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Äspö Hard Rock Laboratory

Prototype Repository

Instrumentation for stress, strain and displacement measurements in rock

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November 2003

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Äspö Hard Rock
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Abstract

SKB is constructing a full-scale replica at Äspö HRL of the deep repository planned for disposal of spent nuclear fuel in Sweden. The Äspö HRL is now in an operating phase where different aspects required for a deep repository will be studied. The 'Prototype Repository' is one of many research areas situated within the 3600 m long tunnel which descends to a depth of about 460 m.

The Prototype Repository is a test area consisting of a TBM-bored tunnel located at a depth of about 450m below ground surface. It includes six vertical deposition boreholes which have a diameter of 1.75 m and a depth of 8m. Each of these boreholes will contain electrically heated canisters that will simulate the heat generated by radioactive waste. One aspect of the research being carried out at this particular test area is an investigation of the rock mechanical properties.

The primary objective of the studies presented in this report is to verify rock mechanical processes during the construction and operation phases of the repository. The mechanical status (e.g. stress and strain fields) of the rock will be changed, and this in turn may lead to changes in the thermal and hydraulic behaviour of the host rock. Stress magnitudes at these depths are high and stress redistribution due to excavation and heating of the canisters may induce stress increases that are close to the strength of the rock [1].

Instrumentation has been installed to allow measurement of the stress redistribution during two phases. The first phase was due to excavation of the deposition boreholes. The second phase will result from the temperature increase in the host rock around the heated canisters. Monitoring of strain and deformations will take place within the intact rock as well as single fractures and fracture zones.

The instrumentation has been installed in two stages. The primary instruments were installed prior to drilling of the deposition holes. These instruments were installed within 60mm diameter vertical boreholes located 0.3m from the planned periphery of the deposition borehole. The complementary instruments were later installed after drilling of the deposition boreholes. The majority of these instruments were installed within horizontal boreholes drilled from within the deposition boreholes. In addition, strain gauges were installed vertically below the base of the deposition holes.

The types of instruments selected, and the locations at which they were installed were designed to verify analyses performed to estimate the rock mechanical response. A total of 16 stress meters, 49 deformation/displacement gauges, and 15 strain gauges have been installed as part of this research.

The objective of this report is to document the selection of the instruments and the details of the instruments as they were installed.

Sammanfattning

SKB skall utföra ett fullskaleförsök på Äspö HRL för simulering av ett slutförvar av högaktivt kärnbränsleavfall i kristallint berg i Sverige. Äspö HRL är inne i en operativ fas där kraven med olika aspekter för ett slutförvar kommer att undersökas och analyseras. Prototypförvaret är ett av flera forskningsutrymmen belägna i den 3 600 m långa tunneln ner till ca 460 meters djup.

Prototypförvaret är ett testområde placerat i en TBM-borrad tunnel belägen på ett djup av 450 m och inkluderar sex vertikala deponeringshål. Hålen är 1.75m i diameter och 8 m djupa. Ett mål med forskningen på denna plats är att undersöka och analysera den bergmekaniska responsen vid uppvärmning av bergmassan. Elektriskt uppvärmda kapslar, som därvid skall simulerar värmen generad från kärnbränsleavfallet, är placerade i deponeringshålen.

Det primära målet med undersökningarna, som presenteras i denna rapport är att verifiera bergmekaniska processer i samband med byggandet av förvaret och i den operativa fasen. Bergmassans mekaniska egenskaper (spänningar och töjningar) kommer att förändras, och detta i sin tur kan resultera i förändringar i termiska och hydrauliska beteendet i bergmassan. Spänningsnivåerna i bergmassan på detta djup är höga och den spänningsomfördelning, som erhålls som ett resultat av tunnel drivning, borrning av deponeringshålen och upphettning, skulle kunna framkalla spänningsökningar som ger totala spänningar nära bergets hållfasthet.

Bergmassan runt två deponeringshål har instrumenterats. Instrumenten har installerats för kontroll och registrering av förändringarna för två lastfaser. Den första fasen innefattar borrningen av deponeringshålen. Den andra fasen kommer att ske när värmeelementen i kapslarna börjar värma berget. Övervakningen av töjningar och deformationer görs av intakta bergarten, över enskilda sprickor, i sprickzoner, samt över avsnitt av bergmassan

De första instrumenten installerades före utborrningen av deponeringshålen. Dessa instrument installerades i borrhål parallella med deponeringshålet och är belägna 0.3m från dess periferi. Kompletterande instrument blev installerade efter att borrningen av deponeringshålen var slutförda. Denna instrumentering innefattar töningsgivare som registrera töjningar radiellt ut från deponeringshålen i två nivåer, 3 och 6 m från hålbotten. Därtill finns det töjningsmätare installerade i ett vertikalt hål i bottnen av deponeringshålen.

Instrumenteringen omfattar totalt 16 spänningsmätare, 49 deformationsmätare, och 15 töjningsmätare.

Syftet med denna rapport är att dokumentera och presentera val av instrumentering, layout, montering och installation.

Contents

1 Introduction

1.1 Äspö Hard Rock Laboratory

According to the Swedish concept for the deep disposal of spent nuclear fuel, high-level radioactive waste will be stored in a repository constructed as a tunnel system in crystalline bedrock at depths of 400m to 700m [2]. SKB (Svensk Kärnbränslehantering AB) is constructing a full-scale replica of the tunnel repository at Äspö Hard Rock Laboratory (HRL). This laboratory is being used for research work for the final disposal of radioactive waste.

The Äspö HRL is now in an operating phase where different aspects required for a deep repository will be studied, including function, handling techniques and development and testing of equipment. The different aspects will be tested, studied and developed in a number of tests.

1.2 Prototype Repository

1.2.1 General Objectives

The Prototype Repository is one of the tests being conducted within the tunnel system at the Äspö HRL. It will provide a full-scale reference for testing of the design and construction principles, as well as testing of the predictive modelling. The Prototype Repository contains six vertical deposition holes with electrically heated, full-size 'canisters' that will simulate the heat generated by radioactive waste.

The objective of the test is to demonstrate the integrated function of the repository components and a comparison of the results with models and assumptions. It will include testing of characterisation methods in the deposition tunnel, boring of deposition holes, placement of the buffer, canister and backfill, construction of plugs and instrument installation. During operation the host-rock, backfill and buffer will be instrumented in order to measure the thermal-hydraulic-mechanical (T-H-M) processes during the test period. The behaviour of the rock mass will be monitored by instruments.

