

# **IN-SITU ROCK STRESS MEASUREMENTS**

*Brief description of methods applied by  
SINTEF*

**Practical applications**

**Lists of clients**

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The Rock Mechanics Laboratory of the Norwegian University of Science and Technology (NTNU) and SINTEF (Foundation of Technical and Scientific Research at NTNU) has been performing in-situ rock stress measurements since 1964. Through SINTEF Building and Infrastructure, Dept. of Rock Engineering, measurements are carried out on a commercial basis.

Several measuring methods have been applied over the years, including the USBM 2D cell and the photoelastic 2D cell. However, the present applied techniques are:

- Self developed and highly improved versions of the originally South African CSIR 2-D Doorstopper
- 3-D CSIR overcoring cells.
- Self developed hydraulic fracturing equipment

**Appendices 1, 2 and 3** show brief principal descriptions of the methods.

The methods have been continuously developed and improved through extensive use and research during more than 30 years.

Whenever possible, the procedures described in the International Society for Rock Mechanics (ISRM) “Suggested methods for Rock Stress Determinations” are used to evaluate the measurements. However, it must be pointed out that these are only suggestions based on papers published in the International Journal for Rock Mechanics and Mining Sciences in 1989, and not by any means a norm or standard. Some of the procedures used by SINTEF are superior to the ISRM suggestions and accordingly used for evaluation.

3-D determination of the stress tensor at a site is normally based on 7 – 10 successful single measurements well away from the influence of the tunnel in a sub-horizontal borehole. The stresses are calculated by the computer programme DISO (Determination of In-situ Stress by Overcoring) developed by SINTEF. By randomly selecting strain readings from different positions along the measuring hole, up to 35,000 groups of results can be achieved. From this statistical calculations are carried out, resulting in mean values and deviation of the principal stresses. The programme automatically removes obvious erroneous strain values. The magnitudes of the principal stresses are presented graphically in a histogram plot, while the directions are given in an equal area lower hemisphere stereonet plot.

The time needed for one single overcoring measurement is about 2 hour. Typically, a complete measuring cycle with 7 – 10 single successful measurements will take about 2,5 days. Preliminary results may normally be given on site, using a laptop computer and elastic constants determined by application of a biaxial cell.

SINTEF normally provides all necessary equipment, including core drilling machine. All equipment, including the hydraulic fracturing system may be shipped by normal air freight.

**Appendices 4, 5 and 6** present lists of clients and projects within mining and civil engineering, comprising some 125 entries from 15 countries throughout the world. As each client or location may represent a number of measuring sites, the total number of sites/measuring holes are in the order of 330, corresponding to approximately 3000 single measurements.

This probably makes SINTEF the most experienced provider of in-situ rock stress determination in the world. The great majority of the projects have been very applied industrial projects connected to a wide variety of civil and mining engineering projects. The measurements are actively used as a practical engineering tool. An important contribution is to provide reliable in-situ rock stresses as in-put in connection with numerical modelling.

The Norwegian mining industry very early recognised that proper use of rock stress measurements could give considerable boost of profits. A typical example is stress measurements in rock pillars, where the results in many cases indicated that valuable ore pillars could be drastically reduced or even removed, and giving considerable increase in ore extraction. In many of the mining projects, regular measurement programmes have been carried out over long periods of time (in one case more than 25 years). The intention of these programmes has been design of mining chambers and pillars, as well as stability control of stopes and pillars as the mining situation changes over time.

During the 1970ies through 1990ies Norway experienced a vast amount of rock engineering projects within hydropower, storage, sports halls and road and rail tunnels. In many cases rock stress problems have been encountered. In other cases, sufficient horizontal stresses have been a prerequisite for stable large span underground caverns. This includes the world's largest rock hall for public use, the Gjøvik Olympic Ice Hockey Rink with a span of 62 m. This has over the years called for a large number of in-situ rock stress measurements, which mainly have been provided by SINTEF/NTNU.

