P-04-23

Oskarshamn site investigation

Overcoring rock stress measurements in borehole KSH02

Jonny Sjöberg, SwedPower AB

December, 2003

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1651-4416
SKB P-04-23

Oskarshamn site investigation

Overcoring rock stress measurements in borehole KSH02

Jonny Sjöberg, SwedPower AB

December, 2003

Keywords: In situ stress, Measurements, Overcoring, KSH02, FN 30, AP PS 400-02-019.

Summary

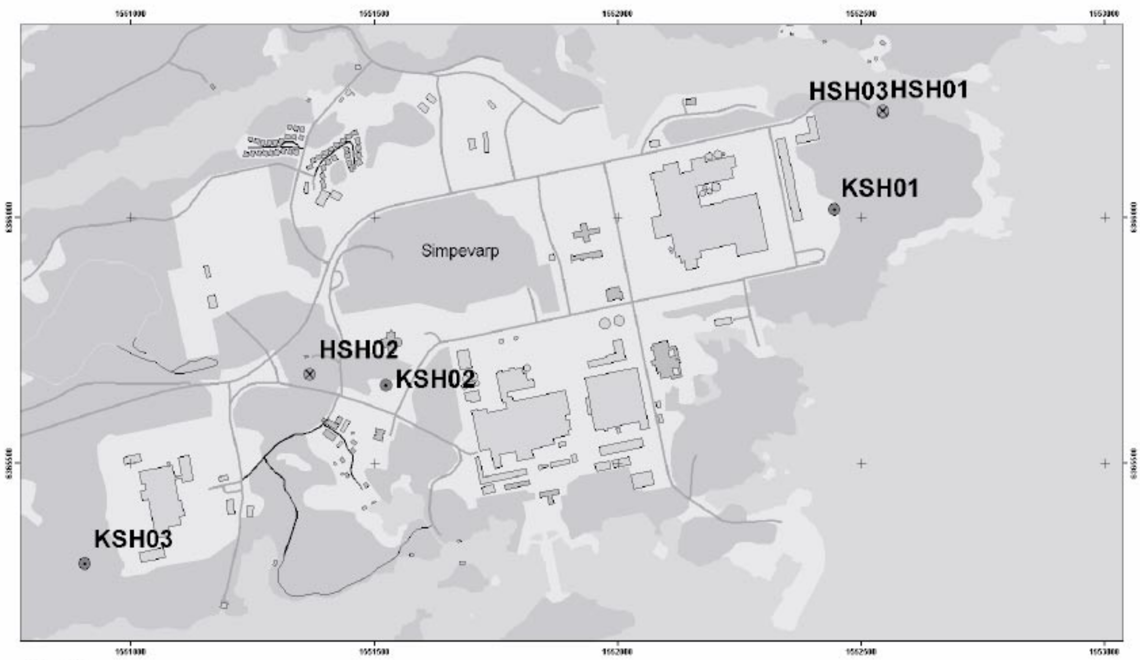
Overcoring stress measurements were conducted in borehole KSH02 at the Oskarshamn site. The equipment used for the measurements was the three-dimensional *Borre* probe. Measurements were attempted at two measurement levels: (i) between 250 and 300 meters depth, and (ii) between 447 and 463 meters depth. The rock conditions for stress measurement purposes were poor for borehole KSH02, with an abundance of subvertical fractures. Out of 15 pilot hole attempts at the two test levels, only one successful measurement was conducted. The results from this test showed very low stress magnitudes, with the maximum principal stress being 8.5 MPa, and the minor principal stress being close to zero. These stress magnitudes are significantly lower than expected at this depth. The reasons for the obtained low values are not clear. Low stiffness of the rock and the high frequency of healed fractures may result in lower stresses but probably not to the extent encountered in the measurement. Since only one measurement was completed, no redundancy was achieved; hence, the obtained stress values should be treated with caution.

Contents

1 Introduction

This document reports the data gained from three-dimensional overcoring rock stress measurements in borehole KSH02, which is one of the activities within the site investigation at Oskarshamn. This borehole is the second core hole for the Oskarshamn site investigation. The location of the hole, in relation to other investigation boreholes in the area, is shown in Figure 1-1.

The borehole was drilled subvertically from the ground surface and is of "telescope" type with the upper 100 meters of larger diameter (250 mm), which subsequently is cased. The rest of the borehole is drilled with 76 mm diameter down to a depth of 1000 meters. Overcoring rock stress measurements were planned to be conducted at approximately 250, 400 and 500 meters depth, during drilling of the hole, according to the activity plan AP PS 400-02-019 (SKB internal controlling document). All results are stored in the SKB database SICADA, Field Note No. 30.



Borrhål:	Y-koordinat:	X-koordinat:	
KSH01	1552442,971	6366013,519	Klart
KSH02	1551528,952	6365658,355	Planerat
KSH03	1550906	6365297	Planerat
HSH01	1552545,717	6366217,770	Klart
HSH02	1551368,337	6365682,896	Klart
HSH03	1552544,526	6366213,946	Klart

Figure 1-1. *Location of core holes (KSH01, KSH02, KSH03) and percussion-drilled holes (HSH01, HSH02, HSH03) at the Oskarshamn site.*

2 Objective and scope

The objective of the overcoring rock stress measurements was to determine the complete in situ stress field in the undisturbed rock mass at three measurement levels: 250, 400, and 500 meters depth. This was to be achieved by 3–4 successful test results from each level.

All measurements were conducted using the three-dimensional *Borre* probe for overcoring (developed and used by SwedPower AB). The method is described in detail in Chapter 3 of this report. Field measurements were done during two periods. The first period started on March 17 and was completed on March 21. The second field period commenced on March 31 and was completed on April 8, 2003. Execution of field measurements is presented in Chapter 4 of this report. All measurement results are presented in Chapter 5, along with a brief discussion of the test results. Measurement data from the tests are reported in Appendices A through D.

The presentation of this report is restricted to the work done and the results obtained, as such. It is neither attempted to put the data into a geological/tectonic context, nor to discuss the implications of the results for future work.

3 Equipment

3.1 The overcoring method

Three-dimensional overcoring rock stress measurements are based on measuring strains when a sample of rock is released from the rock mass and the stresses acting upon it. The in situ stresses can be calculated from the measured strains and with knowledge of the elastic properties of the rock. The complete, three-dimensional, stress tensor is determined from a single measurement, under the assumption of continuous, homogeneous, isotropic and linear-elastic rock behavior /Leeman and Hayes, 1966; Leeman, 1968/.

