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Oskarshamn site investigation

Overcoring rock stress measurements in borehole KAV04

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April 2004

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Summary

Overcoring stress measurements were conducted in borehole KAV04 at the Oskarshamn site. The equipment used for the measurements was the three-dimensional *Borre* probe. Measurements were attempted at three measurement levels in borehole KAV04. The first measurement level included overcoring attempts between 249 and 273 m borehole length. Measurements at the second level were carried out between 429 and 456 m borehole length. The third level comprised measurements between 635 and 645 m. At Level 2, fracturing was too dense for the application of the overcoring method between 439 and 455 m borehole length. At Level 3, fracturing inhibited measurements from 605 to 635 m borehole length, i.e. directly above the conducted measurements. Furthermore, single fractures were encountered near all measurement locations (between 635 and 645 m).

The stress state in borehole KAV04 is characterized by low to moderate stresses, reaching at the most 20 MPa at 640 m depth below the ground surface. The maximum horizontal stress appeared to be oriented E-W to WNW-ESE, with the exception of measurement Level 2, where both a N-S orientation, as well as an E-W orientation prevailed. For Level 1, the obtained stress magnitudes were close to the achievable precision of the measurement method, whereas for Level 2, the presence of poor, fractured rock, probably affected the measurement, in particular stress orientations.

Transient strain analysis pointed to moderately high tensile stresses developing during the overcoring process. Furthermore, the axial strain response was (with a few exceptions) reasonably close to the theoretically expectable values. These findings indicate low potential for core damage in the conducted measurements, with little influence on the recorded strain response. The inverse solution confirmed the obtained stress state at Levels 2 and 3, with one exception, in which a higher maximum horizontal stresses may be possible. However, in light of the large variations and the difficulty in finding stable values in the inverse solution, the obtained values from the inverse solution cannot be regarded as particularly confident.

The test results should be evaluated further, in particular with respect to geological context, and compared to measurements in nearby areas, such as the Äspö HRL.

Sammanfattning

Bergspänningsmätningar med överborrningsmetoden har genomförts i borrhål KAV04 i Oskarshamn. Vid mätningarna användes Borre-cellen, vilken är en tredimensionell mätmetod. Mätningar utfördes på tre mätnivåer i borrhålet. Den första nivån omfattade överborrningsförsök på mellan 249 och 273 m borrhålslängd. Mätningar på den andra nivån utfördes på mellan 429 och 456 m hållängd, medan den tredje mätnivån omfattade mätningar på mellan 635 och 645 m borrhålslängd. På mätnivå 2 var sprickfrekvensen för hög för att mätmetoden skulle kunna tillämpas mellan 439 och 455 m hållängd. Sprickigt berg förhindrade också mätningar mellan 605 och 635 m borrhålslängd på mätnivå 3, dvs direkt ovanför de utförda, lyckade mätningarna. Enstaka sprickor observerades också i närheten av alla utförda mätningar på denna nivå (mellan 635 och 645 m hållängd).

Spänningsfältet i KAV04 karaktäriseras av låga till måttliga spänningar, med som högst 20 MPa på 640 meters djup under markytan. Den största horisontella spänningen var orienterad i Ö-V till VNV-ÖSÖ, med undantag för mätnivå 2 där uppmätt orientering var såväl N-S som Ö-V. Uppmätta spänningsmagnituder på mätnivå 1 var i närheten av mätmetodens precision. För mätnivå 2 påverkades mätningarna (särskilt erhållna riktningar) troligen av närvaron av dåligt, uppsprucket berg.

Transient töjningsanalys av mätningarna visade att måttliga dragspänningar uppkommer under överborrningsförloppet. Den axiella töjningsresponsen var, med några få undantag, i hyfsad överensstämmelse med teoretiska värden. Sammantaget indikerar detta att risken för skador och mikrosprickor i överborrningskärnan var låg, vilket i sin tur innebär endast liten påverkan på uppmätt töjningsrespons. Tillämpning av inverslösning bekräftade de erhållna spänningarna för mätnivå 2 och 3 (med ett undantag där högre horisontalspänning kan vara möjlig). De stora variationerna och svårigheterna att erhålla stabila värden från inverslösningen gör dock att resultaten från inverslösningen är osäkra.

Resultaten bör utvärderas med avseende på geologiska förhållanden, samt jämföras med mätningar i närliggande områden, t ex Äspö HRL.

Contents

1 Introduction

This document reports the data gained from three-dimensional overcoring rock stress measurements in borehole KAV04, which is one of the activities within the site investigation at Oskarshamn. 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 (at approximately 85° dip) from the ground surface and is of "telescope" type with the upper 100 m 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 m. Overcoring rock stress measurements were planned to be conducted at approximately 250, 450 and 600 m depth, during drilling of the hole, according to the activity plan AP PS 400-03-050 (SKB internal controlling document). All results are stored in the SKB database SICADA, field note no 143.