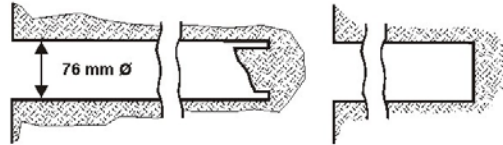
2D and 3D rock stress measurement are used to provide in-put for numerical modelling, as well as to check the tangential and axial stresses in the roof of the excavations and the load on rock pillars between excavations. This may give crucial information about the general stability of rock structures. 2-D doorstopper measurements have also on a number of occasions been successfully used to measure stress in shotcrete and concrete rock support. Doorstopper measurements are the only possible method for stress determination in a thin layer of shotcrete.

Another important market is the determination of the minor principal rock stress in connection with underground hydropower plants with unlined headrace pressure tunnels or pressure shafts. This is the case with many Norwegian power plants, and this technology has also been exported to a number of power plants in other countries. A crucial prerequisite in this case is that the minor principal stress in the rock mass must be larger than the water head. Stress measurements are therefore a must. SINTEF has carried out a large number of stress measurements of this type, both with overcoring and hydraulic fracturing.

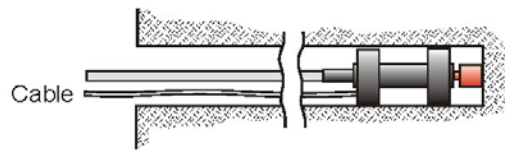
Altogether, the measurements connected to civil and mining engineering projects have given the SINTEF measuring crew an unique practical experience. Though principally relatively simple, the measurements require an experienced crew, who knows all the "tricks of the trade", to obtain reliable results.

The rock stress measurements are quite often only part of larger projects, and SINTEF is also providing rock deformation measurements (Borehole extensometer and tunnel convergence measurements), rock bolt testing, numerical modelling, and civil and mining engineering solutions in general. A number of state-of-the art 2D and 3D numerical modelling codes are available.

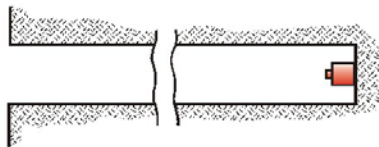
## 2-dimensional Rock Stress Measurements by Overcoring



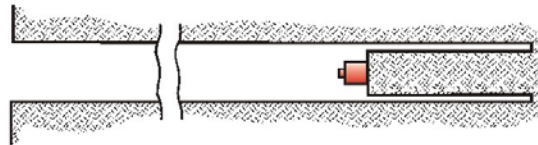
A diamond drill hole (76 mm outer diameter) is drilled to wanted depth. The core is removed and the hole bottom is flattened with a special drill bit.



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.

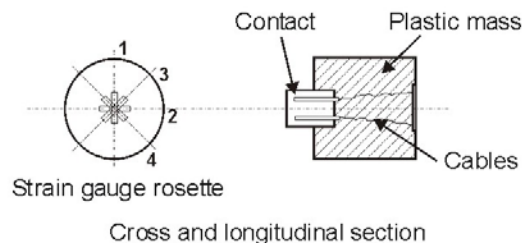


A new core is drilled with the 76 mm Ø diamond drill, thus stress relieving the bottom of the borehole. The corresponding strains at the end of the core are recorded by the strain gauge rosette.



The core is caught 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.

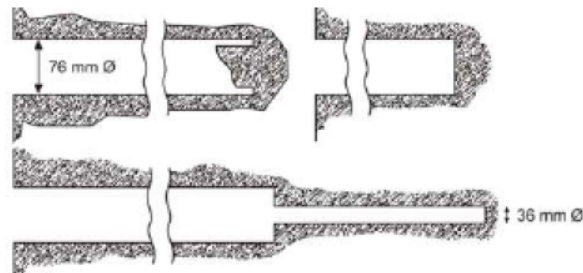
Measuring cell  
"Doorstopper"



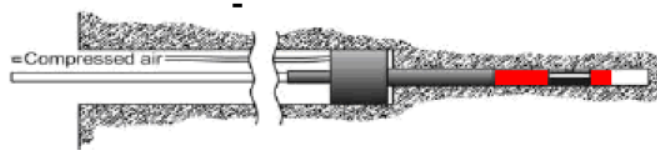
Core drilling 0 - 90° upward (drained holes)

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.	