3.2 Description of field equipment

The *Borre* probe is owned and used by SwedPower AB for stress measurements in deep, water-filled boreholes. The equipment for overcoring rock stress measurements using the *Borre* probe comprises:

- pilot hole drilling equipment for wireline core drilling, including planing tool,
- inspection tool (test probe) with built-in borehole cleaning brush,
- *Borre* probe with built-in data logger,
- set of strain gauges (to be mounted on the *Borre* probe),
- glue (for bonding strain gauges to the borehole wall),
- cell adapter (installation tool),
- biaxial test equipment including load cell, pressure gauge, hydraulic pump and strain indicator, and
- portable computer.

A new pilot hole wireline drilling equipment was recently developed for use with two of the major wireline systems utilized in Sweden – the Hagby WL76 Metric Thinwall Wireline System, and the Atlas Copco CORAC N3/50 System. Both these systems produce a 76 mm overall hole diameter (albeit with slight differences in drill bit diameter for the two systems), whereas the obtained pilot hole diameter is 36 mm using the developed pilot hole equipment. In this project, the Atlas Copco CORAC N3/50 equipment was used for drilling.

The developed wireline pilot hole equipment is fitted to the wireline drill string. Thrusting of the pilot hole drill is controlled through water pressure in the drill string, whereas rotation is transferred through the drill string itself. The unique design of the equipment ensures that the pilot hole is always drilled for a length of 75 cm. The pilot core is recovered through the wireline drill string in the normal fashion for wireline systems. The drilling equipment also includes a planing tool attached to the wireline equipment, which is used to grind the base of the borehole to ensure that it is planar. Overcoring equipment includes a specially manufactured, thinwall, core barrel and coring bit producing a nominal core diameter of 61.7 mm, i.e. equal to that produced by using conventional Craelius T2-76 equipment. This is a requirement for being able to fit samples into the biaxial test cell.

The most vital part of the equipment is the *Borre* probe, which is shown in Figure 3-1. The instrument carries nine electrical resistance strain gauges mounted in three rosettes. Each rosette comprise three strain gauges oriented (i) parallel (axial or longitudinal gauges), (ii) perpendicular (circumferential or tangential gauges), and (iii) at a 45º angle, to the borehole axis, respectively, see Figure 3-2. The strain-gauge rosettes are bonded to three plastic cantilever arms at the lower end of the probe, which is the only part of the instrument that enters into the pilot hole. The arms are located 120º apart with a known orientation to the main body of the instrument. Thus, the nine strain gauges of the *Borre* probe form an array representing seven spatially different directions. All strain gauges are mounted at a depth of 160 mm in the pilot hole.

The strain gauges are connected to a data logger inside the probe. The probe also measures the temperature in the borehole to assess the temperature effects on the readings during the overcoring phase. An extra wire is used, which is wired directly into the wheatstone measuring bridge, thus providing automatic temperature compensation for wire resistance during actual strain recording.

The present version of the logger is termed *Borre III* and has two recording modes – sparse and dense recording. Sparse recording – every 15 minutes – is conducted from the time of activation to a selected start time for dense recording. The sparse recording provides a quality check of glue hardening and possible disturbances prior to overcoring. Dense recording is done in user-specified intervals of between 3 and 60 seconds, from the pre-set start time (set to just before anticipated start of actual overcoring) until the core is recovered and logging terminated. The data logger is programmed through connection to a portable computer before installation of the probe in the borehole. No further connection to the ground surface is required after this programming.

Description of the details of the *Borre* probe and other components of the equipment is presented in /Sjöberg and Klasson, 2003/ and in SKB MD 181.001 (SKB internal controlling document).

Figure 3-1. *The Borre probe.*

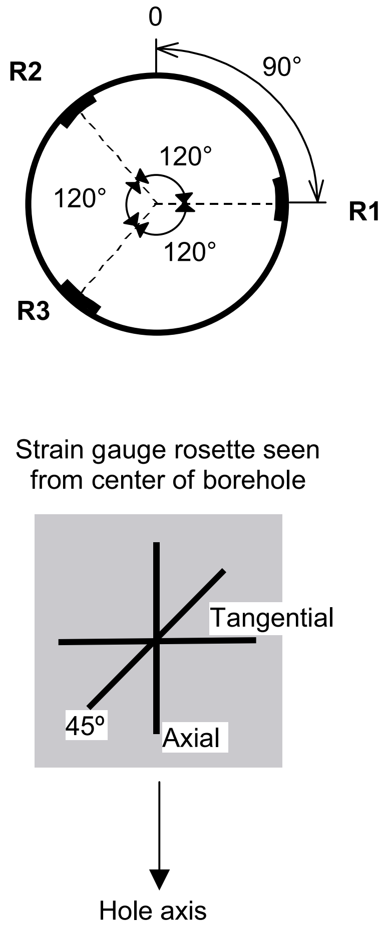


Figure 3-2. *Strain gauge configuration of the Borre probe. Axial strain gauges are denoted L1, L2 and L3 (gauge nos. 1, 4, 7), tangential gauges are denoted T1, T2 and T3 (gauge nos. 2, 5, 8), and inclined gauges are denoted 45-1, 45-2 and 45-3 (gauge nos. 3, 6, 9).*

4 Execution

4.1 Preparations

Preparations before measurement start include (according to the method description):

- functional checks of strain gauges and data logger in the probe,
- calibration of biaxial test equipment,
- glue test on every new glue purchase, and
- functional checks of drilling and installation equipment.

4.2 Execution of measurements

Overcoring stress measurement using the *Borre* probe involves:

1. Pilot hole drilling and examination.
2. Preparation and installation of the *Borre* probe.
3. Overcoring and recovery of the probe.
4. Biaxial testing of the overcore sample.

The procedure for stress measurement using the *Borre* probe is briefly summarized in Figure 4-1. Each stage is succinctly described below.

