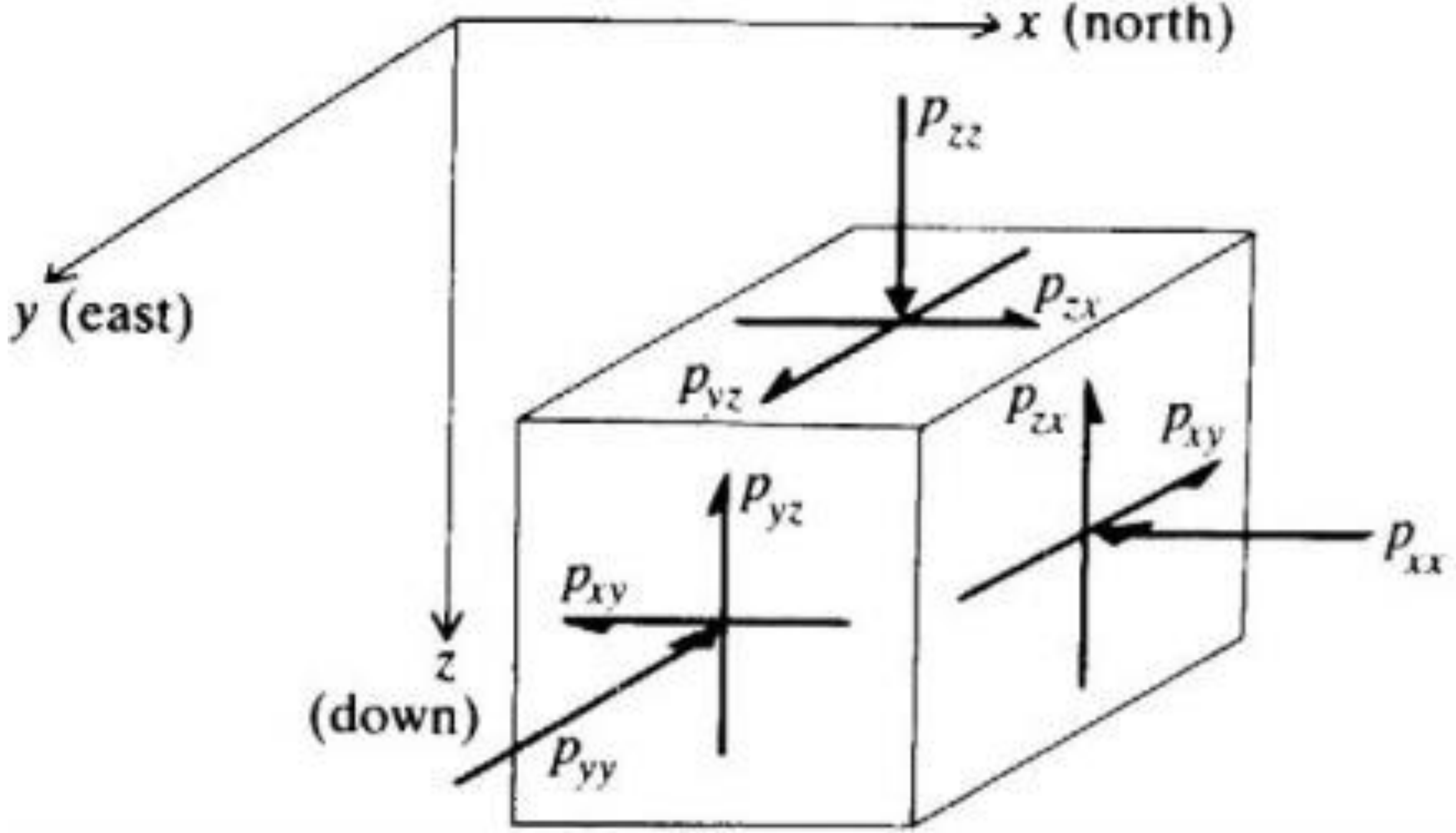

x (north)
y (east)
z
(down)
p_{zz}
p_{zx}
p_{yz}
p_{zx}
p_{xy}
p_{yz}
p_{xx}
p_{xy}
p_{yy}

- The state of stress in the rock mass is inferred to be spatially quite variable, due to the presence of structural features such as faults or local variation in rock material properties
- Since the ground surface is always traction-free, simple statics requires that the vertical normal stress component at a subsurface point is,

$$p_{zz} = \gamma z$$

where γ is the rock unit weight, and z is the depth below ground surface

- For elastic roc $p_{xx} = p_{yy} = \left(\frac{\nu}{1-\nu}\right) p_{zz}$ al normal stress components a

ν is Poisson’s ratio for the rock mass.