1.2.2 Investigation of rock mechanical response

The major objective of the rock mechanical studies is to verify rock mechanical processes in the construction and operation phases of the repository. Instrumentation has been installed to allow measurement of the stress redistribution due to excavation and temperature increase in the host rock around the deposition holes. Monitoring of strain and deformations will take place within intact rock as well as single fractures and fractures zones.

The mechanical processes in the host rock are related to the existing structures, stresses, strains and deformations. These processes are coupled to thermal and hydraulic processes. For example, there is an Excavation Disturbed Zone (EDZ) in which the rock mass properties have been altered, e.g. a zone of enhanced permeability around the excavation. In addition, the temperature rise will affect the local stress distribution, which can shear, close or open rock fractures depending on inclination and orientation to the stress field. These events could affect the fracture permeability. Water pressure in fractures may reduce the normal stress.

The rock mechanical response may be divided into three stages.

- Drilling of the TBM adit tunnel deposition holes
- Drilling of the deposition holes
- Operation stage (heating and swelling pressure during operation)

During each of these stages the host rock will be subjected to distinctly different stress change regimes. Stress redistribution due to the new openings, i.e. the TBM adit tunnel, and the new canister holes, may generate stress concentrations that could cause microcracking and displacement in existing structures. During the operation stage, the increasing temperature will generate thermal loading that will further increase the compressive stresses around the holes.

The mechanical status (e.g. stress and strain fields) of the rock will be changed, and this in turn may lead to changes in the thermal and hydraulic behaviour of the rocks. Stress magnitudes at these depths are high and stress redistribution due to excavation and heating of the canisters may induce stress changes that are close to the strength of the rock [1].

1.2.3 Objectives of this report

The research presented in this report is a part of the research work aimed to investigate the disturbed zone and the rock mechanical response in the host rock around the excavated deposition holes. The objective of the monitoring work carried out by BBK AB is to measure the stress and strain changes of the host rock during two stages: Phase I, construction stage during excavation of the deposition holes; and Phase 2, heating and swelling of the host rock.

This report presents the rationale behind the experimental concept, layout and selection of instruments, details of the completed installations, and a brief description of the planned data collection system.

2 Analysis of rock mechanical response

Testing and analysis have been performed to estimate the primary stresses in the host rock, and the stress changes which will result from construction and operation stages. The major principle stress at the site has been determined, by over-coring methods, to have a magnitude of about 20 MPa, at a bearing 335^{o} with a subhorizontal plunge [3]. The uniaxial compressive strength of the host rock is approximately 170 MPa and the uniaxial crack-initiation about 64 MPa [1].

Numerical analyses, which have been performed as part of the scoping calculations, have shown that the resultant stress redistribution due to the construction phase may induce stresses that are close to the compressive strength of the intact rock. The stress concentration and stress redistribution may induce microcracking and displacement on existing structures that change the mechanical and hydraulic properties around the deposition boreholes [1].

Stresses generated during drilling of the deposition boreholes, and during the heating phase have been analysed by numerical methods based on in-situ rock stress measurements. These analyses have shown that high stresses, up to 120 MPa, may be developed around the deposition holes before operation of the Prototype Repository starts. The heat load during operation, according to scoping calculations, may develop stresses up to about 200 MPa.

Close to the intersection between the TBM adit tunnel and the deposition boreholes the principle stress varies from maximum to minimum (i.e., from compression to tension). According to the scope calculation results, the maximum principle stress is about 200 MPa and the minimum principle stress is about -5 MPa, and a plastic zone may extend near the intersection of the tunnel and boreholes. Scoping calculations have indicated a maximum equivalent strain of about 320 μstrain.

Earlier investigations have shown that the TBM excavation method, used to construct both the adit tunnel and the deposition boreholes, creates a disturbed zone in which fractures are induced in the walls of the borehole. This zone is typically very small, on the order of 3 cm, in comparison to the larger disturbed zone created by drill and blast techniques.

It may be expected that, in the disturbed zone, mechanical as well as hydraulic properties will change. It is of great interest to investigate the magnitude of the stress related disturbed zone and to what extent it may influence the mechanical and hydraulic properties during operation

The parameters that may have an impact on the rock properties, and which are considered as part of this testing program include:

During excavation phase:

- Induced fracturing caused by the excavation technique
- Rock stress development
- Micro-cracking due to stress-redistribution
- Micro-cracking due to stress-redistribution

During operation (heating) phase:

- Rock stress development
- Micro-cracking by thermal loading
- Displacement on pre-existing structures

3 Prototype Repository Layout

The Prototype Repository is located at a depth of about 450m as shown in Figure 3-1 in the tunnel system at Äspö HRL. The length of the Prototype test tunnel is 90m.

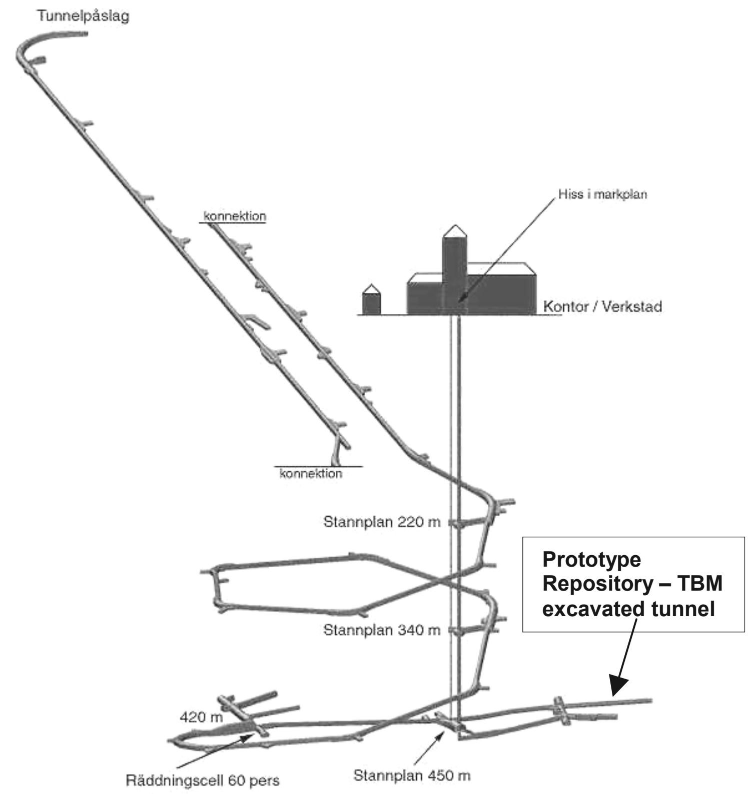

***Figure 3-1**. Location of the Prototype Repository at Äspö HRL.*

The Prototype Repository consists of two test sections (I and II) with four and two depositions holes respectively (see Figure 3-2). In the outer section, Section II, two deposition holes, i.e. Hole 5 and Hole 6 have been instrumented for monitoring stress and strain changes of the host rock. Since the intention is to minimize disturbance during the operation, the test arrangement was such that artificial disturbances of the engineered barriers and the interaction with surrounding rock are kept to a minimum.