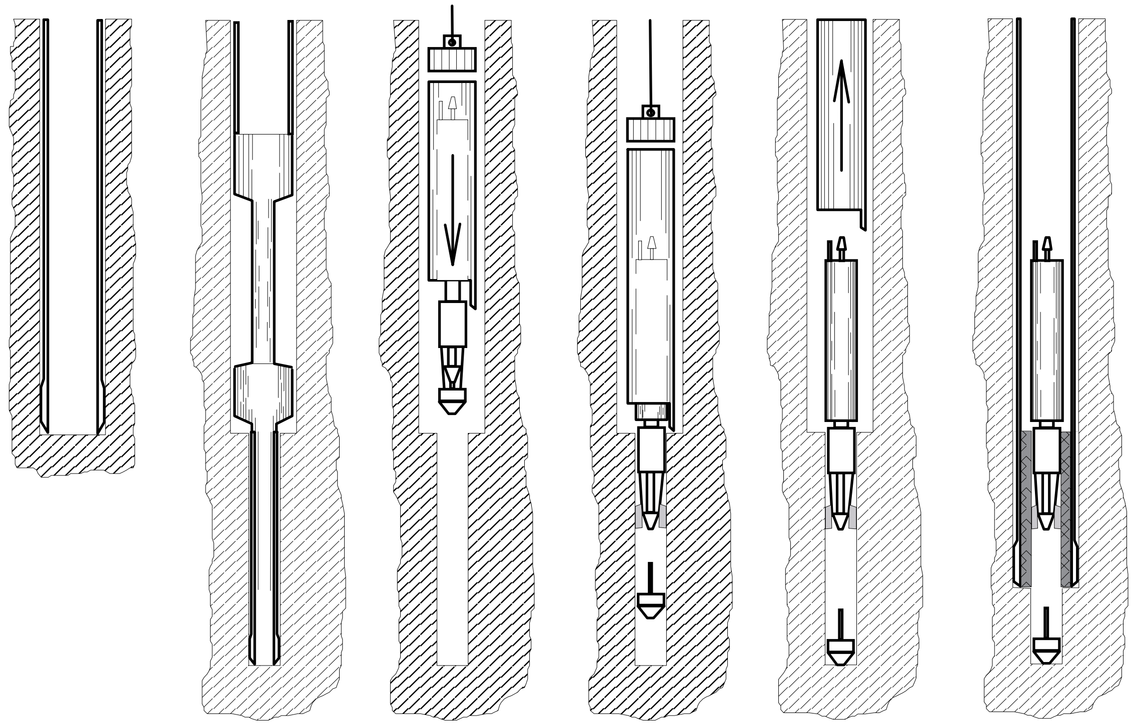


Figure 4-1. *Installation and measurement procedure with the Borre probe:*

1. *Advance 76 mm-diameter main borehole to measurement depth. Grind the hole bottom using the planing tool.*
2. *Drill 36 mm-diameter pilot hole and recover core for appraisal. Flush the borehole to remove drill cuttings.*
3. *Prepare the Borre probe for measurement and apply glue to strain gauges. Insert the probe in installation tool into hole.*
4. *Tip of probe with strain gauges enters the pilot hole. Probe releases from installation tool through a latch, which also fixes the compass, thus recording the installed probe orientation. Gauges bonded to pilot hole wall under pressure from the nose cone.*
5. *Allow glue to harden (usually overnight). Pull out installation tool and retrieve to surface. The probe is bonded in place.*
6. *Overcore the Borre probe and record strain data using the built-in data logger. Break the core after completed overcoring and recover in core barrel to surface.*

4.2.1 Pilot hole drilling

The 76 mm borehole is advanced to the target test depth, specified in advance. Once at this depth, a decision as to whether attempt pilot hole drilling is made. The main criterion for attempting a pilot hole is that the 76 mm drill core shall carry homogeneous rock close to the hole bottom. Discrete fractures may be accepted if the overall fracture frequency and/or orientation of discontinuities indicate that the pilot hole core shall be homogeneous and free of open fractures. If these requirements are not met, the 76 mm borehole is extended another 1–3 m.

Once a decision on pilot hole drilling is taken, drilling and examination of the core is conducted. Using wireline pilot hole drilling, a 0.75 m long pilot hole is drilled and planing of the hole bottom is performed in conjunction with pilot hole drilling. The borehole is flushed and the return water checked for cleanness (free of debris). The retrieved pilot core is inspected to determine whether the hole location is suitable for testing. The criteria on the pilot hole core for the decision to go on with the test are the following:

3–25 cm: (length)	Continuous core, mechanical fractures accepted. No healed fracture that can be extrapolated to cross close to the gauge position at 16 cm during the subsequent overcoring process.
15–17 cm: (length)	No larger mineral crystal than elsewhere on the core shall be present around 16 cm. Pegmatite shall be avoided if possible.

If the pilot hole is judged acceptable for installation, a test probe is lowered down the borehole to check that the pilot hole is open and free from debris.

If these criteria are not met, but conditions appear to better at a slightly deeper location in the pilot hole, planing and grinding of the bottom of the 76 mm hole may be performed to reach a better location for the strain gauges (always installed 16 cm from the bottom of the 76 mm hole). Planing of up to 10 cm can normally be achieved in practice. If planing is not possible within the above limits, a new pilot hole is instead drilled.

4.2.2 Preparation and installation

If the conditions for a suitable pilot hole are satisfied, and the pilot hole is open and free from debris, the *Borre* probe is prepared for installation into the pilot borehole. The prepations include:

- attaching strain gauges to the probe and connecting them to the logger,
- programming of the data logger with start time and sampling interval,
- attaching the probe and the compass to the installation tool, and
- mixing and applying glue to the strain gauges.

The probe is then installed into the pilot hole, as shown in Figure 4-1. The probe is left in the hole for a minimum of 8 hours (usually overnight) for proper bonding of strain gauges to the pilot hole wall.

4.2.3 Overcoring

Overcoring of the probe involves flushing before and after overcoring, to stabilize temperatures. A detailed checklist is followed to control drilling rate, rotational speeds, flushing, etc (according to the method description). The borehole is also left with no on-going activity for 5–10 minutes after completed overcoring but before the core is broken loose from the hole. This procedure ensures that sufficient strain data are recorded to assess temperature effects, possible non-ideal rock behavior, etc. which may affect strain readings and measurement results adversely.

After overcoring, the probe is recovered with the overcore sample inside the core barrel. Strain data are transferred from the data logger to a portable computer. The overcore sample is then mapped with respect to length, concentricity, gauge positions, lithology, structures, microcracks and other possible defects.

4.2.4 Biaxial testing

Biaxial testing of the overcored specimens is conducted to determine the elastic constants of the rock at the measurement position. Testing is carried out on-site as soon as possible after overcoring, using the equipment shown in Figure 4-2. The overcore sample must be at least 24 cm long, without fractures, for biaxial testing to be possible.

The test sequence comprise both loading and unloading in order to study possible inelastic behavior of the rock. The sample is loaded to a maximum radial pressure of 10 MPa, in increments of 1 MPa, and then unloaded in the same manner. The strains induced in the overcore sample are monitored by the strain gauges installed by the *Borre* probe, using the built-in data logger of the probe. After completed test sequence, the *Borre* probe is disconnected from the overcore sample. Supplementary logging of the core is performed to check for potential new fractures. Inner and outer core diameter is also measured.