### 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.



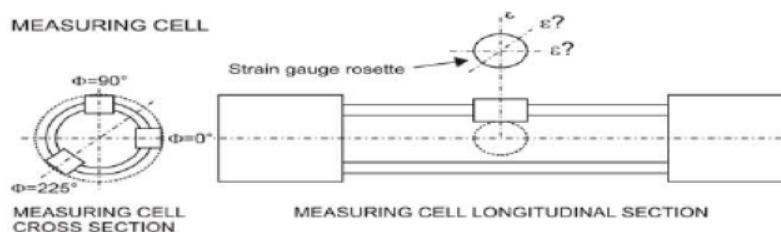
The cell is now ready to start measuring, and continuously logging of strain data is stored in the measuring cell. The installing tool is removed and the cell is ready for overcoring.



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 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.

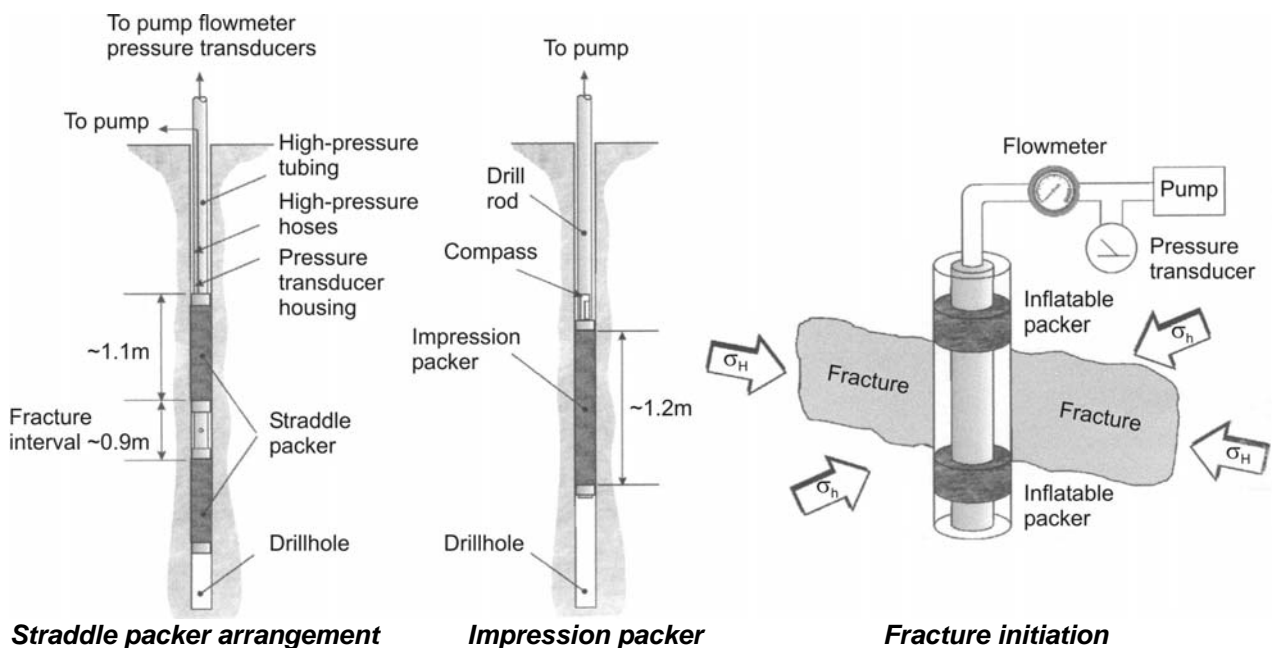


#### Core drilling 0 - 90° upward (drained holes)

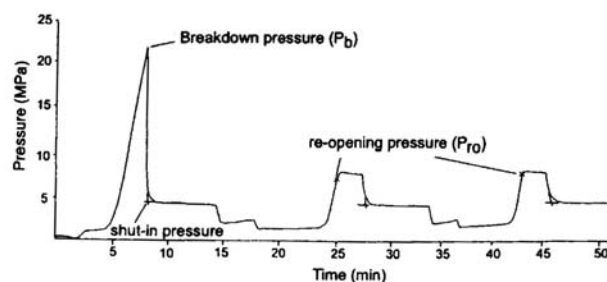
Maximum hole depth from tunnel:	20 m
Borehole diameter:	76 mm
Core diameter:	62 mm
Time per single measurement:	Approx. 1,5 hour
Time per stress tensor (7 – 10 single measurements):	Approx. 2,5 days
Equipment units (including core drilling machine) may be shipped as normal air freight	
Boreholes may, after measurements, be used for stress monitoring and hydraulic fracturing, and also for borehole extensometers.	

