Historical review of rock stress measurements at NTH/NTNU/SINTEF

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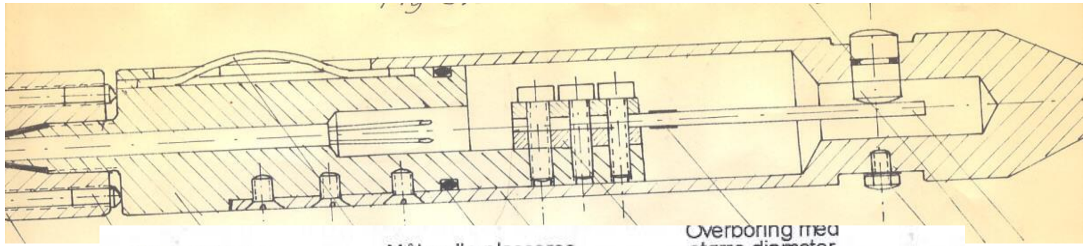
Background

- Around 1960 there were about 40 underground mines in Norway. Most of them were small companies with limited resources
- Quite a few of them eventually experienced stability problems due to high rock stresses
- Virtually all companies were members of the Association of Mining Companies (AMC), which had a research office at NTH
- Professor of mining engineering at that time Arne Hofseth pointed out for AMC that the Norwegian mining industri needed expertise within rock mechanics to handle the rock stress problems, and that a rock mechanics laboratory had to be established. He also pointed out that the Mining Department at NTH would be the logical location for the laboratory
- So from the summer of 1964 the first steps were taken to establish a state of the art rock mechanics laboratory at NTH

The first rock stress measurements by NTH

- In July 1964, the master students Per Gjelvold, Ragnar Moslet og Arne Myrvang were sent to a limestone room and pillar mine in South Norway to carry out a number rock mechanics field experiments, including rock stress measurements to determine limestone pillar load. This was the main content of their M.Sc. Thesis.
- The method used was the USBM overcoring borehole deformation cell.
- After 5 months of hard work, they at last got some reasonable values of pillar load!

US. Bureau of Mines. USBM-Overcoring Cell



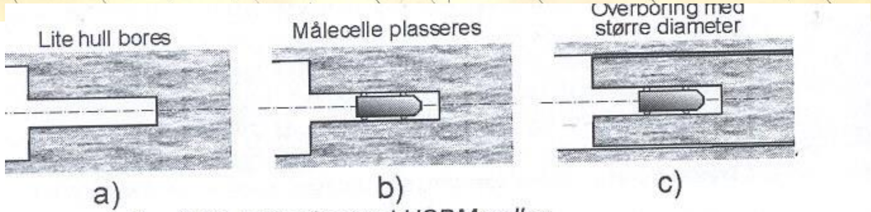


Fig. 6.16: Friboring ved USBM-cellen.

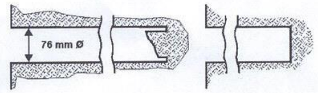
The Doorstopper overcoring method

- After the experiences made with USBM-cell, it was clear that it was too time consuming and inaccurate.
- In connection with Bjørn Li`s Ph.D work, in 1966 NTH got the permission to make their own version ot the South African CSIR Doorstopper overcoring cell.
- Over the years NTH and SINTEF has highly improved the method, and the method is still very much used in connection with mining and civil engeneering projects

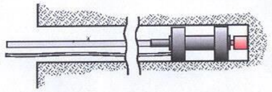
Doorstopper procedure

Appendix 1

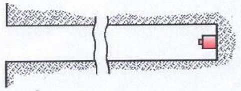
2-dimensional Rock Stress Measurements by Overcoring



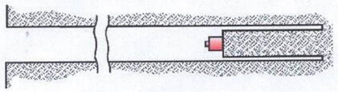
A diamond drill hole (76 mm outer diameter) is drilled to wanted depth. The core is removed and the hole bottom is flattened with a special drill bit.



A two dimensional measuring cell (doorstopper) that contains a strain gauge rosette, is inserted into the hole with a special installing tool and glued to the bottom of the hole.



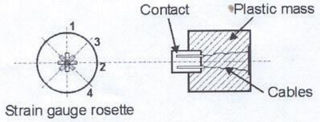
The doorstopper is now fixed to the hole and initial reading (0 recording) is done. The installing tool is removed and the cell is ready for overcoring.



A new core is drilled with the 76 mm Ø diamond drill, thus stress relieving the bottom of the borehole. The corresponding strains at the end of the core are recorded by the strain gauge rosette.