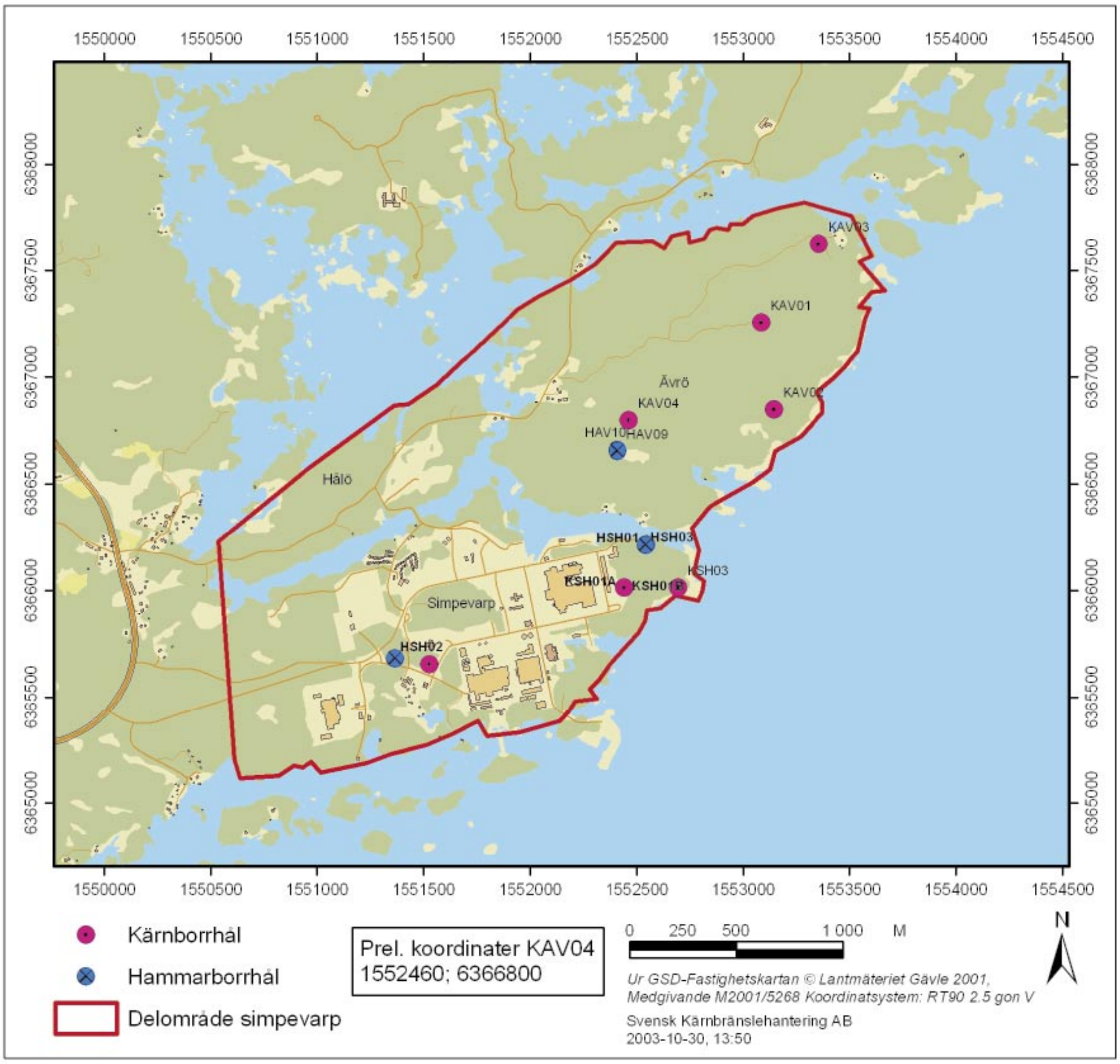


Figure 1-1. *Location of core holes (initial "K") and percussion-drilled (initial "H") holes within the Oskarshamn candidate area, as of October, 2003.*

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, 450, and 600 m borehole length (corresponding to slightly less vertical depth since the borehole is inclined). 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 in three periods during 2004. The first period started January 12 and was completed January 25. The second field period commenced February 5 and was completed February 19. The final and third field campaign begun on February 26 and was concluded March 16.

Execution of field measurements and data analysis is presented in Chapter 4 of this report. In addition to conventional analysis of overcoring data, transient strain analysis was conducted, following the methodology developed by /Hakala et al, 2003/. The objective of this analysis was to aid in: (i) quality control of the overcoring data, (ii) judgment of reliability of single measurements, and (iii) possibly establishing bounds on the measured stresses. Transient strain analysis was only conducted for selected measurements from the two deepest measurement levels (Levels 2 and 3). All measurement results are presented in Chapter 5, along with a brief discussion of the test results. Measurement and analysis data from the tests are reported in Appendices A through G.

All stresses presented in this report are denoted using a geomechanical sign convention with compressive stresses taken as positive. Compressive strains are, however, defined as negative. All stress orientations are given with respect to geographic north (based on borehole orientation measurements), using a right-hand rule notation. Measurement positions are given as the hole length at the gauge position of the measurement probe.

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 behaviour /Leeman and Hayes, 1966; Leeman, 1968/.

3.2 Description of field equipment

The *Borre* probe /Sjöberg and Klasson, 2003/ 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. The latter is a requirement for being able to fit overcored 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 comprises 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 min – 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 further presented in /Sjöberg and Klasson, 2003/ and in SKB MD 181.001 (SKB internal controlling document).