## 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 hydro fracture is oriented parallel with the major secondary principal stress  $\sigma_H$  in a plane perpendicular to the borehole.



### Hydraulic fracturing principles



### Time / fluid pressure recording

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: 250 m
- Borehole diameter: 46 – 76 mm
- Computerised logging equipment
- May be used in combination with overcoring in holes drilled from tunnels
- Equipment units may be shipped by normal air freight

**Appendix 4**
**LIST OF CLIENTS – OVERCORING – CIVIL ENGINEERING PROJECTS**

Client	Country	Years	Branch	Method	Purpose
Eidsiva Vannkraft AS	Norway	2008	Hydro power	2D	Minor principal stress for unlined pressure shaft, Rendalen Kraftverk
Skanska Vinci-HB	Sweden	2007	Road tunnel	2D, 3D	Rock stress measurements, Hallandsåsen
QZM	China	2005	Road tunnel	2D, 3D	World's longest two tube road tunnel, cavern design
Landsvirkjun	Iceland	2005	Hydro power	2D,3D	Stress measurements in power station , Kahranjukar
Vegagerdin	Iceland	2004	Road tunnel	2D,3D	Rock stress measurements, Reydarfjordur
SRG AS	Norway	2004	Hydro power	3D	Design of power station and unlined pressure tunnel, Bláfalli
Selmer Skanska AS	Norway	2002	Hydro power	3D	Design of power station and unlined pressure tunnel, Tyin
Singapore State	Singapore	2001	Strategic storage	3D	Rock stress control
TYRENS Infraconsult	Sweden	2001	Road tunnel	3D	Rock stress check, Gøtatunnelen
Statkraft	Norway	2001	Hydro power	3D	Design of power station and unlined pressure tunnel, Bjølvo
Swedish Rail	Sweden	1999	Railway tunnel	2D	Roof stress control, Hallandsåsen
Norplan	Tanzania	1996-98	Hydro power	3D	Design of power station and unlined pressure tunnel, Lower Kihansi
Trondheim Energi	Norway	1998	Hydro power	2D, 3D	Deformation of powerhouse vs. stress, Nea
Norwegian Road Authority	Norway	1998	Road tunnel	3D	High horizontal stress problems, Lærdal
Lyse Kraft	Norway	1997, 98	Hydro power	3D	Design of unlined pressure tunnel, Fløyrlø
Norsk Hydro	Norway	1987, 98	Oil storage	3D	Initial design and upgrade u.g. caverns, Sture
Statoil	Norway	1997	Gas storage	3D	Design of u.g. gas storage caverns, Kårstø
Sri Lanka Power	Sri Lanka	1996	Hydro power	3D	Design of pressure tunnel, Kukule Ganga
Norwegian Road Authority	Norway	1985, 96	Road tunnel	2D, 3D	High horizontal stress problems, stress in shotcrete, repeated 1996, Kobbekaret, Nordland
Norwegian Road Authority	Norway	1981, 96	Road tunnel	2D, 3D	Check mountain side stresses, stress in shotcrete, repeated 1996, Heggura, Tafjord
Stavanger Mun.	Norway	1996	U.g. sports hall	3D	Design of geometry and support, Tastavarden
Norzink	Norway	1986-95	Waste storage	3D	Design of u.g. waste storage caverns, Odde
Trondheim Energ	Norway	1993	Hydro power	2D	Stress measurements in concrete dam, Sylsjø
Gjøvik Municip.	Norway	1989-93	U.g. sports hall	2D, 3D	Design of geometry and support, Gjøvik Olympic Hall
Norsk Hydro	Norway	1990	Hydro power	3D	Generator displacement vs.rock stress, Mår
Norsh Hydro	Norway	1990	Hydro power	3D	Generator displacement vs.rock stress, Moflåt
Statkraft	Norway	1990	Hydro power	3D	Generator displacement vs.rock stress, Tokke
Statkraft	Norway	1988,90	Hydro power	2D,3D	Design of power station, pressure tunnels and stress control, Kilvik
Opplandskraft	Norway	1988	Hydro power	3D	Design of unlined pressure shaft, Torpa
Research council	Norway	1988	Hydro power	3D	Design of unlined pressure shaft, Osa
N.Trøndelag El.	Norway	1987	Hydro power		Design of unlined pressure shaft, Ormsetfoss
Research council	Norway	1987	Hydro power	3D	Control of air cushion surge, Brattset
Tafjord Kraft	Norway	1986, 87	Hydro power	3D	Control of air cushion surge chambers, Tafjord
Sogn og Fjordane Energi	Norway	1986	Hydro power	3D	Design of power station and unlined pressure shaft, Mel
Statoil	Norway	1986	Oil storage	3D	Design of u.g. oil storage caverns, Mongstad
Norwegian Road Authority	Norway	1986	Road tunnel	3D	Rock stress check, Svartisen, Nordland
Norwegian Road Authority	Norway	1986	Road tunnel	3D	Design of tunnel, Oslotunnelen
Norsk Hydro	Norway	1986	Shore approach tunnel	3D	Rock stress control in North Sea oil pipeline tunnel, Hjartøy
Norsk Hydro	Norway	1985	Hydro power	3D	Design of unlined pressure shaft, Nyset-Steggje
Statkraft	Norway	1985	Hydro power	3D	Design of power station and unlined pressure shaft, Jostedal
Statkraft	Norway	1985	Hydro power	3D	Design of power station and unlined pressure shafts, Kobbelv
Namsos Mun.	Norway	1984	U.g. sports hall	3D	Design og geometry and support, Oasen
Lyse Kraft	Norway	1982	Hydro power	3D	Design of unlined pressure shaft, Tjodan
Norkraft	Norway	1982	Hydro power	3D	Design of unlined pressure shaft, Sørfjord
Norw. Defence	Norway	1982	Access shaft	3D	Design access shaft to military installation
Norwegian Road Authority	Norway	1981	Road tunnel	3D	High horizontal stress problems, Fjærland
Norwegian Road Authority	Norway	1981	Road tunnel	3D	Rock stress check , Flåm
Øvre Otra Kraft	Norway	1980	Hydro power	3D	Water inflow vs. stress direction, Holen (Bykle)
Skedsmo Mun.	Norway	1980	U.g. sports hall	2D	Design and control of roof stress, Tærud
Oslo Municip.	Norway	1980	U.g. sports hall	2D	Design and control of roof stress, Holmlia
Norkraft	Norway	1979, 80	Power station	2D, 3D	Design of power station, stress control, Sildvik