4.3 Data handling

The raw data includes overcoring strain data files, biaxial strain data files, and completed checklists and QA Report Forms from measurements. Routine data processing of measurement data involves importing the strain data file from overcoring into an in-house developed *Microsoft Excel* application for presenting overcoring strain response. Graphing of the strain response is performed automatically by the software application, and strain differences calculated based on input start- and stop-times for the overcoring process.

Similarly, the strain data file from biaxial testing is imported into the corresponding *Excel* application for presentation of biaxial test response and automatic calculation of elastic constants (Young's modulus and Poisson's ratio).

Calculation of stresses is carried out using another in-house developed *Microsoft Excel* application, with input in the form of strain differences, values on elastic constants, and borehole and recorded strain gauge orientation from the probe installation. The stress calculations are based on the theory presented by /Leeman, 1968/. Calculation is performed for a single measurement, or for several successive measurements on one test level, with automatic calculation of average stresses.

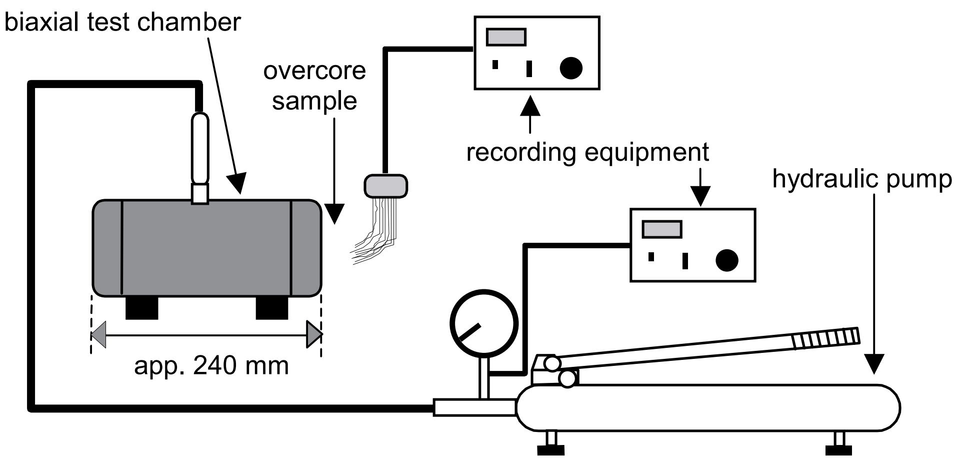


Figure 4-2. *Schematic drawing of the biaxial load cell with pressure generator and recording equipment.*

The primary data reported from the overcoring stress measurements are:

- magnitudes of the three principal stresses,
- orientations of the three principal stresses (bearing and dip),
- magnitudes and orientations of the stresses acting in the horizontal and vertical planes, and
- values on elastic constants from biaxial testing.

4.4 Analyses and interpretation

The *Borre* probe is a "soft" stress cell, which means that the stiffness of the strain gauges is negligible in comparison to the stiffness of the rock. Thus, only the strains induced by overcoring and the elastic constants of the rock, in addition to the orientation of the probe in the borehole (including borehole orientation), are required to determine the complete stress tensor. Calculation of stresses from strain is done under the assumption of continuous, homogeneous, isotropic, and linear-elastic rock behavior /Leeman, 1968/. The stress relief is identical in magnitude to that produced by the in situ stress field but opposite in sign.

The analysis of obtained test data comprise (i) analysis of overcoring strain data, (ii) analysis of biaxial test data, and (iii) stress calculation, using data from the first two tasks. For each task, quality control checks and data assessments are included. Detailed descriptions of each step are given in SKB MD 181.001 (SKB internal controlling document), and are briefly summarized below.

The recorded strain gauge response and temperature are plotted, and the strain differences (after vs. before overcoring) are calculated for each strain gauge for later use as input to the stress calculation.

Recorded strain and pressure data from biaxial testing are plotted and examined. Elastic constants are determined from recorded strain and pressure data from the biaxial testing. For this, the theory for an infinitely long, thick-walled circular cylinder subjected to uniform external pressure is employed /see e.g. KTH, 1990/. Since the Borre probe incorporates three pairs of circumferential and axial strain gauges, three pairs of elastic property-values are obtained from each biaxial test. The aim is to obtain rock parameters that apply to the relaxation experienced by the rock during overcoring. Therefore, the values of E and ν are taken to be secant values, calculated from strain data obtained during unloading of the core specimen. Usually, the secant values between the pressures of 8 and 3 MPa are calculated and averaged for the three strain rosettes. However, elastic constants may be calculated for other pressure intervals, if recorded strain readings are significantly unstable and/or display notable non-linearity for certain pressures.

Calculation of stresses from measured strains is based on the classical theory by /Leeman, 1968/. The details of the formulation can also be found in e.g. /Amadei and Stephansson, 1997/ and are not repeated here. Strain measurements from at least six independent directions are required to determine the stress tensor (which has six components). When all nine gauges of the Borre probe function properly during a measurement, redundant strain data are obtained. A least square regression procedure is used to find the solution best fitting all the strain data, from which the stress tensor components are calculated. Subsequently, the magnitude and orientation vector of each of the three principal stresses are calculated, as well as the stresses acting in the horizontal and vertical planes.

For the case of several measurements on one test level, the average stress state is calculated. This is conducted by first taking the stress tensor components for each of the measurements (defined in a common coordinate system, e.g. the site coordinate system), and averaging each of the stress tensor components. From these average values, the average principal stresses, as well as the average horizontal and vertical stresses, are determined.

5 Results

5.1 Overcoring test data

Measurements were attempted at two measurement levels in borehole KSH02. The first measurement level included overcoring attempts between 250 and 300 meters depth, and the second involved overcoring attempts between 447 and 463 meters depth.

Borehole bearing for the measurement depths in question was 327.63° (clockwise from geographic north) and borehole dip was 86.8° (positive downward from the horizontal). These orientation data were used in the stress calculations described below, together with the measured orientations of the installed *Borre* probe. Magnetic declination was not accounted for in the latter orientation measurements.

Rock conditions for measurement purposes were poor for borehole KSH02. Subvertical fractures were abundant. For the first measurement level, the first pilot hole was drilled at 250.28 meters depth, but this hole was judged unsuitable for installation. Due to poor rock conditions, core drilling was conducted until a suitable 76 mm core was found, after which a second pilot hole was drilled at 280.70 meters depth. This hole was judged acceptable for installation of the probe. Unfortunately, overcoring was unsuccessful as the strain gauge holders were damaged during the overcoring process. This was probably due to problems with the pilot hole wireline equipment resulting in a core stub of approximately 4 cm in the borehole. Hence, no strain data were obtained from this test. At this stage, it was decided (by SKB) to continue measurements at the second measurement level.