Here, it is also assumed that the shear stress components p_{xy}, p_{yz}, p_{zx} are zero

Why determine *in situ* stress?

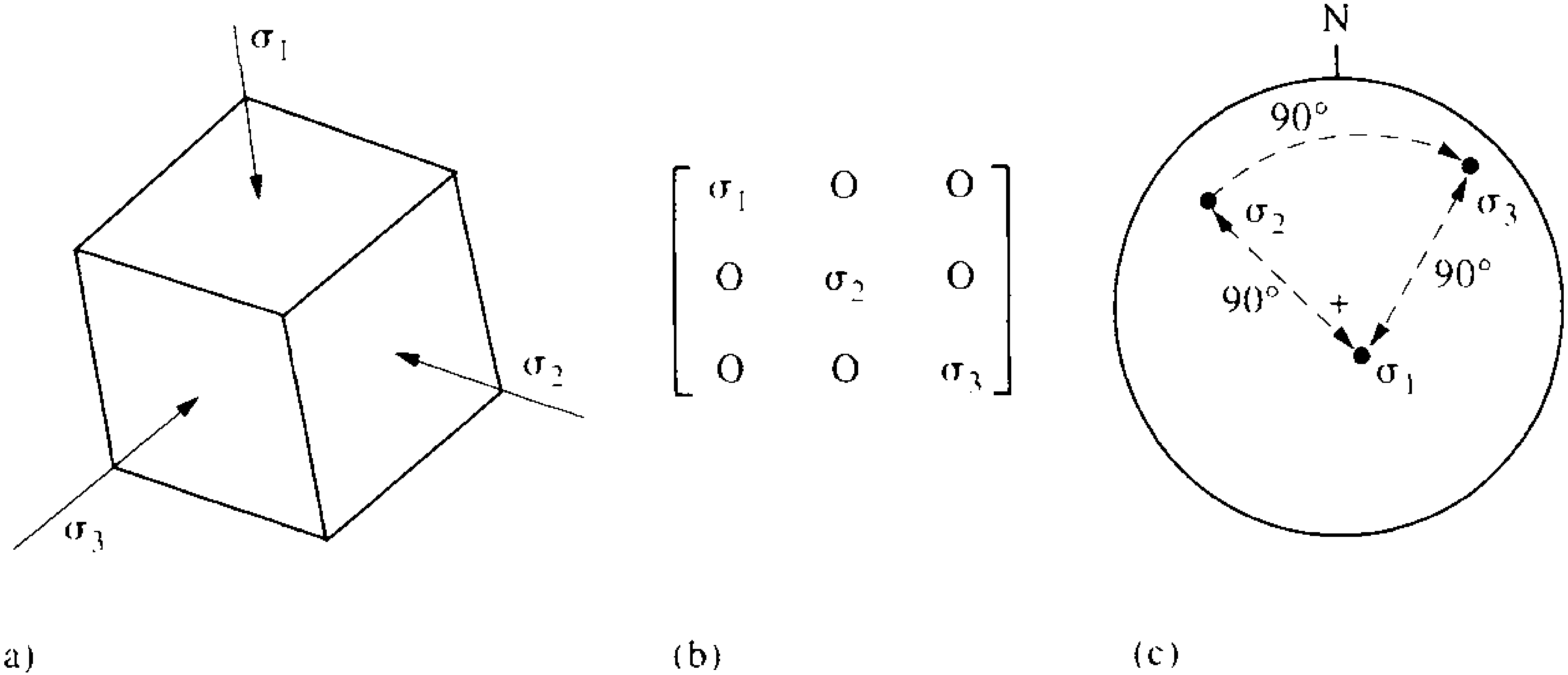
The basic motivations for *in situ* stress determination are two-fold.

1. To have a basic knowledge of the stress state for engineering, e.g. in what direction and with what magnitude is the major principal stress acting? What stress effects are we defending ourselves and our structures against? In what direction is the rock most likely to break? All other things being equal, in what direction will the groundwater flow? Even for such basic and direct engineering questions, a knowledge of the stress state is essential.