The core is catched with a special core catcher, and immediately after removal from the hole the second recording is done. From the recorded strains the stresses in the plane normal to the borehole, may be calculated when the elastic parameters determined from laboratory tests are known.

Measuring cell "Doorstopper"



Cross and longitudinal section

Core drilling 0 - 90° upward (drained holes)

Maximum hole depth from tunnel:	10 m
Borehole diameter:	76 mm
Core diameter:	62 mm
Time per single measurement:	Approx. 1 hour
Time per stress tensor (7 – 10 single measurements):	Approx. 1,5 days

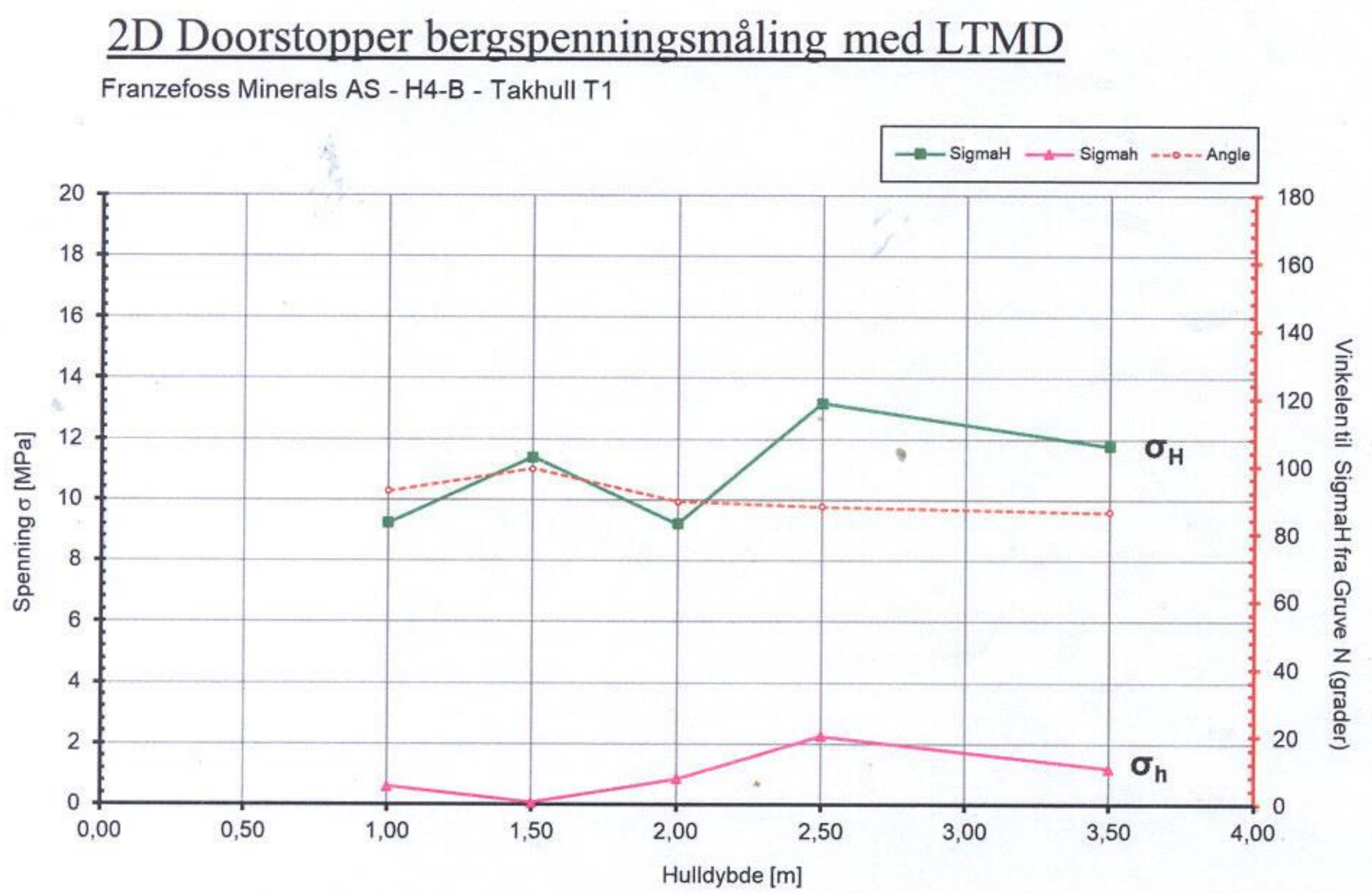
Equipment units (including core drilling machine) may be skipped as normal air freight
Boreholes may, after measurements, be used for stress monitoring and hydraulic fracturing, and also for borehole extensometers.