For the second measurement level, a total of 13 pilot holes were drilled (between 447 and 463 meters depth), in search of suitable pilot holes. Only two (2) holes were found acceptable for installation. The other pilot holes were rejected due to presence of fractures and/or poor rock. One successful installation (at 449.96 m) was carried out with subsequent overcoring and recording of strain data.

Problems with equipment handling (the protective cone was dropped into the borehole prior to installation) prohibited installation in the other pilot hole (at 451.88 m). The test probe was sent down to clear the hole; however, the probe was stuck at 287 meters depth when being hoisted up, indicating poor rock and borehole instabilities in this portion of the hole. Furthermore, rock and concrete fragments had been observed in several of the drilled pilot holes, probably originating from the upper portion of the borehole. After overcoring and retrieval of the test probe and protective cone, additional pilot hole drilling was conducted. A second test probe was sent down the hole, but was stuck at the same position as previously. At this stage, SKB decided to terminate the measurement campaign.

Hence, only one successful overcoring measurement was conducted in borehole KSH02, as summarized in Table 5-1. The strain gauge response curves registered during the overcoring process are presented in Appendix A. Results from logging of the overcore sample are shown in Appendix D. All original data are stored in the SKB database SICADA, Field Note No. 30.

Table 5-1. General test data from measurements in borehole KSH02, Oskarshamn.

Level no.	Measurement no. (pilot hole no. *)	Hole depth [m]	Comment	Included in evaluation
1	1 (1:1:2)	280.98	Failed	No
2	1 (2:1:3)	449.96	Succesful	Yes

*) numbering scheme: *(measurement level : test no. : pilot hole no.).*

5.2 Biaxial test data

All suitable overcore rock samples were tested in the biaxial cell to determine the elastic properties. For borehole KSH02, only the overcore sample from the successful overcoring test at the second measurement level (449.96 meter depth) could be tested. The gauge response-curves from this test are shown in Appendix B. Calculated values of Young's modulus and Poisson's ratio are shown in Table 5-2. All original data are stored in the SKB database SICADA, Field Note No. 30.

5.3 In situ stress state

The in situ stress state was calculated using (i) the measured strain response (difference between strain gauge readings after and prior to overcoring), (ii) recorded orientation of strain gauge rosettes in the borehole, and (iii) values on elastic constants determined from biaxial testing. The resulting stresses are shown in Appendix C, and in Table 5-3, Table 5-4, and Table 5-5. All orientations are given relative to geographic north. Orientations of the principal stresses are also shown in Figure 5-1. All original data are stored in the SKB database SICADA, Field Note No. 30.

Table 5-2. Results from biaxial testing on overcore samples from borehole KSH02, Oskarshamn.

Level no.	Measurement no. (pilot hole no. *)	Hole depth [m]	Young's modulus, E [GPa]	Poisson's ratio, v
2	1 (2:1:3)	449.96	35.55	0.45

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*

Table 5-3. Magnitudes of principal stress as determined by overcoring in borehole KSH02.

Level no.	Measurement no. (pilot hole no. *)	Hole depth [m]	$\sigma 1$ [MPa]	$\sigma 2$ [MPa]	$\sigma 3$ [MPa]
1	1 (2:1:3)	449.96	8.5	3.4	0.1

*) numbering scheme: (measurement level : test no. : pilot hole no.)

Table 5-4. Orientations of principal stress as determined by overcoring in borehole KSH02.

Level no.	Measurement no. (pilot hole no. *)	Hole depth [m]	σ1 Trend/Plunge [°]	σ2 Trend/Plunge [°]	σ3 Trend/Plunge [°]
1	1 (2:1:3)	449.96	157/28	048/32	279/45

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*

Table 5-5. Horizontal and vertical stress components calculated from measured principal stresses in borehole KSH02.

Level no.	Measurement no. (pilot hole no. *)	Hole depth [m]	σH [MPa]	σh [MPa]	σv [MPa]	Trend σH [°]
1	1 (2:1:3)	449.96	7.1	2.1	2.9	166

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*

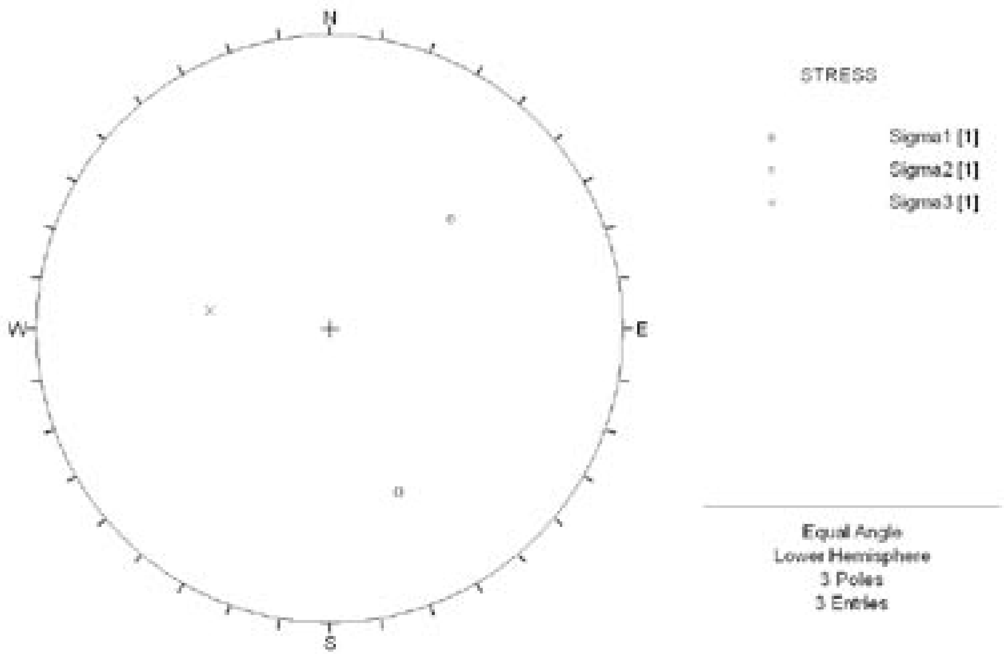


Figure 5-1. *Orientations of measured principal stresses in borehole KSH02 shown in a lower hemisphere projection.*

5.4 Discussion

The rock quality encountered during the overcoring measurements in borehole KSH02 did not permit good stress measurements, due to the high frequency of subvertical fractures. Out of 13 pilot hole attempts, only one successful overcoring measurement was conducted. The results from this single test showed very low stress magnitudes, with the maximum principal stress being 8.5 MPa, and the minor principal stress being close to zero. These stress magnitudes are significantly lower than expected at this depth. For comparison, the measured major principal stress at the nearby Äspö HRL is around 30 MPa at this depth.