Lørenskog Mun.	Norway	1979	U.g. sports hall	2D	Design and control of roof stress, Skårer
Norwegian Road Authority	Norway	1978	Road tunnel	3D	Check mountain side stresses, Pollfjell, Troms
Norwegian Road Authority	Norway	1977,78	Road tunnel	3D	High horizontal stress problems, Høyanger
Statkraft	Norway	1975, 76	Hydropower	3D	Design of unlined air cushion chamber, Ulla Førre
Statkraft	Norway	1974, 75	Hydropower	3D	Design of power station and unlined pressure shafts, Eidfjord
Norwegian Road Authority	Norway	1974	Road tunnel	3D	High horizontal stress problems, Strynefjell
VBB Stockholm	Sweden	1973	Hydropower	2D, 3D	Control of high horizontal stress and stresses in shotcrete in headrace tunnel, Ljungaverk
Statkraft	Norway	1970	Hydropower	3D	Design of unlined pressure shaft, Mauranger
Statkraft	Norway	1970	Hydropower	3D	Design of underground power station, Skjomen

Each client may comprise several measuring sites.

## Appendix 5

### LIST OF CLIENTS – OVERCORING – MINING ENGINEERING PROJECTS

Client	Country	Years	Branch	Method	Purpose
Franzefoss Miljøkalk As	Norway	2008	Limestone mining	2D, 3D	Design and stress control underground r&p mining, Ballangen
Sala Mineral	Sweden	1999,05	Limestone mining	2D, 3D	Design and stress control underground r&p mining
Norcem	Norway	1966-2005, 2008	Limestone mining	2D, 3D	Regular programme for design and stress control in 2 underground room-and-pillar mines
Boliden Mineral	Sweden	1973-90, 04,05	Cu,Pb,Au mining	2D,3D	Design and stress control in 6 mines
Glærum Kalksteinsbrudd	Norway	2004	Limestone mining	2D,3D	Design of underground mining
Store Norske Coal	Norway Spitsbergen	1977-2004-2007	Coal mining	2D, 3D	Design and control of longwall and room-and-pillar methods in 4 mines (partly in permafrost)
Naas Kalkstein	Norway	1998, 2004	Limestone mining	3D	Design of r & p and sublevel stoping u.g. mine
Norcalsitt	Norway	1997, 00, 03, 07	Limestone mining	2D, 3D	Design of r & p and stress control in pillars and roof
Rana Gruber	Norway	1978 – 2003 - 2007, 2008	Fe-mining	2D, 3D	Design of underground crusher station, design of new sublevel stop. Underground mine, stress control in pillars
Industrimineraler	Norway	1999, 00,02	Olivine mining	2D, 3D	Design of room and pillar system and stress control in roof and pillars in a new u.g. mine
North Cape Minerals	Norway	1988- 02, 06	Olivine mining	2D, 3D	Regular programme for design and stress control in a room and pillar mine
Hustad Group	Norway	78-02-07	Limestone / marblemining	2D, 3D	Design of room-and-pillar and sublevel stoping systems in 4 mines
Hammerfall	Norway	2001	Dolomite mining	2D, 3D	Design of u.g. room & pillar mining
IMM-EU research	Italy	2001	Marble quarry	3D	Evaluation of possible rock stress related problems in 3 marble quarries in the Cararra.