Figure 3-1. *The Borre probe.*

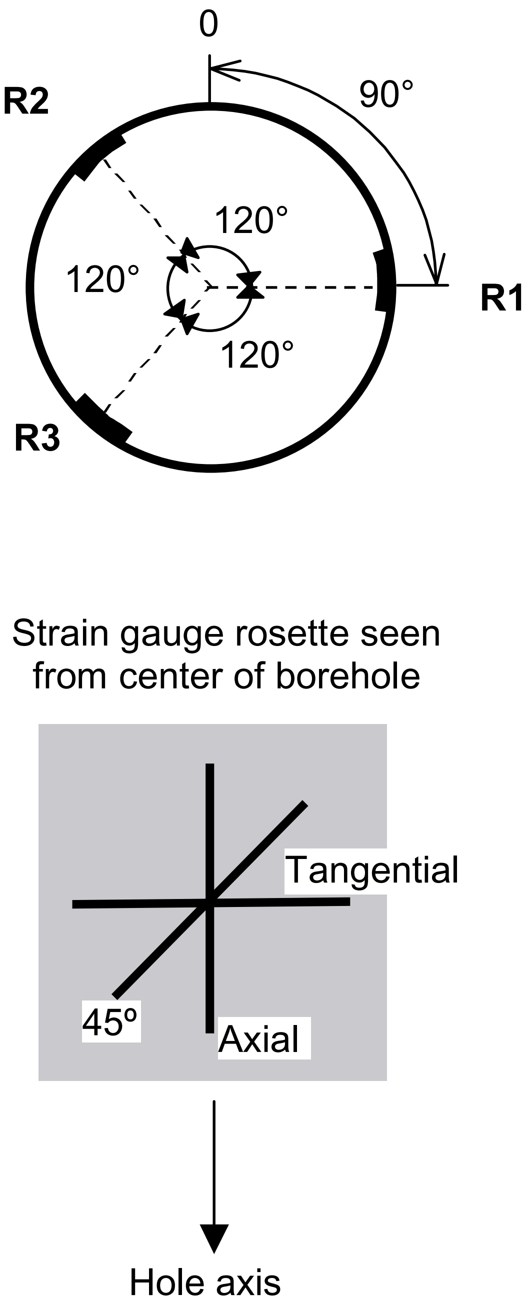


Figure 3-2. Strain gauge configuration of the Borre probe. Axial strain gauges are denoted L1, L2, and L3 (gauge nos 1, 4, 7), tangential gauges are denoted T1, T2, and T3 (gauge nos 2, 5, 8), and inclined gauges are denoted 45-1, 45-2, and 45-3 (gauge nos 3, 6, 9).

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.

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, the bottom of the 76 mm hole is grinded to ensure that it is planar. Using wireline pilot hole drilling, a 0.75 m long pilot hole is drilled. 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 and/or different mineral crystals than elsewhere on the core shall be present around 16 cm. Pegmatite shall be avoided if possible.

- Any direct or indirect information on core damage (core discing, microcracking, etc) on the pilot core surface is an evidence of non-linear and inelastic behaviour, which render the core unacceptable.

As the hollow overcored core is more vulnerable to core damage, there is no reason to proceed with measurement if there is any core damage or any features present as described above.

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.

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.

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 preparations 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 checklist is followed to control drilling rate, rotational speeds, flushing, etc (according to the method description). Coring advance is done at a specified constant rate (normally 3 cm/min). In practice, it is difficult for the drilling contractor to maintain a constant rate throughout the overcoring process; hence, variations are almost always present. The coring advance was registered manually using a watch and markers on the drill string.

The borehole is left with no on-going activity for approximately 15 min 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 behaviour, 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.

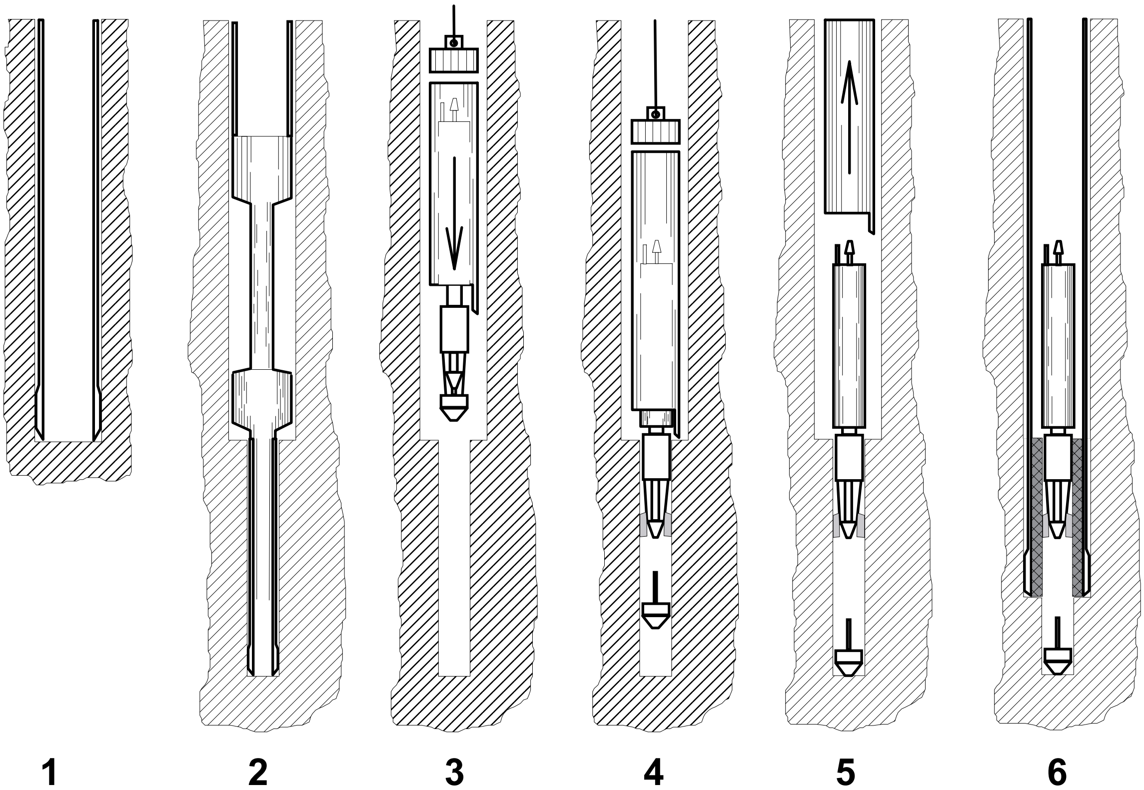


Figure 4-1. *Installation and measurement procedure with the Borre probe:*

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 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 comprises both loading and unloading in order to study possible inelastic behaviour 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.