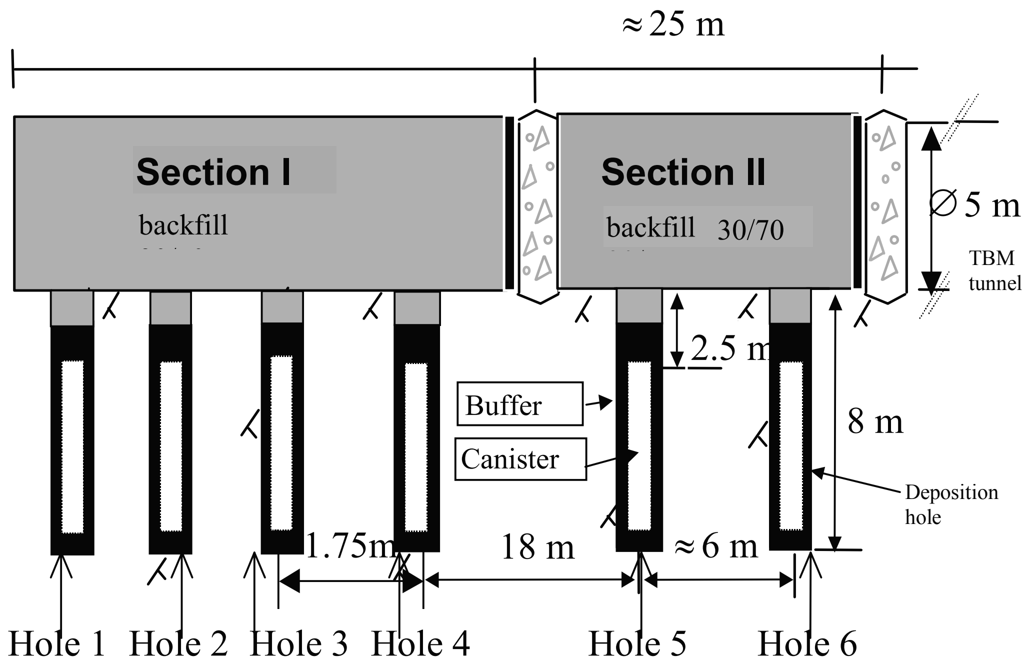

Figure 3-2. *Schematic view of the layout of the Prototype Repository and deposition holes (not to scale)*

The deposition holes in the Prototype Repository were mechanically excavated by a hard rock TBM machine converted for down hole boring. The excavation technique was based on inducing high stresses to the rock by cutters that rotate on the rock surface. The method is probably comparable to the method that will be used in the deep repository.

4 Selection of instrumentation

The instrumentation for monitoring rock mechanical response was installed in two stages. The instruments used to monitor the drilling phase of the canister boreholes were installed within vertically drilled boreholes located 0.3m from the periphery of the deposition hole. Following drilling of the deposition holes, complementary instruments were then installed within boreholes drilled from within the deposition holes. Details regarding the selection of these instruments are discussed in the following sections as primary instruments and complementary instruments. Technical details of the instruments that have been installed are presented in Appendix A.

4.1 Primary instruments

4.1.1 Stress measurements

The Geokon model 4350 vibrating wire biaxial stressmeter was installed for monitoring stress changes. This instrument was designed to measure compressive stress changes in rock, salt, concrete or ice. The instrument consists of a stiff high-strength steel cylinder, which is grouted into a BX (60 mm) size borehole. Stress changes in the host material cause the cylinder to deform, and the deformations in the plane perpendicular to the borehole are measured by means of two sets of three vibrating wire sensors spaced at 60^o intervals (measurements are made at two levels within the cylinder). The gauges also include two longitudinal strain sensors and temperature sensors. The deformation of the steel cylinder, and resulting changes in resonate frequency of the vibrating wires, are used to determine both the magnitude and orientation of the change in stress in the host material.

As was mentioned in Section 2, close to the intersection between the TBM tunnel and the deposition boreholes the principle stresses vary from compressive to tensile stresses. Since decreasing compressive stresses may yield unreliable measurements when using the biaxial stressmeter, another type of gauge has been chosen: the Geokon model 4360-1 Soft stress cell.

The Soft stress cell is designed to measure changes in borehole diameters caused by changes in stress in rock and concrete. In use, an instrumented steel ring is installed in a borehole and pre-stressed in place by forcing platens into contact with the borehole walls. A vibrating wire strain gage measures the deformation of the ring, which is also the deformation of the borehole. Both compressive and tensile measurements can be made. Unlike the biaxial stressmeters that contain sets of 3 vibrating wires, the soft stress cells measure deformation changes in only one direction. For this reason the soft stress cells are installed in pairs to measure stress changes tangential and radial to the deposition holes.

4.1.2 Vertical deformation measurements

Vertical deformations around the deposition holes are measured with deformation gauges installed within the same boreholes used for the biaxial stressmeters. The measuring lengths and locations were based on fracture mapping of cores taken from the installation.

The Geokon model 4430 Deformation meter is designed to measure longitudinal deformations in boreholes. The deformation meter consists of a tube with an anchor at each end. Within the tube a beam of graphite will transfer any distance changes between the two anchors to a vibrating wire sensor. In each deformation meter a temperature sensor is included for temperature corrections.

4.1.3 Strain measurements

At some particular locations, Geokon model 4200 strain gauges have been installed over single fractures. This model gauge is designed for direct embedment in cast concrete and for installation in grouted boreholes. A steel wire is tensioned between two end blocks and the strain of the wire is measured using the vibrating wire principle. Deformations in the rock mass induced movements of the hard cement causing the two end blocks to move in relation to each other across a joint, thereby altering the tension in the wire. The tension in the wire is measured by plucking the wire and measuring its resonant frequency of vibration using an electromagnetic coil.

4.2 Complementary instruments

The objective of the complementary instruments is to perform measurements in horizontal sections perpendicular to the axis of the deposition borehole. Each horizontal measuring section was instrumented to measure both deformation and temperature in intervals approximately parallel and perpendicular to the axis of the TBM tunnel, however offset by 10^{o} to avoid conflicts with the primary instruments. Strain gauges and temperature sensors have also been installed vertically at the bottom of the deposition holes. The exact locations and orientations of the instruments were decided based on characterisation of the deposition holes.