Brønnøy Kalk AS	Norway	2000	Limestone mining	3D	Design of a underground mine
Lundhs Labrador	Norway	1999	Labrador quarry	2D, 3D	Destressing of high, near surface horizontal stress
Björka Mineral	Sweden	1998	Limestone mining	2D, 3D	Design and stress control underground mining
Grong Gruber	Norway	1976-98	Pb, Zn-mining	2D, 3D	Regular programme for design and stress control of sublevel stopes and pillars until operations ceased
J. Grønseth	Norway	1997	Labrador quarry	3D	Evaluation of underground quarrying of labrador
Nikkel & Olivin	Norway	1989, 97	Ni-mining	2D, 3D	Design of u.g. sublevel stoping and r & p mining methods, stress control in pillars
Skaland Grafitt	Norway	1983, 97,09	Graphite mining	3D	Design of sublevel stoping u.g. mining
Sydvaranger	Norway	1971-96	Fe-mining	2D, 3D	Open pit stability control, design of new sublevel stop. Underground mine, stress control until operations ceased
Fauskemarmor	Norway	1996	Marble quarry	3D	Destressing of high, near surface horizontal stress
Norwegian Talc	Norway	1992	Talc mining	3 D	Design of underground r & p mine, Raudberget
Gudvangen Stein	Norway	1992	Aggregate mining	-----"-----"	-----"-----"
Norstone	Norway	1992	Aggregate mining	3D	Design of potential underground mining of gneiss
Folldal Verk	Norway	1971-92	Fe-mining	2D, 3D	Control of high stress area
Falkhammar Magn	Norway	1991	Fe-mining	3D	Design of r & p mining
Fosdalen Mining	Norway	1977, 90	Limestone / marblemining	2D, 3D	Control of high stress area
Bleikvassli Mines	Norway	1976-90	Pb, Zn-mining	2D, 3D	Design of u.g. mining methods and stress control
Dannemora Mine	Sweden	1989	Fe-mining	3D	Evaluation of after-use for gas storage
Orkla Mining	Norway	1966-87	Cu,Zn – mining	2D, 3D	Regular programme for design and stress control of sublevel stopes and pillars until operations ceased
Gränges	Sweden	1986	Fe-mining	2D,3D	Design sublevel caving mining, pillar stress control
Elkem Skorovas	Norway	1971-85	Fe-mining	2D, 3D	Control of high stress area (sublevel stoping)
Sulitjelma Mining	Norway	1967-85	Cu-mining	2D, 3D	Control of high stress area (room and pillar)
Minnor Minerals	Norway	1984	Quarz mining	3 D	Design of underground mining
Greenex Mines	Greenland	1983	Pb, Zn-mining	2D	Control of pillar load in a r&p u.g. mine in permafrost
Titania Mines	Norway	1976, 83	Ilmenite mining	3D	Open pit stability, design of u.g. product storage silos
Arna Knuseverk	Norway	1982	Aggregate mining	2D	Stress control in pillars and roof in u.g. r & p mine
Rautarukki OY	Finland	1978-80	Fe-mining	2D, 3D	Design and stress control   3 sublevel stoping mines
Rødsand Mining	Norway	1966-80	Fe-mining	2D, 3D	Control of high stress area
Franzefoss	Norway	1976-78	Limestone mining	2D	Stress control in pillars in r & p mine in an urban area
Røros Copper	Norway	1971,77	Cu-mining	2D	Design of room-and-pillar mining