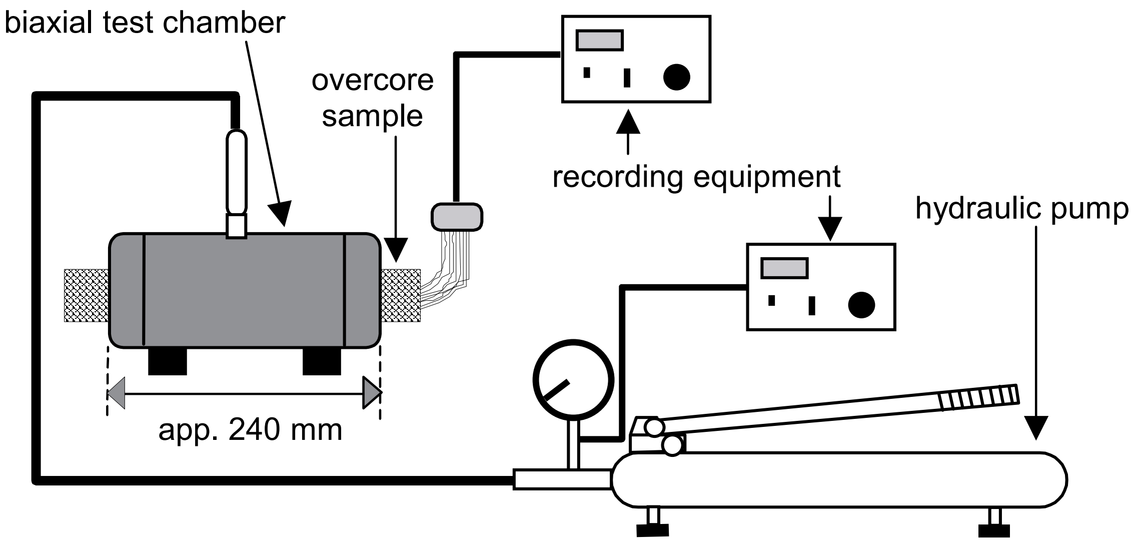


Figure 4-2. *Schematic drawing of the biaxial load cell with pressure generator and recording equipment.*

4.3 Data handling

The raw data include 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 or several test levels, with automatic calculation of average stresses for each level.

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 Data analyses

4.4.1 Classical overcoring analysis and stress calculation

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 behaviour /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 vs recorded time, and the strain differences due to overcoring and stress relief are calculated for each strain gauge for later use as input to the stress calculation. The overcoring strain change is normally determined as the difference between (i) recorded strain after completed overcoring with flushing on, and (ii) recorded strain at the start of overcoring with flushing on. It is important that all conditions, except the overcoring stress relief itself, are as similar as possible for these two instances (e.g. flushing, water pressures, temperatures, etc). Furthermore, the strain values should be stable (little or negligible strain drift) at these instances. In some cases, stable and ideal strain response can be observed during the first portion (typically 20–30 cm) of the overcoring process, whereas significant strain drifts occurs during the rest of the overcoring. In theory, practically all of the strain relief takes place during the first 24 cm of overcoring (with gauge positions at 16 cm), see e.g. /Hakala et al, 2003/. For such cases, strain differences may be determined from stable values of this portion of the strain response curve (corresponding to approximately 20–30 cm drill bit position or more). It should also be noted that small changes in strains (a few μstrains), which may arise from choosing different start- and stop-times for the overcoring, have very small influence on the calculated magnitudes and orientations of the *in situ* stress state.

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 (Young's modulus) and ν (Poisson's ratio) 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. For each test, one tangential or inclined gauge and/or two axial gauges may be rejected or recalculated without impairing the determination of the stress tensor. Recalculation is only performed if evidence of malfunctioning gauges exists, see also /Sjöberg and Klasson, 2003/ and SKB MD 181.001 (SKB internal controlling document). 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.

4.4.2 Transient strain analysis

A methodology for transient strain analysis of overcoring data was presented by /Hakala et al, 2003/). The methodology involves calculating the theoretical strains corresponding to a given stress field (by using pre-calculations from a three-dimensional numerical model). The theoretical strain response is calculated for the entire overcoring process and can thus subsequently be compared to the actual recorded strain response from the overcoring measurement.

The analysis can be used to assess whether the measured strain differences and calculated stresses are compatible. Larger deviations in terms of measured vs calculated (theoretical) strains are indications of imperfect conditions at the time of measurements, e.g. debonding, microcracking, heterogeneities, anisotropy, etc. The analysis cannot, however, be used to detect systematic measurement errors.