The instruments installed in these complementary boreholes are Geokon model VCE-4200 strain gauges, and Geokon model 4430 displacement transducers.

4.3 Summary of selected instruments

The following numbers and types of instruments were selected for installation to allow monitoring of stresses and strains within the host rock surrounding the deposition holes.

Table 4-1. Summary of primary instruments

Parameter measured	Instrument type	Total number installed
Compressive stress change in intact rock	Geokon model 4350 biaxial stressmeter	8
Compressive and tensile stress change in intact rock	Geokon model 4360-1 Soft stress cell	8
Vertical movements in intact rock, over single fractures and within fracture zones	Geokon model 4430 deformation meter	17
Vertical strain measurements in intact rock and over single fractures	Geokon model 4200 strain gauge	7

Table 4-2. Summary of complementary instruments

Parameter measured	Instrument type	Total number installed
Horizontal deformation perpendicular to the axis of the deposition hole	Geokon model 4430 displacement transducer	32
Vertical strains beneath the deposition hole	Geokon model 4200 strain gauge	8

5 Field activities and installation locations

5.1 Installation of primary instruments

The layout of the primary instruments around the deposition holes is shown in Figure 5-1 and Figure 5-2. The primary instruments were installed within vertical boreholes drilled at a distance of 0.3m from the periphery of the deposition holes. A total of eight 60mm diameter boreholes (four around each of the two deposition holes) were drilled. The majority of the instruments were installed within these boreholes. These holes are designated as A, C, E and G- 5 and 6. In addition, a total of four 76mm diameter boreholes (two at each deposition hole) were drilled to shallower depths to allow installation of the soft stress cell meters. These larger diameter holes are designated as H and D-5 and 6.

Installation of the gauges was accomplished by inserting the gauge into the grout-filled boreholes. Special cement, Densitop T2, was used to insure that the grout reached properties close to those of the rock. Laboratory tests [4] of the grout have revealed a uniaxial compressive strength of 192±13 MPa and a Young's Modulus of 52±1 GPa [5]. The water-cement ratio at the time of installation was 0.19.