Typical use of doorstoppers in practise

- **The doorstopper is a 2D method measuring the stresses perpendicular to the borehole.**
- **The results are sensitive to high stresses along the borehole axis. Therefore the doorstoppers are used in cases where the axial stress is low.**
- **Rock pillars where the stressfield is close to uniaxial**
- **To check the stress condition close to the surface of large span openings**
- **Under difficult conditions for 3 D measurements , doorstopper measurements in a vertical hole in the roof of a tunnel may give an indication of high horizontal stresses**

Location of a recent midspan measurement in a 25 m span

Measurement results. Solid compressive stresses perpendicular to the longitudinal axis secures a stable roof



Figur 27 Målt spenning er vist i grafen over. Hulldyp angis fra takkontur og oppover i hullet

PROSJEKTNR RAPPORTNR VERSJON

Longtime monitoring of stress change using a special doorstopper

SINTEF

Long time doorstopper (Modified doorstopper)

The cell is cemented to the flattened bottom of a standard 76 mm diameter diamond drilled hole. During drilling of the hole, standard doorstopper measurements are taken at selected intervals to obtain the initial stresses (figure 1).

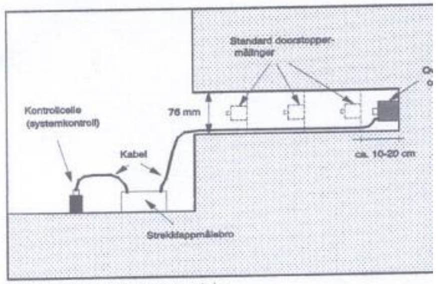


Figure 1 Measuring procedure

The last measurement is taken as close as possible to the selected depth of the monitoring doorstopper (normally within 10 cm). The monitoring cell is then installed as described in the previous section. Readings are taken of a standard, high quality strain gauge bridge. Reading frequency may be adjusted to actual conditions. Continuous monitoring can easily be established by a permanent connection to a strain gauge bridge. The stress change is calculated, using the strain difference from the initial zero reading and the elastic parameters of the rock. The calculated stress change is calculated is then compared with the closest initial stress values obtained from standard doorstopper measurements.

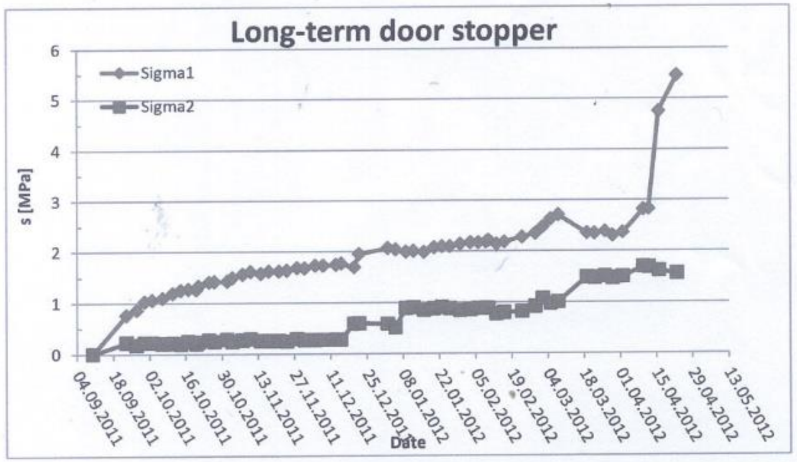


Figure 2Monetoring doorstopper readings

A major concern in connection with long time measurement is the stability of the measuring system as such. To control this, a similar doorstopper is glued to a distressed drill core from the same area. This core is kept at the measuring site between readings, and the doorstopper is read simultaneously with the active one. After long time of operation the general experience is that the long-time stability is very good.

3 D overcoring stress measurements

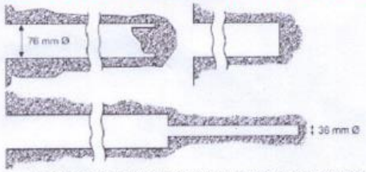
- **The introduction of the doorstopper in 1966 was a major step forward, but the limitations were also clear. At this time CSIR in South Africa at developed a 3D overcoring cell. NTH was again permitted to make their own version of the cell.**
- **In 1966 Arne Myrvang was offered a 4 years scolarship funded by the mining industri for a PhD study. The study should follow up the new method with laboratory and field investigations, and also use the stress results in modelleing connected to an iron ore mine in West Norway. This was pre numerical modelling, so 2D photoelastic fysical models where used.**
- **So the next 3 -4 years were used to come up with practical solutions**

3 D overcoring cell. The first successful comercial measurements were made in 1971 in connection with a hydroelectric project near Narvik, North Norway. Over the years the method has been continiously been refinded and improved.