Transient strain analysis was carried out using the computer code and methodology developed by /Hakala et al, 2003/. For each test (measurement point), the reported stress state and accompanying field parameters were input to the transient strain analysis program. Transient and final strains were calculated and the final strains compared with the measured final strains. The strain differences (measured vs calculated strains) were evaluated and the maximum difference calculated for each strain gauge as follows:

$$M\_diff_i = \frac{\left|(\varepsilon_i - \varepsilon\_calc_i)\right|}{\varepsilon\_amp_i} \ ,$$

$$\varepsilon\_amp_i = \varepsilon_{i,max} - \varepsilon_{i,min} \ ,$$

where

M_diff_i = maximum strain difference for one of the strain gauges (i=1, 2,..9) (%),

ε_i = measured strain for one of strain gauges (i=1, 2,..9),

ε_calc_i = back-calculated strain from the calculated stress state for one of the strain gauges (i=1, 2,..9),

ε_amp_i = amplitude for the calculated transient strain curve for one of strain gauges (i=1, 2,..9),

$\varepsilon_{i,max}$ = maximum recorded strain value for one of strain gauges (i=1, 2,..9),

$\varepsilon_{i,min}$ = minimum recorded strain value for one of strain gauges (i=1, 2,..9).

In addition, the amount of unexplained strain was calculated using the program. Initially, the strain differences from the measurement are used to calculate stresses, using the least-square regression procedure described in Section 4.4.1. The resulting stresses were then used to back-calculate the corresponding strains for each of the strain gauges of the probe. The amount of unexplained strain was defined as the sum of absolute differences between measured and calculated strains divided by sum of calculated strains, i.e. /Hakala et al, 2003/

$$AUS = \frac{\sum_{i=1}^{9}\left|(\varepsilon_i - \varepsilon\_calc_i)\right|}{\sum_{i=1}^{9}\varepsilon\_calc_i} \ ,$$

where

AUS = amount of unexplained strain (%),

ε_i = measured strain for each of the strain gauges (i=1, 2,..9), and

ε_calc_i = back-calculated strain from the calculated stress state for each of the strain gauges (i=1, 2,..9).

A higher value on *AUS* indicates larger difference between measured and theoretical strain values. This value can thus be used to estimate the heterogeneity, anisotropy, reliability, or successfulness of measurements.

The stress path developing during the overcoring process was also calculated, including the maximum tensile stress acting on the overcore sample. A high value on the tensile stress is an indicator of high possibility of tensile damage of the rock during overcoring. At this stage, strength values are not known for this site. For illustrative purposes, a uniaxial compressive strength of 200 MPa and a uniaxial tensile strength of 20 MPa were assumed to define a failure criterion. It should be noted that only linear-elastic analysis is conducted; hence, very high tensile stresses can develop, which, in reality, would be limited as the strength of the rock is exceeded. The post-peak process and associated stresses and strains can, obviously, not be studied with this computer program.

Finally, the developed code has the capability to solve for the *in situ* state of stress based on the measured transient or final strains (/Hakala et al, 2003/, following the method presented by /Fouial et al, 1998/). This inverse solution enables, in theory, stresses to be determined from the early, pre-overcoring, strain response. The inverse solution is exact if calculated strain values and coring advance are exact. In reality, there are always errors associated with the measurements. /Hakala et al, 2003/ stated that for the inverse solution to be useful, coring advance must be measured with an accuracy of ±1 mm, or better. This is clearly difficult to achieve in practice. During overcoring measurements in borehole KAV04, overcoring was attempted at a constant rate (normally 3 cm/min) for the different measurements. Manual registration of the coring advance was conducted, which often proved that the coring rate varied due to practical constraints (variations in rock type, drill string extension, etc), thus resulting in varying error in the determination of coring advance. Consequently, in most cases, the local maxima and minima of the measured and theoretical strains, respectively, did not match perfectly. For such cases, the measured strain response curves were corrected to match the theoretical strains with respect to position/core advance, thus resulting in an improved inverse solution. The inverse solution was applied to selected measurements in KAV04, as described in the following.

5 Results

5.1 Overview

Measurements were attempted at three measurement levels in borehole KAV04. The first measurement level included overcoring attempts between 249 and 273 m borehole length. Measurements at the second level were carried out between 429 and 456 m borehole length. The third level comprised measurements between 635 and 645 m. It should be noted that zones of fractured rock were encountered both on the second and third measurement levels. At Level 2, fracturing was too dense for the application of the overcoring method between 439 and 455 m borehole length. At Level 3, fracturing inhibited measurements from 605 to 635 m borehole length, i.e. directly above the conducted measurements. Furthermore, single fractures were encountered near all measurement locations (between 635 and 645 m). It can be noted that the measurements at Level 3 were the deepest three-dimensional overcoring measurements ever conducted in a borehole from the ground surface.

A brief summary of conducted measurements is given in Table 5-1. All tests have been numbered as follows: *measurement level : test no : pilot hole no* Thus, e.g. test 1:7:2 denotes measurement level 1, test (or measurement) no 7 at that level, and pilot hole no 2 (to reach an acceptable measurement location for this test). Each test is presented with a rating reflecting successfulness and reliability of that particular measurement. Ratings were assigned per the following criteria:

Rating	Description and criteria
a	**Successful test**
	• Stable strain response prior to, and during, overcoring with minimal strain drift (strain change less than 10 μstrain per 15 min for undisturbed conditions).
	• No fractures and/or core discing observed in the overcore sample (at least 24 cm intact core).
	• Linear and isotropic (20–30% deviation acceptable) strain response during biaxial testing. Minor hysteresis (< 100 μstrain) accepted.
	• Stress calculation possible with classical analysis (Section 4.4.1). Values on elastic constants may be assumed from nearby tests if biaxial test data are lacking, and all other criteria above are satisfied.
b	**Partly successful test**
	• Signs of debonding but fairly stable strain response up until peak value (typically at 24–30 cm drill bit position).
	• Stress calculation possible with classical analysis (Section 4.4.1) but results judged uncertain and/or less reliable.
	• Additional stress determination may be conducted using inverse solution of transient strain analysis (Section 4.4.2).
c	**Failed test**
	• Installation failed or incomplete.
	• Debonding of strain gauges and/or large strain drift.
	• Fractures/joints detected in overcore sample.