2. To have a specific and 'formal' knowledge of the boundary conditions for stress analyses conducted in the design phase of rock engineering projects.

We have already emphasized that there are many cases in rock engineering where the stresses are not **applied** as such; rather, the stress state is altered by the engineering activities, e.g. in the case of excavating a rock slope or tunnel

Presentation of stress (in-situ)



(a) Principal stresses acting on a small cube, (b) Principal stresses expressed in matrix form, (c) Principal stress orientations shown on a hemispherical projection.

Determination of in-situ stress

Clearly, any system utilized for estimating the *in situ* stress state must involve a minimum of six independent measurements.

Direct methods:
The four direct methods recommended by the International Society for Rock Mechanics ISRM (Kim and Franklin, 1987) are:
(a) the flatjack test;
(b) the hydraulic fracturing test;
(c) the United States Bureau of Mines (USBM) overcoring torpedo; and
(d) the Commonwealth Scientific and Industrial Research Organization (CSIRO) overcoring gauge.

Some indirect indicator methods are:
(a) borehole breakouts—damage to a borehole indicating principal stress orientations;
(b) fault plane solutions—back analysis of principal stresses causing faults;
(c) acoustic emission—the rock emits low-intensity 'noise' when it is stressed;
(d) anelastic strain relaxation—core exhibits expansion/contraction on removal from the borehole;
(e) differential strain analysis—pressurizing a piece of rock indicates its previous stress state through differential strain effects;
(f) core discing—geometry of stress-induced core fracturing indicates stress components;
(g) observations of discontinuity states, e.g. open discontinuities are not transmitting stress across the gap

1. **Flatjack**

$$\begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ & \sigma_{yy} & \tau_{yz} \\ \text{Symm.} & & \sigma_{zz} \end{bmatrix}$$

One normal stress component determined, say parallel to x-axis.

2. **Hydraulic fracturing**

$$\begin{bmatrix} \sigma_{1} & 0 & 0 \\ & \sigma_{2} & 0 \\ \text{Symm.} & & \sigma_{3} \end{bmatrix}$$

Principal stresses assumed parallel to axes i.e. plane of the fracture, two determined, say σ_1 and σ_3, one estimated, say σ_2.

3. **USBM overcoring torpedo**

$$\begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ & \sigma_{yy} & \tau_{yz} \\ \text{Symm.} & & \sigma_{zz} \end{bmatrix}$$

Three components in 2-D determined from three measurements of borehole diameter change.

4. **CSIRO overcoring gauge**

$$\begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ & \sigma_{yy} & \tau_{yz} \\ \text{Symm.} & & \sigma_{zz} \end{bmatrix}$$

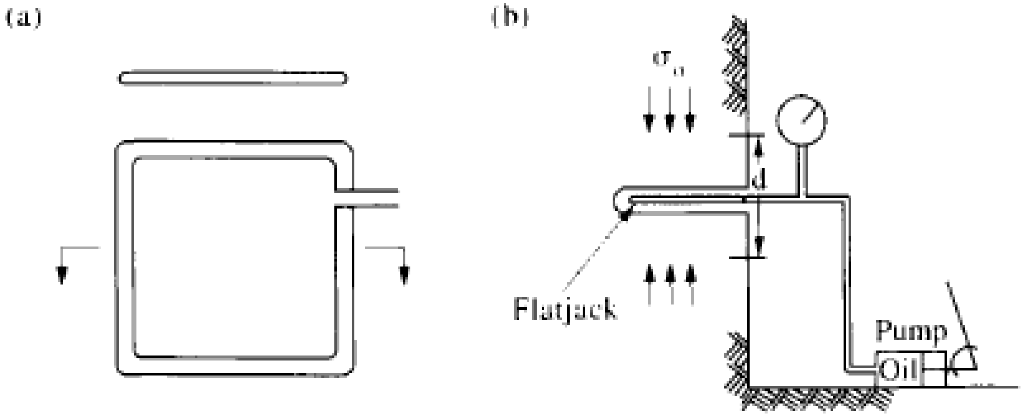
All six components determined from six (or more) measurements of strain at one time.

FlatJack

A flatjack, which is comprised of two metal sheets placed together, welded around their periphery and provided with a feeder tube.