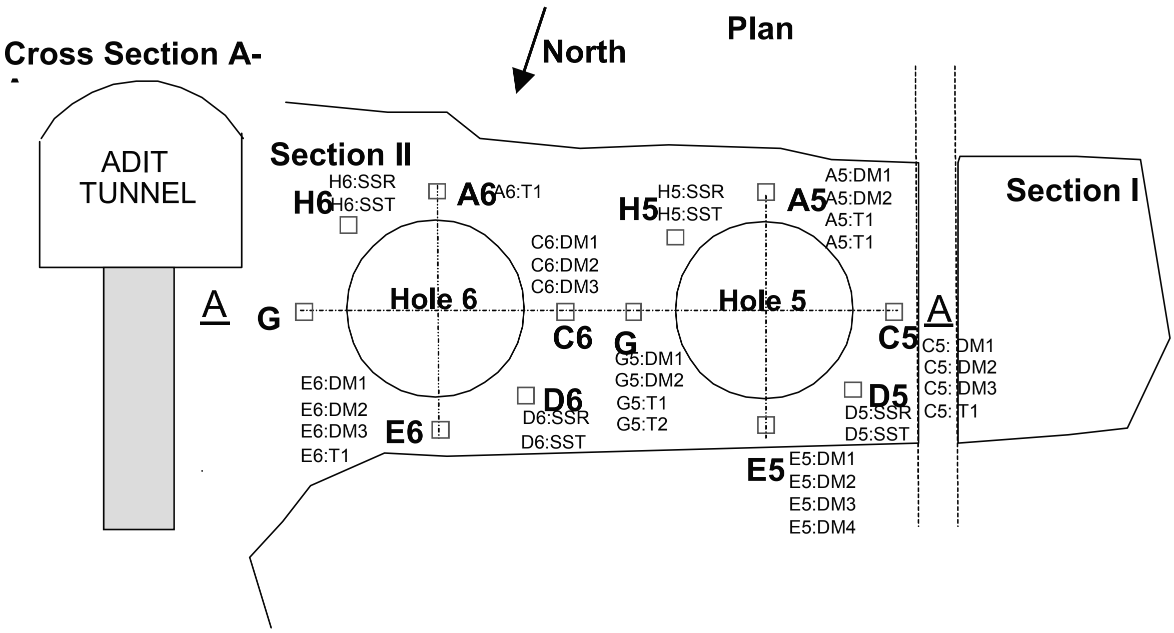

Figure 5-1. *Primary instrument locations in plan view*

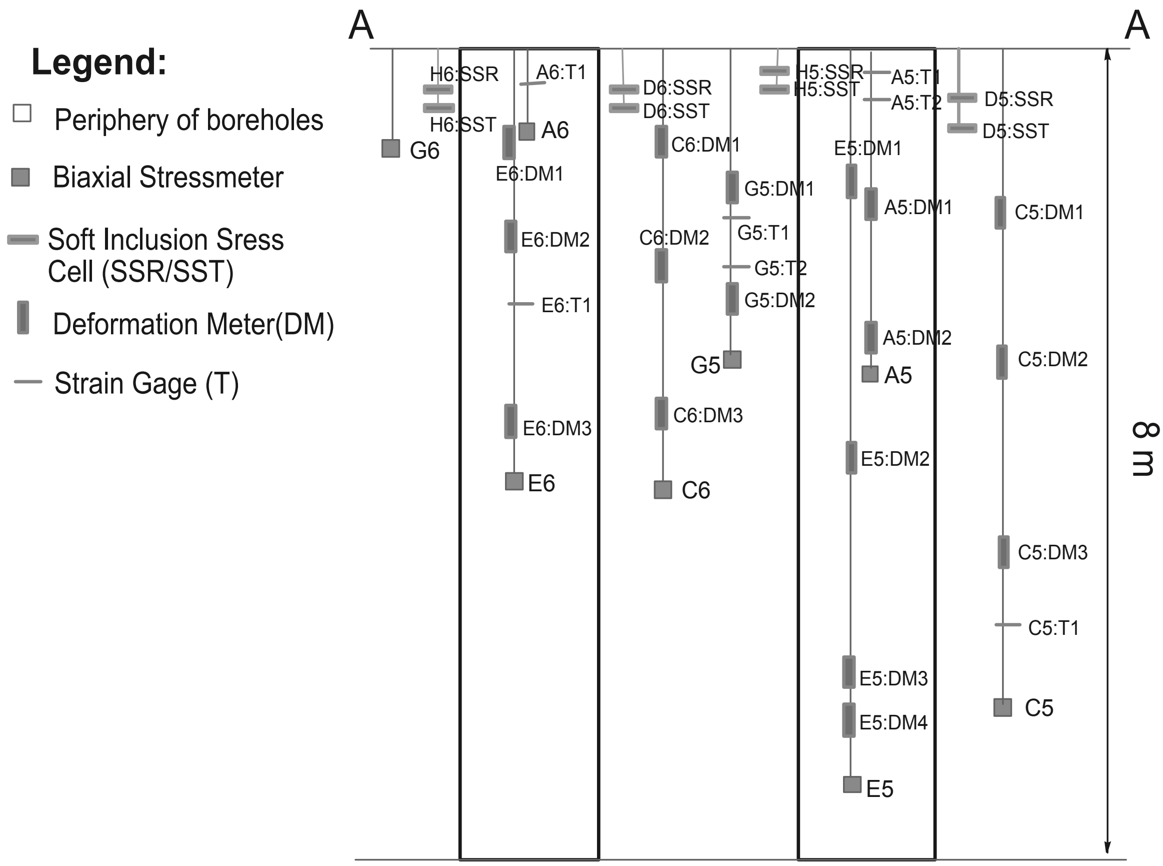

Figure 5-2. *Primary instrument locations in elevation view*

5.1.1 Installation of stressmeters

The biaxial stressmeters were positioned in non-fractured parts of the rock mass. The installation had to be carefully executed in order to position the instrument at the pre-selected depth. The gauges were pushed into the grout, and oriented so that the first vibrating wire (V_r1) was positioned tangentially to the deposition hole. The borehole was then completely filled with grout. The positioning of the instruments at the selected depths could typically be made with a precision of less than ±100mm.

The eight biaxial stressmeters were initially planned to be install at the depths of 1 m, 3m, 4 m, and 7m. The final locations differ from the planned ones in order to avoid natural rock fractures, and as a result of the precision to which it was possible to install the stress meters. The final locations are presented in Table 5-1.

Table 5-1. Location, depths and identification of Biaxial stressmeters installed around the deposition holes

Code	SKB Label	Borehole No.	Direction	Installation depth [m]
A5:Bi	SR54110	KA3551G03	Vertical	3.25
C5:Bi	SR50110	KA3552G03	Vertical	6.5
E5:Bi	SR54210	KA3551G04	Vertical	7.4
G5:Bi	SR50710	KA3550G03	Vertical	3.0
A6:Bi	SR65110	KA3545G03	Vertical	0.85
C6:Bi	SR60110	KA3546G03	Vertical	4.2
E6:Bi	SR65210	KA3545G04	Vertical	4.1
G6:Bi	SR60710	KA3544G03	Vertical	0.9

A total of eight Soft stress cell gauges were installed in the 76mm diameter boreholes. In each borehole two instruments were installed oriented at 90^o to each other; one to measure tangential stress and one to measure radial stresses relative to the periphery of the deposition holes. The depths and positions within the boreholes are presented in Table 5-2.

Table 5-2. Location, depths and identification of Soft Stress Cells installed around the deposition holes (SST indicates string radial to deposition hole, and SST indicates string tangential to deposition hole)

Code	SKB Label	Borehole No.	Direction	Installation depth [m]
D5:SSR	JR52r20	KA3552G02	Vertical	0.6
D5:SST	JR52t10	KA3552G02	Vertical	0.8
H5:SSR	JR56r20	KA3550G02	Vertical	0.2
H5:SST	JR56t10	KA3550G02	Vertical	0.3
D6:SSR	JR62r20	KA3546G02	Vertical	0.3
D6:SST	JR62t10	KA3546G02	Vertical	0.4
H6:SSR	JR66r20	KA3545G04	Vertical	0.3
H6:SST	JR66t10	KA3544G02	Vertical	0.4

5.1.2 Installation of deformation gauges and strain gauges

Vertical movements around the deposition holes are measured with deformation gauges installed within the 60mm diameter boreholes which were used also for the biaxial stressmeters. The measuring lengths and locations were based on fracture mapping of the cores taken from the installation. Final locations of the deformation meters are listed in Table 5-3.

Strain gauges were installed over single fractures for monitoring of the vertical deformations. The final locations of strain gauges are also presented in Table 5-3. The strain gauges were fixed to a fibreglass rod and pushed down to the selected depth in the borehole. Measurements taken by these gauges will be in the direction of the borehole; therefore the majority of the fractures that have been instrumented are sub-horizontal.

Table 5-3. Identification, depth and location of deformation meters (DM) and strain gauges (T)

Code	SKB Label	Borehole No.	Direction	Installation section and gauge length [m]
A5:DM1	DR54130	KA3551G03	Vertical	0.05 – 1.55
A5:DM2	DR54120	“	“	1.55 – 3.05
A5:T1	TR54150	“	“	0.125 – 0.275
A5:T2	TR54140	“	“	0.425 – 0.275
C5:DM1	DR50150	KA3552G03	Vertical	0.10 – 1.70
C5:DM2	DR50140	“	“	1.70 – 3.20
C5:DM3	DR50130	”	”	3.20 – 5.10
C5:T1	TR50120	”	”	5.425 – 5.575
E5:DM1	DR54250	KA3551G04	Vertical	0.10 – 1.30
E5:DM2	DR54240	“	“	1.30 – 4.10
E5:DM3	DR54230	”	”	4.10 – 6.30
E5:DM4	DR54220	”	”	6.10 – 6.60
G5:DM1	DR50750	KA3550G03	Vertical	0.00 – 1.50
G5:DM2	DR50720	“	“	1.50 – 2.50
G5:T1	TR50740	“	“	1.625 – 1.775
G5:T2	TR50730	“	“	2.025 – 2.175
A6:T1	TR65120	KA3545G03	Vertical	0.175 – 0.325
C6:DM1	DR60140	KA3546G03	Vertical	0.0 – 1.0
C6:DM2	DR60130	“	“	1.0 – 2.3
C6:DM3	DR60120	”	”	2.3 – 3.6
E6:DM1	DR65250	KA3545G04	Vertical	0.0 – 1.1
E6:DM2	DR65240	“	“	1.1 – 2.0
E6:DM3	DR65220	“	“	2.0 – 3.8
E6:T1	TR65230	“	“	2.175 – 2.32

5.2 Installation of complementary instruments

Installation of the complementary instruments took place following drilling of ten boreholes having about a 75mm diameter from within the two deposition boreholes. The locations of these ten boreholes are shown schematically as well as in plan and elevation in Figures 5-3 to 5-6. The instruments installed within these boreholes consisted of displacement transducers ranging in length from 0.3m to 1.2m, and strain gauges which were 0.15m in length. Thermocouples were also installed within the boreholes by Clay Tech, however these will be monitored and reported separately.