Borehole orientations for the measurement depths in question are shown in Table 5-2, as measured after completed drilling of the hole. These orientation data were used in the stress calculations described below, together with the measured orientations of the installed *Borre* probe.

Table 5-1. General test data from measurements in borehole KAV04, Oskarshamn.

Test no (pilot hole no *)	Hole length [m]	Vertical depth [m] **)	Over-coring	Biaxial testing	Transient strain analysis	Rating	Comments
1:1:1	250.12	249.35	No	No	No	*c*	Probe did not release properly from the installation tool (adapter), protective cone was loose, strain gauge tongues bent – possibly due to debris in the pilot hole.
1:2:2	251.51	250.73	Yes	Yes	No	*a*	Successful test. Drill string had to be rotated when fed down the hole resulting in some disturbances prior to overcoring.
1:3:1	252.57	251.79	Yes	Yes, unstable response	No	*c*	Fracture in overcore sample resulted in unstable strain response.
1:4:5	260.82	260.01	Yes	Yes, unstable response	No	*c*	Installation failed; probe not at correct depth in the pilot hole. Reasons for this may be debris in the pilot hole or a countersink at the pilot hole collar. Unstable strain response during overcoring and biaxial testing.
1:5:3	263.75	262.93	No	No	No	*c*	Installation failed; probe not at correct depth in the pilot hole. Reasons for this may be debris in the pilot hole or a countersink at the pilot hole collar. Gauges ceased to function after the adapter was retrieved.
1:6:1	265.15	264.33	Yes	Yes	No	*a*	Successful test. Minor strain drift at the end of overcoring.
1:7:2	272.87	272.02	Yes	Yes	No	*a*	Successful test. Some strain drift during the latter half of the overcoring process.
2:1:1	429.66	428.28	Yes	Yes	No	*a*	Successful test.
2:2:2	431.64	430.25	Yes	Yes, sample failed	No	*c*	Unsuccessful test. Gauge tongues damaged and dislocated probably due to debris in the borehole. Sample also failed during biaxial testing at 8 MPa load (cf Appendix F).
2:3:1	432.76	431.37	No	No	No	*c*	Installation failed as the probe was stuck at 360 m borehole length due a pre-existing fracture at this location.
2:4:1	435.36	433.96	Yes	Yes, partially success-ful	No	*a*	Successful test. Larger temperature increase (5.5°C). Non-linear biaxial test response for rosette no 2.
2:5:2	437.23	435.82	Yes	Yes, partially success-ful	Yes	*b*	Partly successful test. Strain rosette no 2 debonded. Non-linear biaxial test response for rosette nos 1 and 2.
2:6:1	438.66	437.24	Yes	Yes, partially success-ful	No	*a*	Successful test. Minor strain drift during overcoring (latter half). Some non-linearity and hysteresis observed in biaxial testing.
2:7:4	455.25	453.76	Yes	Yes	No	*a*	Successful test. Larger temperature increase (4.5°C) leading to larger strain drift.

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

**) vertical depth (below ground surface) interpolated from borehole orientation measurements (every three metre)

Table 5-1. (continued.)

Test no (pilot hole no *)	Hole length [m]	Vertical depth [m] **)	Over-coring	Biaxial testing	Transient strain analysis	Rating	Comments
2:8:1	456.35	454.86	Yes	Yes	No	*a*	Successful test. Some strain drift during the latter half of the overcoring process.
3:1:5	635.03	632.70	Yes	Yes, partially success-ful	Yes	*a*	Successful test, but signs of debonding after core break. Rosette nos 2 and 3 displayed non-linear and scattered strain response in biaxial testing.
3:2:4	639.57	637.22	Yes	Yes, partially success-ful	Yes	*b*	Debonding of several strain gauges (most notably rosette no 2) due to large amount of drill cuttings in the pilot hole (probably due to extensive grinding to reach an acceptable position).
3:3:1	644.71	642.33	Yes	Yes	Yes	*a*	Successful test but large strain drift after having passed the strain gauges. Good bonding and stable strain response during biaxial testing (only gauge no 9 malfunctioning).
3:4:1	645.92	643.54	Yes	Yes, partially success-ful	Yes	*a*	Successful test but large strain drift having passed the strain gauges. Non-linear response (debonding) of rosette no 3 during biaxial testing.

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

**) vertical depth (below ground surface) interpolated from borehole orientation measurements (every three metre)

Table 5-2. Borehole orientation for overcoring measurement points in borehole KAV04. Orientations taken from nearest (3 m) measured section.

Level no	Test no (pilot hole no *)	Hole length [m]	Borehole bearing [°] **)	Borehole dip [°] ***)
1	1:1:1	250.12	74.3	85.5
1	1:2:2	251.51	74.6	85.5
1	1:3:1	252.57	74.6	85.5
1	1:4:5	260.82	74.8	85.5
1	1:5:3	263.75	75.0	85.5
1	1:6:1	265.15	75.0	85.5
1	1:7:2	272.87	76.1	85.4
2	2:1:1	429.66	85.7	84.8
2	2:2:2	431.64	85.6	84.9
2	2:3:1	432.76	85.6	84.9
2	2:4:1	435.36	85.4	84.9
2	2:5:2	437.23	85.8	84.9
2	2:6:1	438.66	85.8	84.9
2	2:7:4	455.25	88.4	84.7
2	2:8:1	456.35	88.4	84.7
3	3:1:5	635.03	100.5	84.3
3	3:2:4	639.57	100.7	84.4
3	3:3:1	644.71	100.5	84.4
2	3:4:1	645.92	100.5	84.4

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

**) clockwise from geographic north

***) positive downward from the horizontal

5.2 Overcoring test data

Results from all tests with rating *a* and *b* in Table 5-1 are presented in the following and in Appendices A through G. Key measurement data (recorded times for borehole activities) are presented in Appendix A. Furthermore, core logs and photos are presented in Appendices F and G.