Rio Tinto Mines	Spain	1974, 75	Cu-mining	2D, 3D	Design of mining and pilar stress control in 2 mines
LKAB	Sweden	1972	Fe -mining	3-D	Virgin stress determination, Malmberget mine

Each client may comprise several measuring sites within one or more mining areas, and in many cases measurements have been carried out over a number of years

**Appendix 6**
**LIST OF CLIENTS – HYDRAULIC FRACTURING – CIVIL AND MINING ENGINEERING PROJECTS**

Client	Country	Years	Branch	Purpose
Suldal Hydro AS	Norway	2009	Hydro power	Minor principal stress for unlined pressure shaft, Suldal Kraftverk
Statkraft AS	Norway	2009	Hydro power	Minor principal stress for unlined pressure shaft, Nedre Røssåga
AF Gruppen AS	Norway	2009	Hydro power	Minor principal stress for unlined pressure shaft, Imsland
Risa Rock AS	Norway	2009	Hydro power	Minor principal stress for unlined pressure shaft, Jøssang
Multiconsult	Nepal	2008	Hydro power	Minor principal stress for unlined pressure shaft, Upper Tamakoshi
SNSG AS	Norway	2008	Coal mining	Det. of tectonic horizontal stresses in a vertical borehole in connection with a new u.g. mine, Lunkefjell
Småkraft AS	Norway	2007	Hydro power	Minor principal stress for unlined pressure shaft, Steinsvik
Sweco Grøner	Norway	2006	Hydro power	Minor principal stress for unlined pressure shaft, Leirfossen
Landsvirkjun	Iceland	2006	Hydro power	Minor principal stress for unlined pressure shaft, Karanhjukur
Veidekke	Norway	2006	Hydro power	Minor principal stress for unlined pressure shaft, Kjøssnesfjorden
Sauda Kraftverk	Norway	2005	Hydro power	Minor principal stress for unlined pressure shaft, Sønnå Sauda
Veidekke ASA	Norway	2005	Hydro power	Minor principal stress for unlined pressure shaft, Dalvatn
SRG	Norway	2005	Hydro power	Minor principal stress for unlined pressure shaft, Saudefallene
Sunnhordland kraftlag AS	Norway	2002, 2004	Hydro power	Minor principal stress for unlined pressure shaft, Blåfalli kraftverk
Tritech	Singapore	2004	Oil / gas storage	Minor principal stress
NTE	Norway	2004	Hydro power	Minor principal stress for unlined pressure shaft /tunnel, Follafoss
Statkraft SF	Norway	2004	Hydro power	Minor principal stress, vertical hole from surface, Kobbelv
Mesta AS	Norway	2004	Hydro power	Minor principal stress for unlined pressure shaft or tunnel, Svartdalen
Sweco Grøner AS	Norway	2004	Hydro power	Minor principal stress, Matre
Veidekke ASA	Norway	2003	Hydro power	Minor principal stress for unlined pressure shaft, Framruste kraftverk
Norcem AS	Norway	2002	Limestone mining	Stress magnitude , Dalen mine
Veidekke ASA	Norway	2002	Hydro power	Minor principal stress for unlined pressure shaft or tunnel, Øyberget kraftverk
Selmer Skanska	Norway	2002	Hydro power	Minor principal stress for unlined pressure shaft, Nye Tyin kraftverk
NCC anlegg AS	Norway	2001	Hydro power	Minor principal stress for unlined pressure shaft, Nye Bjølvo kraftverk
Veidekke ASA	Norway	2001	Hydro power	Minor principal stress for unlined pressure shaft, Lindland kraftverk
Norske Skog / Statkraft Grøner	Norway	2001	U.g. rail terminal / export storage	Horizontal stresses for design of large span rock caverns, Sauøya, Halden