The measured vertical stress is only some 25% of the theoretical value corresponding to the overburden pressure at this depth.

The reasons for the obtained low values are not clear. The recorded strain response is fairly typical of overcoring measurements and the test is considered experimentally successful (Appendix A). Strain recording during hardening of the glue showed, however, an almost linear drift in strain gauge readings for most of the gauges, the reasons of which remain uncertain. However, over the time period of the actual overcoring (around 15 minutes), this drift is judged to be of minor importance.

The biaxial testing showed somewhat nonlinear strain response and also some hysteresis for the stress-strain curves (Appendix B). Anisotropy is, however, mild. The obtained value on the Young's modulus is relatively low, whereas the value on Poisson's ratio is unrealistically high. Such high values for Poisson's ratio often occurs if the core is fractured before or during the biaxial testing. However, the obtained overcore sample did not exhibit any visible fractures or microfractures. The overcore did, however, display at least two healed fractures – one that appeared to intersect the entire core at an oblique angle. The effect of these healed fractures (which also occurred in high frequency throughout the borehole) is not known.

In conclusion, the obtained stress data are questionable and the low magnitudes are not easily explained. It appears plausible that lower stresses may prevail in areas of poor rock (with low stiffness), as was the case in borehole KSH02, but not to the extent encountered in the measurement. Since only one measurement was completed, no redundancy was achieved. Consequently, the obtained stress values should be treated with caution.

6 References

Amadei B, Stephansson O, 1997. Rock stress and its measurement. London: Chapman & Hall, 490 pp.

KTH, 1990. Formelsamling i hållfasthetslära. Publikation nr 104, Institutionen för hållfasthetslära, Kungliga Tekniska Högskolan, Stockholm (in Swedish).

Leeman E R, Hayes D I, 1966. A technique for determining the complete state of stress in rock using a single borehole. In *Proceedings of the 1st International Congress on Rock Mechanics (Lisboa, 1966)*, *Vol. 2*, pp. 17–24.

Leeman E R, 1968. The determination of the complete state of stress in rock using a single borehole – laboratory and underground measurements. Int. J. Rock Mech. & Min. Sci. 5, 31–56.

Sjöberg J, Klasson H, 2003. Stress measurements in deep boreholes using the *Borre* (*SSPB*) probe. Int. J. Rock Mech. Min. Sci. 40, No. 7–8, pp. 1205–1233.

Appendix A

Registered strains during overcoring in borehole KSH02

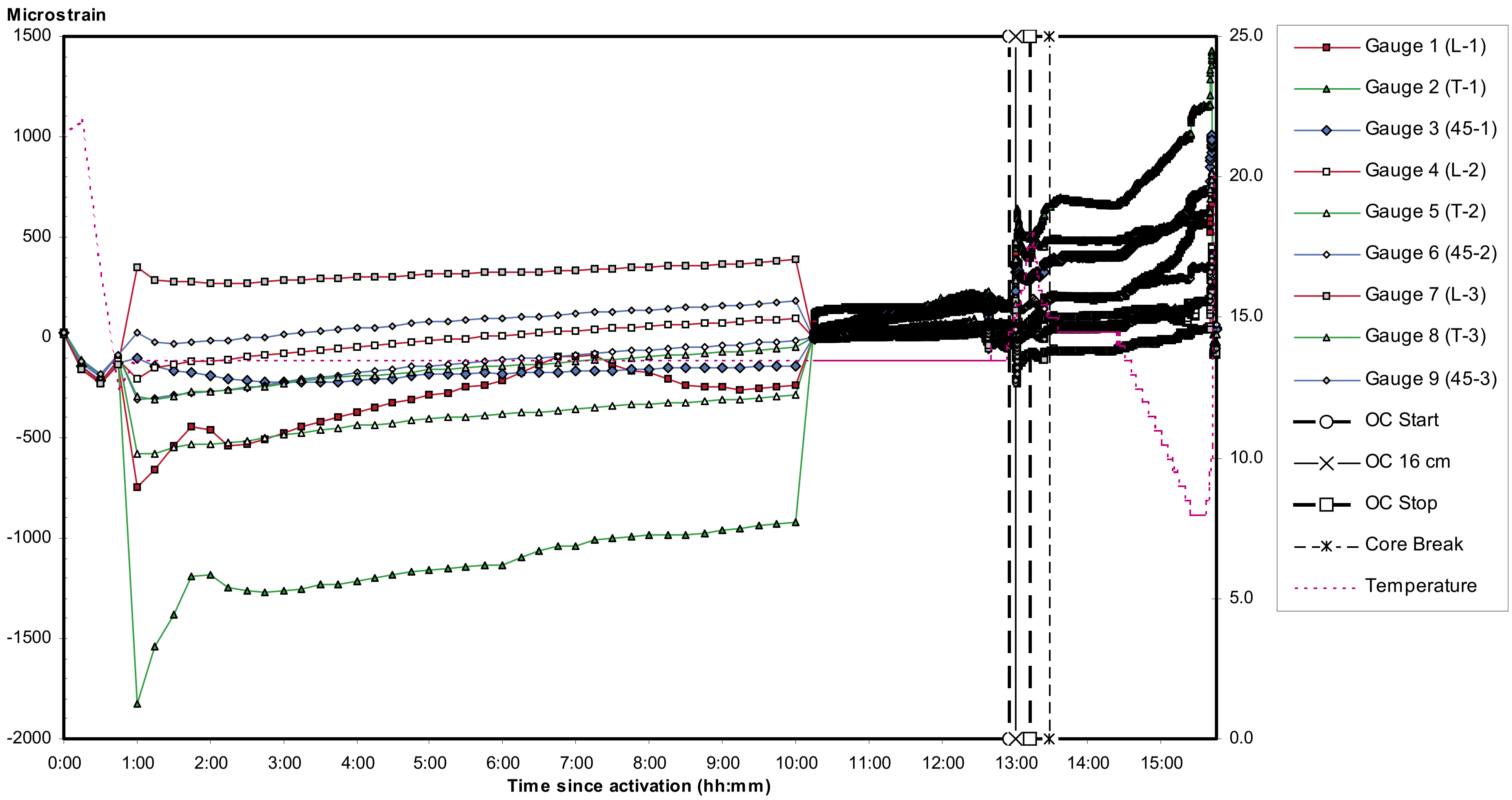


Figure A-1. *Strain response during glue hardening: KSH02, Level 1, Test 1, hole depth 449.96 meter. Time since activation of the data logger.*