The strain response for each test is shown in Appendix B. Each test is presented with two plots showing (i) the complete strain record (from activation of probe to core recovery), and (ii) the strain response from overcoring start to overcoring stop. The latter was used to define strain differences for later input to stress calculation. The times for which the strain differences have been determined ("OC Start" and "OC Stop") are shown in the Figures, as well as in Appendix A.

In the following, a short description is presented for each of the measurement attempts at the three levels. All original data are stored in the SKB database SICADA, field note no 143.

5.2.1 Measurement level 1

For the first measurement level in borehole KAV04, a total of 7 installation attempts were made. Three successful tests were obtained (test nos 1:2:2, 1:6:1, and 1:7:2). Installation failed for tests 1:1:1, 1:4:5 and 1:5:3. For test 1:3:1, the probe was installed correctly, but a fracture in the overcore sample (not detected in the pilot core, cf Appendix F) resulted in unstable strain response, rendering this test unsuccessful.

The strain responses for the successful tests were stable during overcoring, and with moderate temperature increase (between 2 and 3.5°C). Somewhat larger strain drift was observed after the core break and during core retrieval (hoisting of the drill string). For test 1:2:2 the drill string had to be rotated when being fed down the hole to ream the borehole to its nominal diameter (from surface to the measurement level), which have some impact on the pre-overcoring strains.

The overcoring rate for test nos 1:6:1 and 1:7:2 varied somewhat and was distinctly higher after having passed the gauge position at 16 cm (cf Appendix A), despite efforts by the drilling contractor at keeping the overcoring rate constant for the first 30 cm of overcoring. This change does not, however, appear to have affected the strain response in any significant manner. For test no 1:7:2, some of the gauges, most notably gauge no 6, reacted strongly after approximately 50 cm of overcoring. This may be due to a sudden and unpredicted change in overcoring rate at this stage, but the significance of this event is judged to be small and was not accounted for in the analysis and stress calculation. For both these tests, strain differences were determined for stable peak values after 30 cm drill bit position or more (but not at completed overcoring due to minor strain drift during the latter half of the overcoring process) per the criteria specified in Section 4.4.1.

5.2.2 Measurement level 2

For the second measurement level, a total of 8 installation attempts were made. Installation failed in two cases, due to debris in the borehole. Of the remaining tests, five successful measurements were obtained (test nos 2:1:1, 2:4:1, 2:6:1, 2:7:4, and 2:8:1). Strain response for test no 2:1:1 was very stable, even after core break and during core retrieval. For the other tests, fairly stable strain response was recorded. Test no 2:5:2 was only partly successful as one strain gauge rosette debonded during overcoring. For several tests, e.g. 2:7:4, the drill string had to be rotated during the last few meters to ream the borehole to its nominal diameter. This may have caused some disturbance on recorded strains before overcoring start.

A significantly larger temperature increase was noted for test nos 2:4:1 and 2:7:4 (4.5–5.5°C) compared to all other tests in which the temperature only increased 2–3°C. Since the drilling procedure was identical, the reason for this larger temperature increase may be that harder, more abrasive rock was encountered at these locations. Thus, strain differences were determined from stable strain values prior to the maximum temperature reached for these two tests (cf Appendices A and B).

For test no 2:6:1 some strain drift was observed during the latter half of the overcoring process. Strain differences were determined from stable, near-peak, values corresponding to approximately 22 cm drill bit position. Strain drift was also observed for test 2:8:1, but with stabilizing values near the end of overcoring, which consequently were used for calculating strain differences.

5.2.3 Measurement level 3

A total of four installations were made. Three were considered successful, whereas one (test 3:2:4) was partly unsuccessful due to large amount of drill cuttings in the pilot hole, resulting in poor bonding of the strain gauges. This was, in turn, caused by more extensive planing and grinding (than usual) to find an acceptable measurement location in the fractured rock. The large depths at which these measurements were taken made cleaning of the hole (through flushing) more difficult. It should be noted that fracturing was quite extensive throughout Level 3, making it difficult to obtain good measurement locations per the criteria specified in Section 4.2.1.

Borehole temperatures were higher at these depths – approximately 16°C initial temperature and increasing to around 21°C during overcoring. Depth correlations (overcoring advance) are also more uncertain for this level, as the exact position of the drill bit is more difficult to determine for the drilling contractor, due to e.g. larger drill string extension at these depths.

For the three successful tests, bonding of the strain gauges was judged good through visual inspection and hands-on testing. However, the rock appeared to contain more mica minerals than at the upper measurement levels, which may have impacted on the rock-glue interface. Test 3:1:5 exhibited the most stable strain response of the three successful tests. Strain differences were determined for stable post-overcoring values at approximately 45 cm drill bit position, but different positions could have been chosen without impairing the results.

For test nos 3:3:1 and 3:4:1, significant strain drift was observed during the latter portion of the overcoring process. The decrease in strain could be correlated to the increase in borehole temperature, and with decreasing temperatures, strains increased back to stable values (cf Figure B24 and Figure B27). The strain changes with temperature were, however, much larger than what is normally seen (approximately 100 μstrain per °C compared to 10 μstrain per °C in normal cases). The reason for this is not known. The strain response during the first 20–30 cm of overcoring – during which practically all of the strain relief takes place – was stable for these tests, implying that they could be used for stress calculation. Strain differences were thus determined for this portion of the strain response curve (cf Appendices A and B). These tests were, however, further analysed using transient strain analysis as presented in Section 5.5 below.