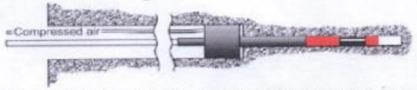
SINTEF

Appendix

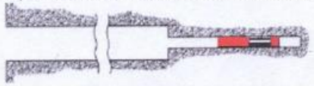
3-D In-Situ Rock Stress Measurements by Overcoring



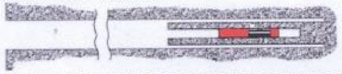
A diamond drill hole (76 mm outer diameter) is drilled to the desired depth. Usually, this depth is 1,5 times the span of tunnel/ cavern. The hole bottom is flattened with a special drill bit, and a concentric hole with smaller diameter (36 mm o.d) is drilled approximately 30 cm further.



A measuring cell with strain gauges and data log unit is installed with a special installing tool containing orienting device. Compressed air is used to expand the cell in the hole, and the strain gauges are fixed to the walls in the hole.

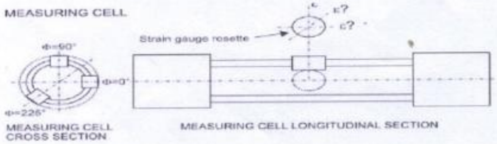


The cell is now ready to start measuring, and continously logging of strain data is stored in the measuring cell. The installing tool is removed and the cell is ready for overcoring.



The small hole is over cored by the larger diameter bit, thus stress relieving the core. The corresponding strains are recorded by the strain gauge rosettes.

The core is recovered from the hole with a special core catcher, and immediately after removal from for the hole the recorded data is transferred to the computer. When the elastic parameters are determined from biaxial- and laboratory test, the stresses may be calculated.



Core drilling 0 - 90° upward (drained holes)

Maximum hole depth from tunnel:		20
Borehole diameter:		76 m
Core diameter:		62 m
Time per single measurement:	Approx.	1,5 ho
Time per stress tensor (7 – 10 single measurements):	Approx.	2,5 da

Equipment units (including core drilling machine) may be skipped as normal air freight

Boreholes may, after measurements, be used for stress monitoring and hydraulic fracturing, and also for borehole extensometers.

Both the 2 D and 3 D overcoring cells can only be used in drained dry boreholes. Therefore as an additional method, hydraulic fracturing was introdused in 1980, when an HF rig was built at a NTH mechanical workshop

Hydraulic Fracturing for Rock Stress Determination

The hydraulic fracturing technique may be used to determine the in-situ rock stress in a plane perpendicular to borehole. This is done by application of fluid pressure (normally water) in a test section in a borehole isolated by packers until the rock fails in tension. The fluid pressures required to generate, propagate, sustain and reopen tensile fractures in the rock are recorded as function of time, and these may be related to magnitude of the existing stress field.

Directions of measured stress are normally achieved by observing and measuring the orientation of the hydraulically induced fracture plane by the use of a so-called impression packer. The induced hydrofracture is oriented parallel with the major secondary principal stress σ_H in a plane perpendicular to the borehole.

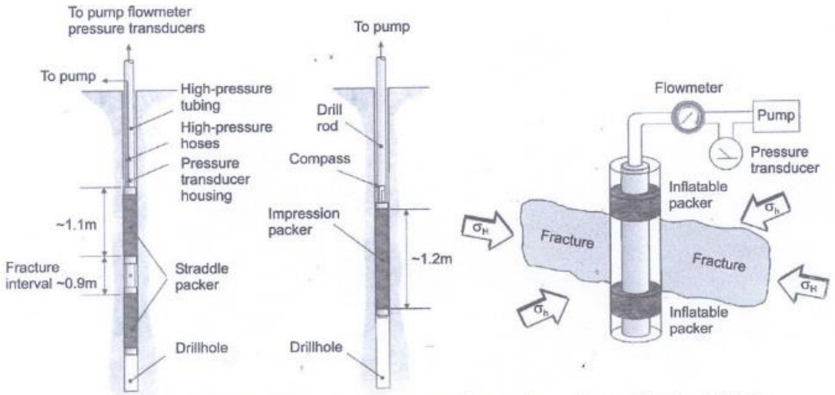


Figure 1 Showing from the left Straddle packer arrangement, impression packer and fracture initiation.