Veidekke	Norway	2000	Hydro power	Minor principal stress for unlined pressure shaft or tunnel, Åbjørø
Veidekke ASA	Norway	2000	Hydro power	Minor principal stress for unlined pressure shaft, Åbjørø kraftverk
NGU	Norway	1999	Research	Horizontal stress vs. neo-tectonics, Stuuragurra fault, Masi,
Aura Kraft	Norway	1998	Hydro power	Minor principal stress for unlined pressure shaft, Grøa
Lyse Kraft	Norway	1997, 98	Hydro power	Minor principal stress for unlined pressure shaft, Fløyrlil
Norplan	Tanzania	1996-98	Hydro power	Minor principal stress for unlined pressure shaft, Lower Kihansi
Buskerud Kraft	Norway	1996	Hydro power	Minor principal stress for unlined pressure shaft, Askerudfoss
Norconsult	Pakistan	1996	Hydro power	Minor principal stress for unlined pressure shaft, Neelum Jhelum
NGU	Norway	1996	Research	Water flow and stress, Ytre Sogn
Sydskraft Konsult	Sweden	1994	Hydro power	Minor principal stress for test storage facility, Lövesåsen
Grøner Consult	Norway	1994	Hydro power	Minor principal stress for unlined pressure shaft or tunnel, Skjerka
BKK Bergen	Norway	1993	Hydro power	Minor principal stress for unlined pressure shaft, Åsebotn
Norplan	Tanzania	1993	Hydro power	Minor principal stress for unlined pressure shaft, Pangani Falls
Norconsult	Tanzania	1993	Hydro power	Minor principal stress for unlined pressure shaft, Lower Kihansi Falls
Norconsult	Nepal	1993	Hydro power	Minor principal stress for unlined pressure shaft, Kali Gandaki
Rana Gruber	Norway	1993	Fe- mining	Det. of tectonic horizontal stresses in a vertical borehole in connection with a new u.g. mine, Rana
NGU*	Norway	1993	Research	Horizontal stress vs. groundwater flow in cryst. rock, Hvaler
Store Norske Coal	Norway Spitsbergen	1991	Coal mining	Det. of tectonic horizontal stresses in a vertical hole drilled through a glacier into rock ( permafrost ) in connection with a new longwall coal mine
Vestfold Kraft	Norway	1991	Hydro power	Minor principal stress for unlined pressure shaft or tunnel Daleelven
Nuuk Kraft	Greenland	1991	Hydro power	Minor principal stress for unlined pressure shaft, Buksefjord ( in permafrost )
Opplandskraft	Norway	1990	Hydro power	Minor principal stress at air cushion, Torpa
Research council	Norway	1990	U.g gas storage	Minor principal stress for test storage facility, Fosdalen
GUN**	Sweden	1990	Gas storage	Minor principal stress, Dannemora
Research council	Norway	1990	U.g. cold storage	Minor principal stress vs. water, Ladehammeren
Research council	Norway	1988	Hydro power	Minor principal stress at air cushion, Tafjord K5
Research council	Norway	1988	Hydro power	Minor principal stress, Osa

BKK Bergen	Norway	1988	Hydro power	Minor principal stress, unlined pressure shaft, Fossmark
Research council	Norway	1987	Hydro power	Determination of minor principal stress at underground air cushion surge chamber, Brattset
Tafjord Kraft	Norway	1987	Hydro power	Minor principal stress, unlined pressure shaft, K1
N.Trøndelag El.	Norway	1987	Hydro power	Minor principal stress for unlined pressure shaft Ormsetfoss

Each client may comprise several test sites and boreholes.

\* NGU = Geological Survey of Norway

\*\* GUN = Gass Utvikling i Norden (Natural gas development in the Nordic countries).