Working principles:

- Two pins are drilled and fixed into the excavation boundary. The distance, *d,* between them is then measured accurately.
- A slot is cut into the rock between the pins.
- If the normal stress is compressive, the pins will move together as the slot is cut. Flatjack is then grouted into the slot. On pressurizing the flatjack with oil or water, the pins will move apart.
- It is assumed that, when the pin separation distance reaches the value it had before the slot was cut, the force exerted by the flatjack on the walls of the slot is the same as that exerted by the pre-existing normal stress.



The major disadvantage of flatjack

- The major disadvantage with the system is that the necessary minimum number of six tests, at different orientations, have to be conducted at six different locations and it is therefore necessary to distribute these around the boundary walls of an excavation. Invariably, these tests will be conducted under circumstances where the actual stress state is different at each measurement location. Hence, to interpret the results properly, it is also necessary to know the likely stress distribution around the test excavation.

The hydraulic fracturing method

- The hydraulic fracturing method is the only direct method available for stress measurement at any significant distance from the observer (i.e. distances greater than 100 m), and it has been used to depths of several kilometres.

The hydraulic fracturing method of stress measurement basically provides two pieces of information via the breakdown pressure and the shut-in pressure

- A length of borehole is chosen for the stress measurements and an interval, typically 1 m long, is located for the test and isolated using a straddle packer system. The isolated zone is pressurized by water until a fracture occurs in the rock.
- The two measurements taken are

1. the water pressure when the fracture occurs and

2. the subsequent pressure required to hold the fracture open, known, respectively, as the breakdown and shutin pressures

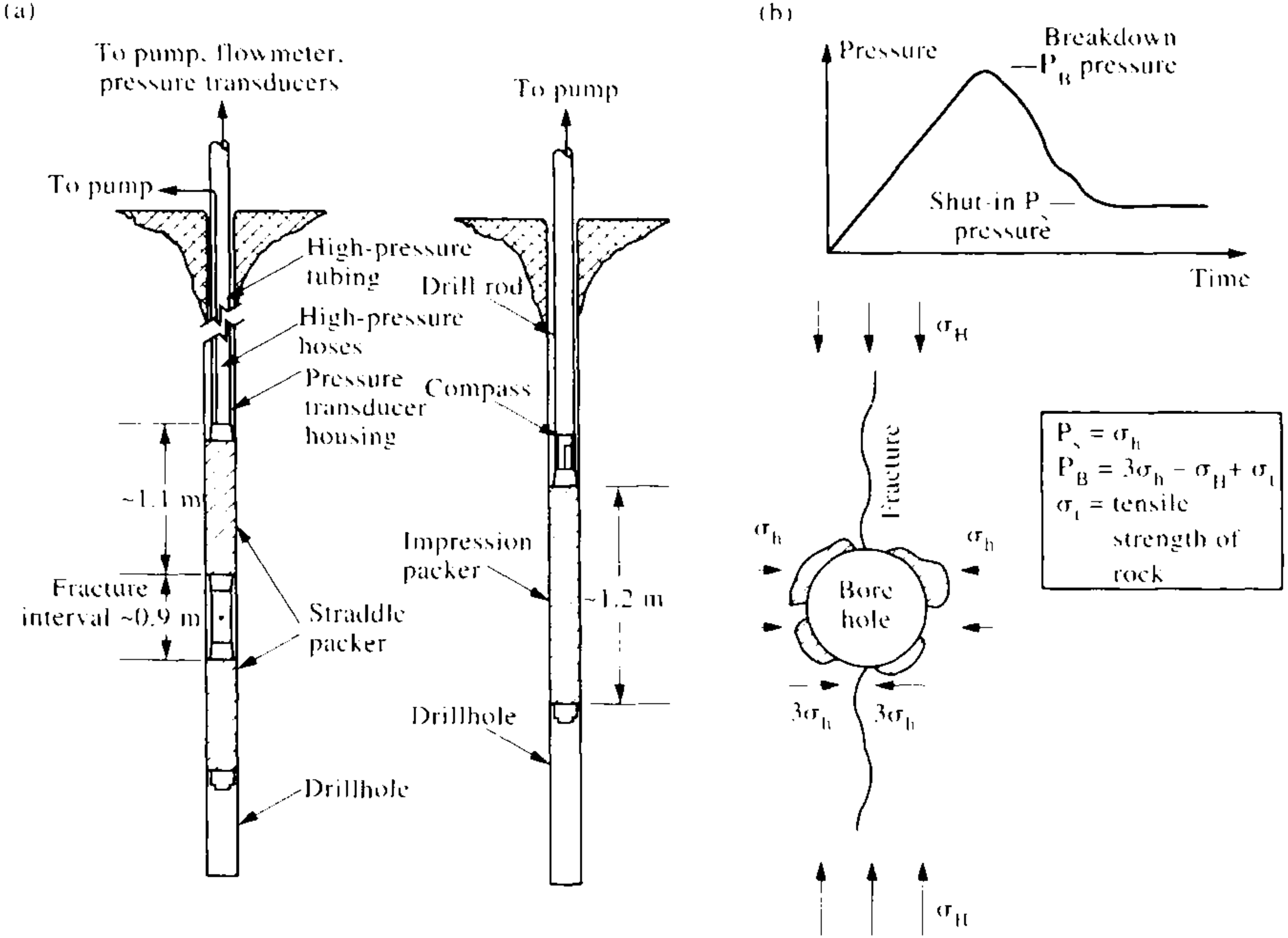
- It is most important to realize the following.