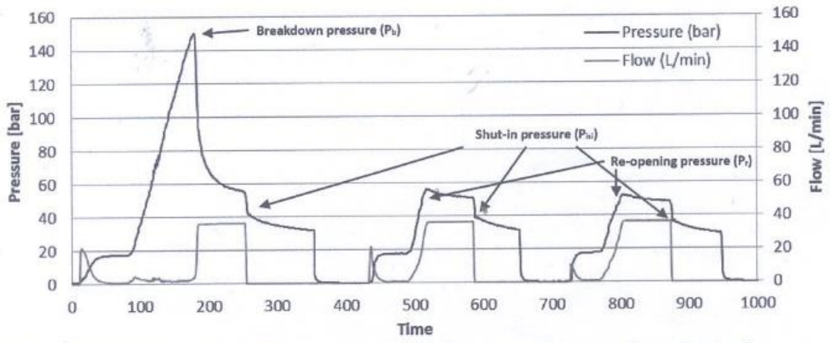


Figure 2 Diagram of results from a hydraulic fracturing test. Both water pressure vs. time and water flow vs. time is shown.

Hydraulic fracturing may be carried out in vertical holes drilled from the surface or underground in holes drilled from tunnels (vertical, inclined or horizontal). May be combined with overcoring from tunnels, i.e. hydraulic fracturing is carried out after overcoring in the same hole.

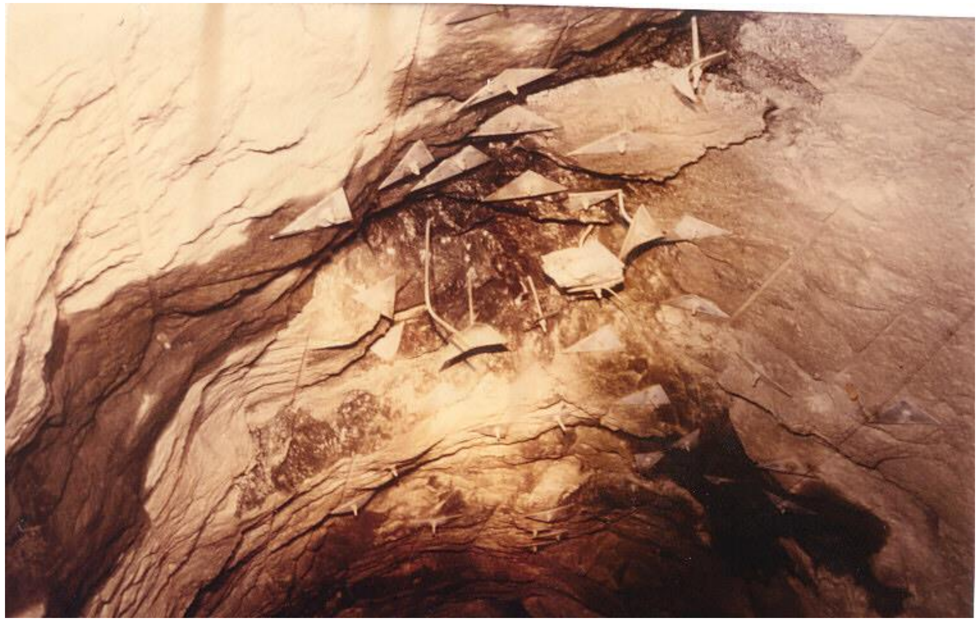
- Maximum borehole length: 400 m
- Borehole diameter: 60 – 110 mm

General comments

- **Until 1984, comercial measurements were made by NTH. Then SINTEF established a section for rock and soil mechanics, which took over the measurements.**
- **Over the years, NTH/SINTEF has carried out projects within mining and civil engineering in 16 countries in Europe, Asia and Africa in about 160 locations.**
- **As each location may represent a number of measuring sites, the total number of measuring holes are in the order of 400, corresponding to approximately 4000 single measurements.**
- **A large number of projects has been connected to hydroelctric power plants, where the most imortant issue is to determine the minimum principal rock stress, which in the case of unlined high pressure headrace tunnels have to be higher than the water head**

General Comments

- **In most cases, the measured vertical stress is in accordance with the gravity induced stress**
- **However, in Norway the measured horizontal stress is often much higher than the gravity horizontal stress, and also much higher than the vertical stress. This means that the horizontal stress is the major principal rock stress**
- **This will often give high stress concentration in the tunnel roof, which results in spalling or rock burst**



General comments

- **However, high horizontal stress may also be favourable, like in the mining situation below, where reasonably high compressive stresses in the roof give a stable 40 m span where only scattered roof bolting is necessary**