Final locations and details of the displacement gauges and strain gauges are listed in Table 5-4 and Table 5-5.

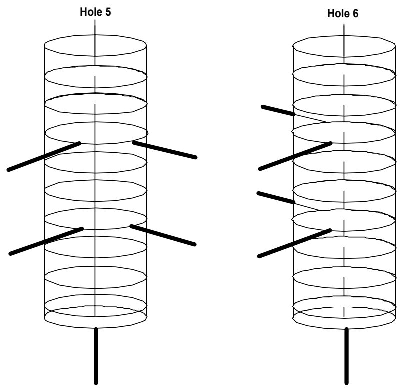

Figure 5-3. *Schematic view of complementary boreholes.*

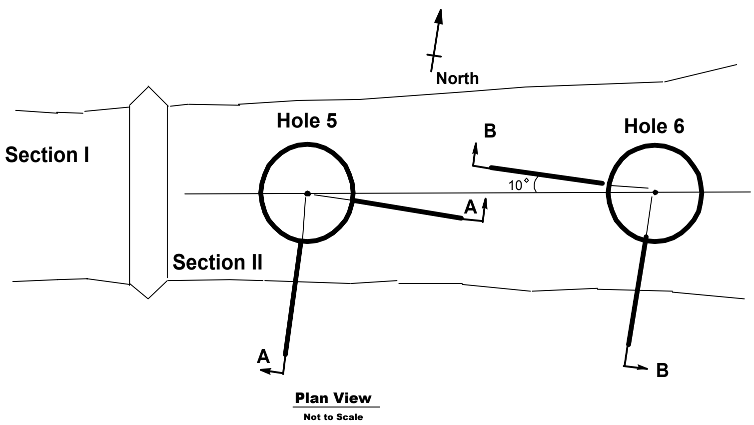

Figure 5-4. *Plan view of complementary boreholes.*

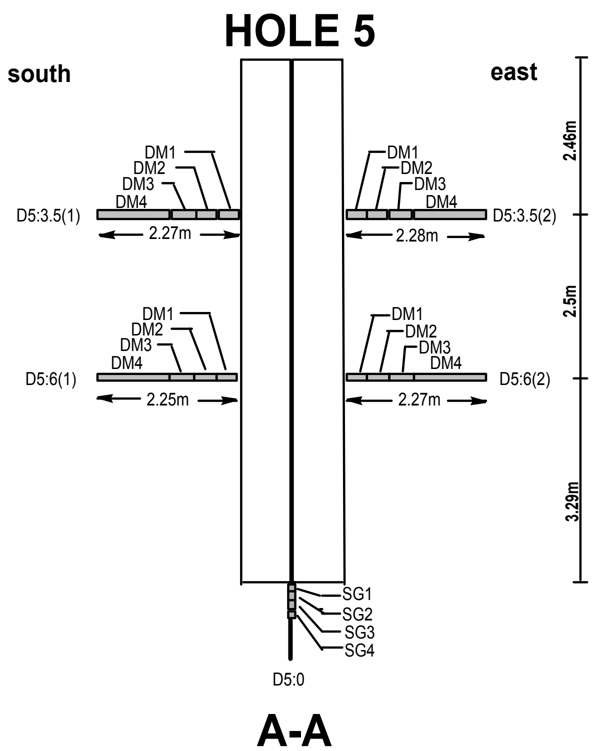

Figure 5-5. *Elevation view of complementary instruments in deposition Hole 5.*

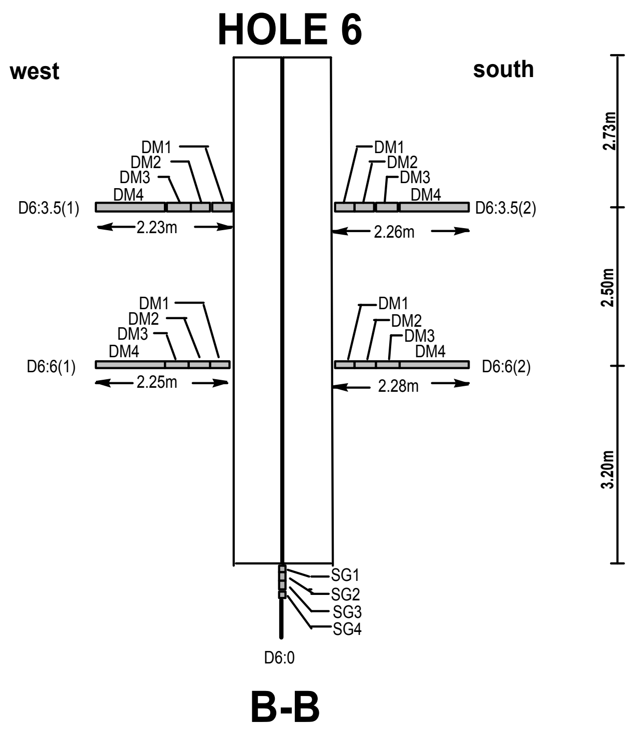

Figure 5-6 *Elevation view of complementary instruments in deposition Hole 6.*

Table 5-4. Complementary instruments in Deposition Hole 5

Borehole D5:3.5(1); Orientation – Horizontal; Total length – 2.27m; Depth from top of deposition hole – 2.46m		
Code / SKB Label	**Instrument Type**	**Gauge length (m)**
DM1 / DR50314	Displacement transducer	0.3
DM2 / DR50313	Displacement transducer	0.3
DM3 / DR50312	Displacement transducer	0.4
DM4 / DR50311	Displacement transducer	1.2
Borehole D5:3.5(2); Orientation – Horizontal; Total length – 2.28m; Depth from top of deposition hole – 2.46m		
Code / SKB Label	**Instrument Type**	**Gauge length (m)**
DM1 / DR50514	Displacement transducer	0.3
DM2 / DR50513	Displacement transducer	0.3
DM3 / DR50512	Displacement transducer	0.4
DM4 / DR50511	Displacement transducer	1.2
Borehole D5:6(1); Orientation – Horizontal; Total length – 2.25m; Depth from top of deposition hole – 4.96m		
Code / SKB Label	**Instrument Type**	**Gauge length (m)**
DM1 / DR50324	Displacement transducer	0.3
DM2 / DR50323	Displacement transducer	0.3
DM3 / DR50322	Displacement transducer	0.4
DM4 / DR50321	Displacement transducer	1.2
Borehole D5:6(2); Orientation – Horizontal; Total length – 2.27m; Depth from top of deposition hole – 4.96m		
Code / SKB Label	**Instrument Type**	**Gauge length (m)**
DM1 / DR50524	Displacement transducer	0.3
DM2 / DR50523	Displacement transducer	0.3
DM3 / DR50522	Displacement transducer	0.4
DM4 / DR50521	Displacement transducer	1.2
Borehole D5:0; Orientation – Vertical; Total length – 1.08m; Depth from top of deposition hole – 8.25m		
Code / SKB Label	**Instrument Type**	**Gauge length (m)**
SG1 / DR54340	Strain gauge	0.15
SG2 / DR54330	Strain gauge	0.15
SG3 / DR54320	Strain gauge	0.15
SG4 / DR54310	Strain gauge	0.15