First, the packed-off section should be free from fractures so that a **new** fracture is in fact created: a method of establishing this is to use a borehole television camera.

Second, it is obviously best if the water pressures are measured at the test section, i.e. downhole rather than at the surface, if possible.

Third, it is necessary to use an impression packer or equivalent system to establish the orientation and location of fracture initiation. Finally, it should be remembered that, using the basic technique, it has to be assumed that the orehole is parallel to a principal stress direction.

- Hydraulic fracturing method



- Calculation procedures of hydraulic fracturing

- In the calculation method shown in Fig. (b), it is assumed that the stress concentration of a principal stress component around the borehole in the horizontal plane shown has extreme values of -1 and 3. As shown, the shut-in pressure, Ps, is assumed to be equal to the minor horizontal principal stress, (σh. The major horizontal principal stress, σH, is then found from the breakdown pressure.
- In the formula in Fig.b the breakdown pressure, PB, has to overcome the minor horizontal principal stress (concentrated three times by the presence of the borehole) and overcome the *in situ* tensile strength of the borehole rock; it is assisted by the tensile component of the major principal horizontal stress.

- Disadvantages of hydraulic fracturing method
- Setting of measurement points can often be difficult, also difficult to identify a 1 m length of borehole which is fracture free.
- Difficulties in measuring water pressures accurately, and in correctly identifying the breakdown and shut-in pressures.
- There is the question of whether the crack initiating at the borehole wall in fact propagates in the same direction
- Lastly, it is often a completely unjustified assumption that the borehole is indeed parallel to a principal stress.

- **USBM** borehole deformation gauges
- The USBM technique allows the complete stress state in a plane to be determined from three measurements of the change in different diameters of a borehole when the stresses are released by overcoring the borehole
- Procedure: When the torpedo is inserted in a borehole, six 'buttons' press against the borehole wall and their diametral position is measured by strain gauges bonded to the sprung steel cantilevers supporting the buttons. When this borehole is overcored by a larger drill, the stress state in the resulting hollow cylinder is reduced to zero, the diameter of the hole changes, the buttons move, and hence different strains are induced in the strain gauges.

The CSIRO overcoring gauge

- This device operates on a similar principle to the USBM torpedo except that it is a gauge which is glued into the borehole and can measure normal strains at a variety of orientations and locations around the borehole wall.
- The gauge is glued into position within the pilot hole, initial readings of strain are taken and the gauge is then overcored. This destresses the resulting hollow cylinder and final strain gauge readings are taken.

Prediction of natural in-situ stresses using elasticity theory

- the *in situ* stress field is conveniently expressed via the orientations and magnitudes of the principal stresses. As a first approximation, therefore, let us assume that the three principal stresses of a natural *in situ* stress field are acting vertically (one component) and horizontally (two components).
- It becomes possible to predict the magnitudes of these principal stresses through the use of elasticity theory

- As the depth below the ground surface increases, due to the weight of the overburden. As rules of thumb, taking the typical density of rock into account:

1 MPa is induced by 40 m of overlying rock, or
1 psi is induced by 1 ft of overlying rock.

More generally, we should use the expression

induced vertical stress, $\sigma_v = \gamma z$ MPa

where z is the depth, measured in metres, below the ground surface and γ is the unit weight, measured in MN/m^3. Examples of γ are:

γ = 0.01 MN/m^3 for some coals,
= 0.023 MN/m^3 for some shales,
= 0.03 MN/m^3 for gabbro.