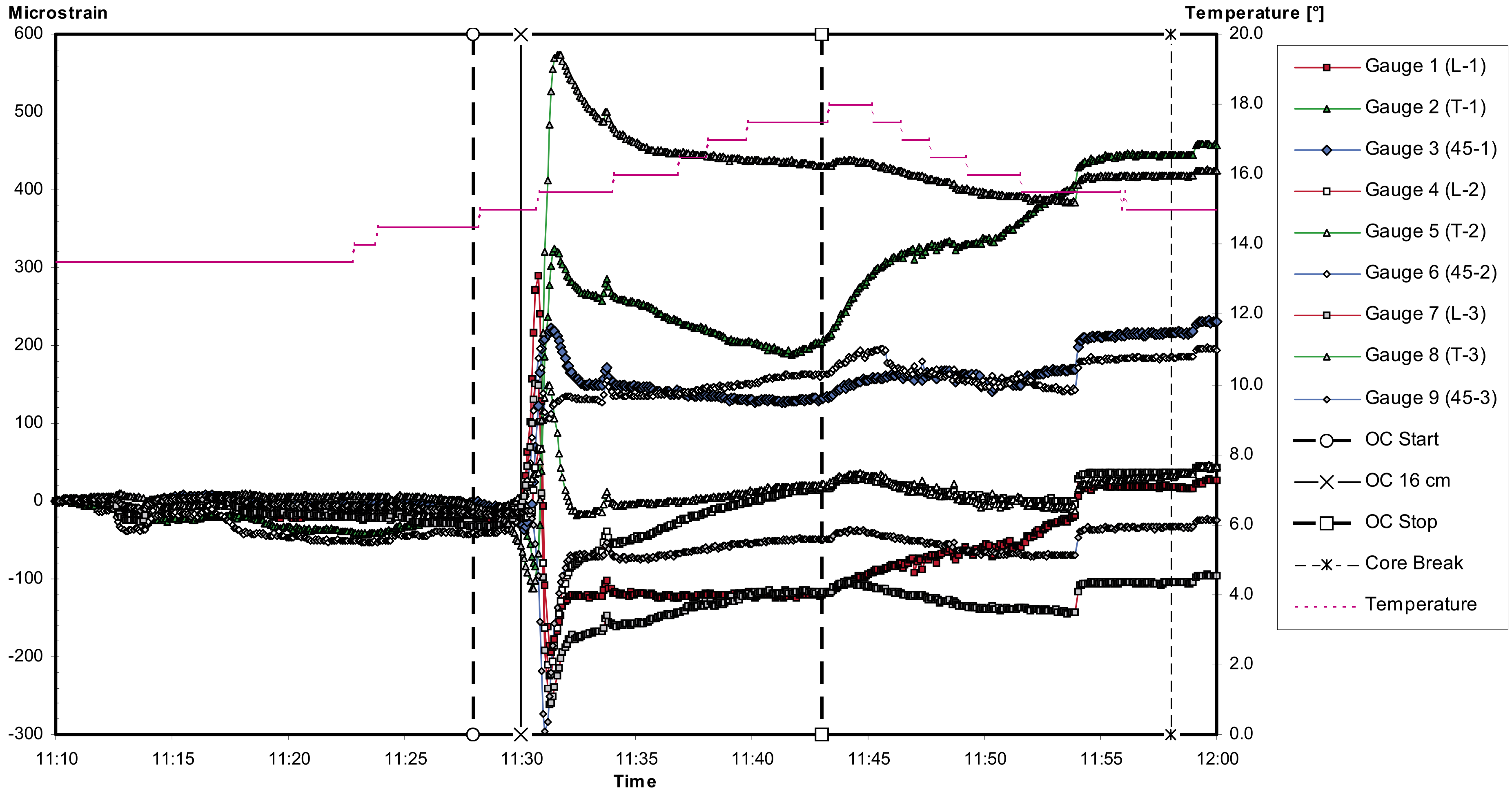


Figure A-2. *Strain response during overcoring: KSH02, Level 2, Test 1 (2:1:3), hole depth 449.96 meter. Actual time.*