Table 5-5. Complementary instruments in Deposition Hole 6

Code / SKB Label	Instrument Type	Gauge length (m)
Borehole D6:3.5(1); Orientation – Horizontal; Total length – 2.23m; Depth from top of deposition hole – 2.73m		
Code / SKB Label	**Instrument Type**	**Gauge length (m)**
DM1 / DR60314	Displacement transducer	0.3
DM2 / DR60313	Displacement transducer	0.3
DM3 / DR60312	Displacement transducer	0.4
DM4 / DR60311	Displacement transducer	1.2
Borehole D6:3.5(2); Orientation – Horizontal; Total length – 2.26m; Depth from top of deposition hole – 2.73m		
Code / SKB Label	**Instrument Type**	**Gauge length (m)**
DM1 / DR60414	Displacement transducer	0.3
DM2 / DR60413	Displacement transducer	0.3
DM3 / DR60412	Displacement transducer	0.4
DM4 / DR60411	Displacement transducer	1.2
Borehole D6:6(1); Orientation – Horizontal; Total length – 2.25m; Depth from top of deposition hole – 5.23m		
Code / SKB Label	**Instrument Type**	**Gauge length (m)**
DM1 / DR60324	Displacement transducer	0.3
DM2 / DR60323	Displacement transducer	0.3
DM3 / DR60322	Displacement transducer	0.4
DM4 / DR60321	Displacement transducer	1.2
Borehole D6:6(2); Orientation – Horizontal; Total length – 2.28m; Depth from top of deposition hole – 5.23m		
Code / SKB Label	**Instrument Type**	**Gauge length (m)**
DM1 / DR60424	Displacement transducer	0.3
DM2 / DR60423	Displacement transducer	0.3
DM3 / DR60422	Displacement transducer	0.4
DM4 / DR60421	Displacement transducer	1.2
Borehole D6:0; Orientation – Vertical; Total length – 1.12m; Depth from top of deposition hole – 8.43m		
Code / SKB Label	**Instrument Type**	**Gauge length (m)**
SG1 / DR60540	Strain gauge	0.15
SG2 / DR60530	Strain gauge	0.15
SG3 / DR60520	Strain gauge	0.15
SG4 / DR60510	Strain gauge	0.15

6 Data collection and future works

As the backfilling and final construction of Prototype Repository are being completed, the instruments will be connected to a datalogger system. This system will consist of eight multiplexers, to which the sensors are connected. The multiplexers are then in turn connected to two dataloggers.

The multiplexers will be Geokon model 8032 units which expand the number of channels that can be read by the dataloggers. The two dataloggers will be Geokon MICRO-10 units which are built around the Campbell Scientific CR 10 MCU which is a microcomputer, clock, multimeter, calibrator, scanner, frequency counter and controller.

When the connections from the individual sensors to the datalogger have been completed, the raw data will be downloaded and saved at Äspö HRL. At regular intervals will the raw data be analysed and used for calculation of the intereresting parameters. Proper and correct data will after this quality assurance procedure be stored in the SICASA data base, all in compliance with the Äspö HRL procedure for handling of data from experimentsl.

References

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[3] Myrvang, A., 1997. Evaluation of in-situ rock stress, measurements at the Zedex test area. Äspölaboratoriet Progress Report HRL-97-22.

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Appendix A

Model 4350 VW Biaxial Stressmeter

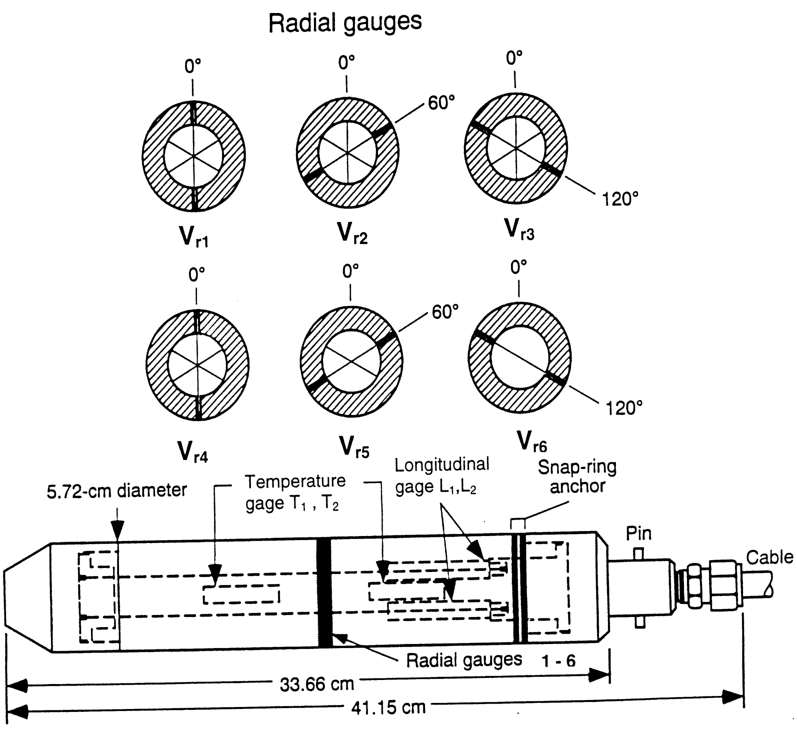
The Model 4350 VW Biaxial Stressmeter is designed to measure compressive stress changes in rock, salt, concrete or ice. Three or six VW sensors oriented at 60° intervals allow the principal stress changes to be measured in the plane perpendicular to the stressmeter axis. The stressmeter consists of a high strength steel cylinder which is grouted (or frozen, in the case of ice) into a BX (60mm (2.36in.)) size borehole

Specifications

Standard Range	70 MPa (10,000psi)
Sensitivity[1]	14 to 70 KPa (2 to 10psi)
Accuracy	±0.1% F.S.
Temperature Range[2]	–20°C to +80°C
Borehole Diameter	BX (60mm (2.36in.))