Appendix B

Biaxial test data, borehole KSH02

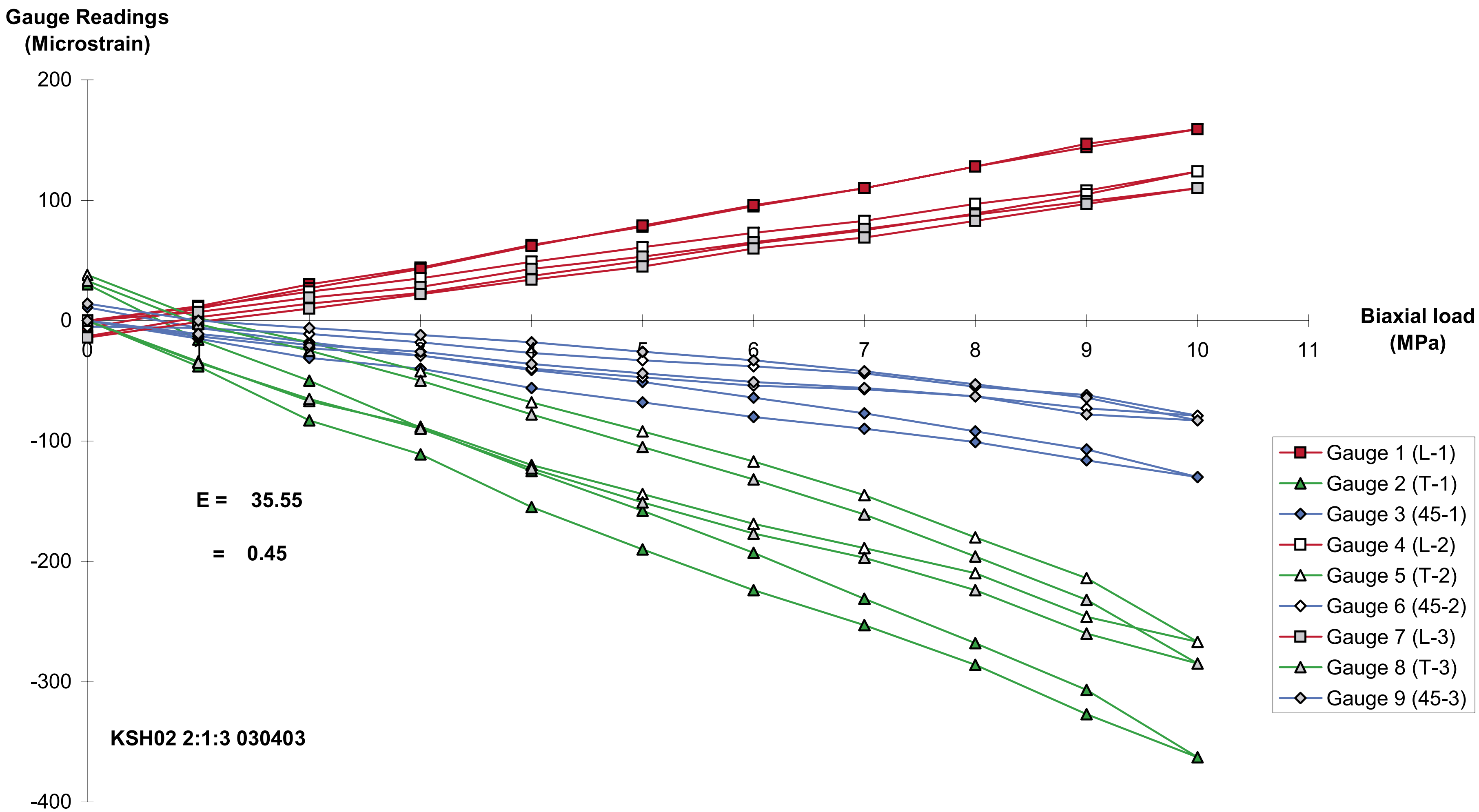


Figure B-1. *KSH02, Level 2, Test 1, Measurement depth: 449.96 m.*

Appendix C

Stress calculation input data and results, borehole KSH02

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description :	Overcoring KSH02, Level 2, Test 1
Date :	2003-04-02
Borehole Dip :	86.8
Borehole Bearing :	327.63
Measurement Depth :	449.96

Input Data

(values for gauge and resistance factor are always 2 and 1, respectively)

Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	Overcoring Time [hh:mm]	Overcoring Time [hh:mm]
63	35.55	0.45	Start=11:28	Stop=11:43

Strains

ε_{L1} (gauge no. 1) [µstrain]	ε_{T1} (gauge no. 2) [µstrain]	ε_{45_1} (gauge no. 3) [µstrain]	ε_{L2} (gauge no. 4) [µstrain]	ε_{T2} (gauge no. 5) [µstrain]	ε_{45_2} (gauge no. 6) [µstrain]	ε_{L3} (gauge no. 7) [µstrain]	ε_{T3} (gauge no. 8) [µstrain]	ε_{45_3} (gauge no. 9) [µstrain]
-102	221	136	30	38	203	-87	437	-34

Principal Stresses

σ_1 [MPa]	σ_1 - Dip [º]	σ_1 - Bearing [º]	σ_2 [MPa]	σ_2 - Dip [º]	σ_2 - Bearing [º]	σ_3 [MPa]	σ_3 - Dip [º]	σ_3 - Bearing [º]
8.5	28.1	157.0	3.4	31.7	47.8	0.1	45.1	279.4

Horizontal and Vertical Stresses

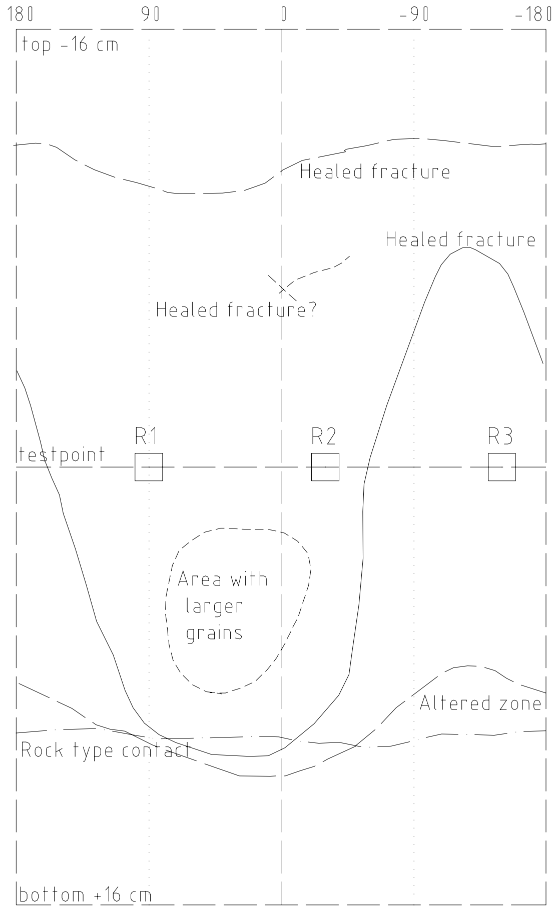
Major stress σ_A [MPa]	σ_A - Bearing [º]	Minor stress σ_B [MPa]	σ_B - Bearing [º]	Vertical stress σ_z [MPa]	Error (sum of squares)	Strains re-calculated?
7.1	165.9	2.1	75.9	2.9	10742.1	No

Appendix D

Logging of overcore samples from borehole KSH02

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KSH02, Level 2, Test 1 (2:1:3), 449.96 m



Angle clockwise in borehole direction
rosette 1 =+90 grader
rosette 2 =-30 grader
rosette 3 =-150 grader

LOGY

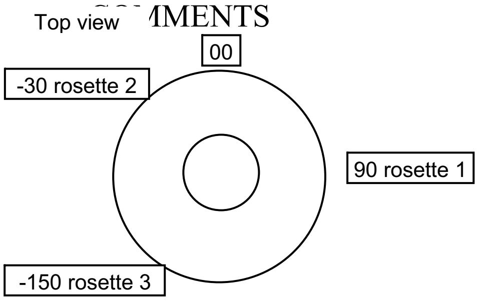
Diorite dominating. Zone with altered rock near bottom of sample. Zone with larger grans found just below gauge positions.

CTURES (JOINTS)

Several healed fractures intersecting the sample.

Mark any observed fractures

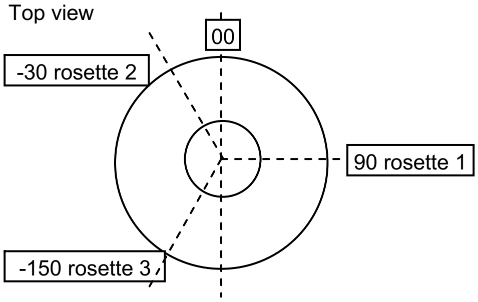
Top view IMENTS



Strain gauge orientation OK.

Control of strain gauge orientation

Top view



Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.