[1]Depends on rock modulus
[2]High temperature versions (up to 200°C) available on request

BIAXIAL STRESSMETER LAYOUT



Specifications and details of Biaxial Stressmeter. Source: Geokon Inc.

Model 4360 VW Soft Inclusion Stress Cell (SISC)

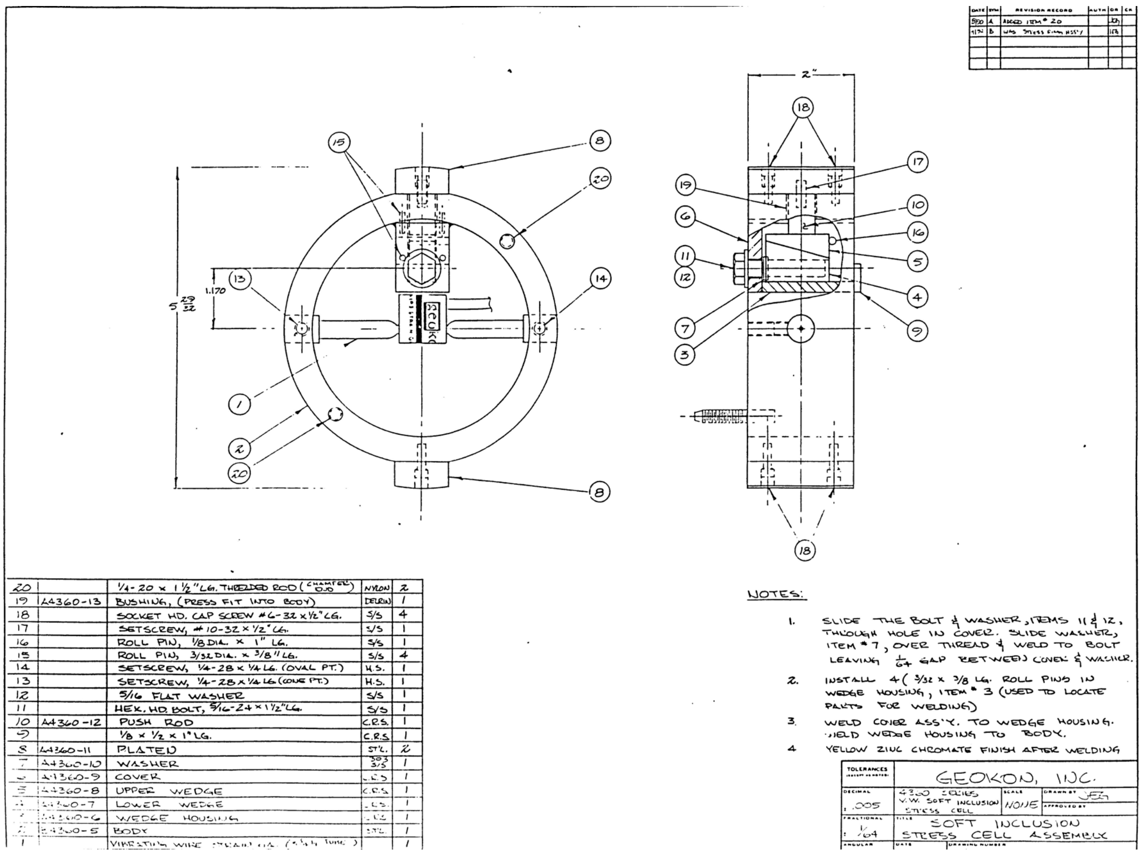
The Model 4360 Vibrating Wire SISC is a larger version of the Model 4300 Borehole Stressmeters. The SISC is pre-loaded by wedging it into a large size diamond drill hole using an integral screw mechanism or hydraulic piston and can be set to measure both tensile and/or compression stress changes. It has been used successfully in 152mm (6in.) dia. overcoring holes (drilled to measure in-situ stresses) to measure Aggregate/Alkali Reactions (AAR) in concrete dams.

Specifications

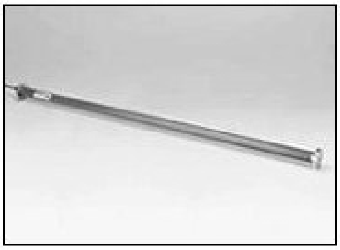
Standard Range[1]	±35 MPa (±5000psi)
Sensitivity[1]	35 KPa (5psi)
Temperature Range	–20°C to +80°C
Borehole Diameter[2]	NX, PQ, HQ, 152mm (6in.)

[1]Proportional to rock modulus; figures given are for E = 0.03 x 106 MPa (5 x 106psi)
[2]Other diameters available on request

.



Specifications and details of the Soft Inclusion Stress Cell Source: Geokon Inc



Model 4430 Soil Strain Meter

The Model 4430 Soil Strain Meter with flanged ends is designed to measure longitudinal deformation in dams and embankments. It can also be grouted or held in place by hydraulic anchors to measure deformations in boreholes (over the gage length). Gage lengths from 2 to 300 feet are available.

Specifications

Standard Ranges[1]	25, 50,100mm (1, 2, 4in.)
Sensitivity	0.02% F.S.
Accuracy	±0.1% F.S.
Nonlinearity	< 0.5% F.S.
Temperature Range	–20°C to +80°C
Length x Diameter	varies x 50mm (2in.)

[1]Other ranges available on request

Specification of the deformation meter Source: Geokon Inc.

Model VCE-4200/ 4210/ 4202 Concrete Embedment Type

These Strain Gages are designed for direct embedment in concrete. The VCE-4200 (standard model) has a 153mm (6in.) gage length and 1 microstrain sensitivity and is commonly used for strain measurements in foundations, piles, bridges, dams, tunnel linings, etc. It is also available as a high temperature version (up to 200°C). The VCE-4210 has the same range as the Model 4200 but has a 250mm (10in.) gage length making it particularly suitable for use in large aggregate concrete. The 4202, with a 51mm (2in.) gage length, is designed for laboratory use and/or where there are space limitations.

Specifications	4200	4210	4202
Standard Range	3000 microstrain (for each model)		
Sensitivity (microstrain)	0.5 to 1.0	0.4	0.4
Accuracy	±0.1% F.S.	±0.1% F.S.	±0.1% F.S.
Nonlinearity	< 0.5% F.S.	< 0.5% F.S.	< 0.5% F.S.
Temperature Range[1]	–20°C to +80°C (for each model)		
Active Gage Length	153mm (6in.)	250mm (10in.)[2]	51mm (2in.)

[1]Model 4200 high temperature version (up to 200°C) available on request
[2]Other lengths available on request

Specifications of the strain gauge Source: Geokon Inc.