5.3 Biaxial test data

All suitable overcore rock samples were tested in the biaxial cell to determine the elastic properties. For Level 1, three successful tests were conducted. The strain response for test no 1:7:2 showed significant hysteresis for several strain gauges, but the resulting values on the elastic constants were similar for all three strain rosettes and were thus used in the following. Common for all tests was the high values on Poisson's ratio, which often is a sign of microcracking of the sample. No observable microcracks were, however, found during logging of the samples (cf Appendix F).

Tests at Level 2 exhibited, in general, good strain response during biaxial testing. However, for test nos 2:4:1, 2:5:2, and 2:6:1, one or several strain rosettes had to be excluded from the calculation of elastic constants due to highly non-linear behaviour. At least for test 2:5:2, this was caused by debonding of the strain rosette. For test no 2:6:1, large hysteresis and anisotropic behaviour was observed even for the functioning gauges, indicating non-ideal behaviour of the rock sample. However, linearity was fairly good in the 8 to 3 MPa pressure range and obtained values on E and ν were realistic.

Biaxial testing of samples from Level 3 resulted in fairly stable strain response; however, several strain gauges had to be excluded from the evaluation, due to non-linearity. The remaining gauges resulted in reasonable values on the elastic constants, although Poisson's ratio was notably high for all tests.

The results from the successful biaxial tests are presented in Table 5-3. The gauge response-curves from these tests are shown in Appendix C. All original data are stored in the SKB database SICADA, field note no 143.

Table 5-3. Results from biaxial testing on overcore samples from borehole KAV04.

Level no	Measurement no (pilot hole no *)	Hole length [m]	Young's modulus, E [GPa]	Poisson's ratio, ν
1	1:2:2	251.51	72.4	0.40
1	1:6:1	265.15	83.6	0.36
1	1:7:2	272.87	82.5	0.42
2	2:1:1	429.66	55.6	0.23
2	2:4:1	435.36	77.9	0.26
2	2:5:2	437.23	51.9	0.25
2	2:6:1	438.66	73.2	0.23
2	2:7:4	455.25	75.4	0.37
2	2:8:1	456.35	82.1	0.44
3	3:1:5	635.03	63.6	0.37
3	3:2:4	639.57	85.0	0.43
3	3:3:1	644.71	78.2	0.37
3	3:4:1	645.92	80.9	0.44

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

5.4 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. Strain differences were determined from stable strain values before overcoring vs stable peak values (corresponding to approximately 20–30 cm drill bit position or more), as described above (cf Appendices A and B).

For Levels 1 and 3, average stresses were calculated from all successful (rating *a*) measurements. Stress averaging was difficult for Level 2 due to large variation in the obtained stress states from each measurement point. Also, fractured rock was encountered between the locations of test nos 2:4:1 (431.64 m) and 2:5:2 (437.23 m), as well as between test nos 2:6:1 (438.66 m) and 2:7:4 (455.25 m). Based on this and the deduced stresses from each test, three groups of different stress states may be inferred, as follows:

A. Test nos 2:1:1 and 2:4:1 (429.66 to 431.64 m borehole length).

B. Test nos 2:5:2 and 2:6:1 (437.23 to 438.66 m borehole length).

C. Test nos 2:7:4 and 2:8:1 (455.25 to 456.35 m borehole length).

The first and the third groups represent the experimentally most successful tests, whereas the tests in the second group (especially 2:5:2) are less reliable. Average values were calculated for each of these groups. Test no 2:5:2 was only partly successful; however, by recalculating the debonded axial gauge (setting it equal to the other two axial gauges), a reasonable stress estimate was obtained with fairly small error value. Thus, it is possible that the strains that would have been recorded by the debonded strain rosette were so small that the error by neglecting these is small. This test is further analysed in Section 5:5.1.

The resulting stresses for each test, as well as the averages for each Level are shown in Appendix D, and in Table 5-4, Table 5-5, and Table 5-6. All orientations are given relative to geographic north. Orientations of the principal stresses are also shown in Figure 5-1 through Figure 5-5, for Levels 1 through 3, respectively. All original data are stored in the SKB database SICADA, field note no 143.

Table 5-4. Magnitudes of principal stress as determined by overcoring in borehole KAV04.

Level no	Measurement no (pilot hole no *)	Hole length [m]	σ_1 [MPa]	σ_2 [MPa]	σ_3 [MPa]
1	1:2:2	251.51	4.5	3.0	0.7
1	1:6:1	265.15	4.5	0.9	–0.3
1	1:7:2	272.87	10.7	5.0	3.2
1	**Average**	**–**	**5.2**	**3.6**	**2.0**
2	2:1:1	429.66	14.0	11.2	6.1
2	2:4:1	435.36	18.3	7.8	2.3
2:A	**Average**	**–**	**15.8**	**9.4**	**4.6**
2	2:5:2	437.23	17.1	8.6	3.9
2	2:6:1	438.66	20.1	8.9	6.7
2:B	**Average**	**–**	**14.5**	**11.9**	**6.2**
2	2:7:4	455.25	9.4	3.6	1.5
2	2:8:1	456.35	11.6	8.3	7.0
2:C	**Average**	**–**	**10.3**	**6.1**	**4.3**
3	3:1:5	635.03	28.1	10.2	5.2
*3 **)*	*3:2:4 **)*	*639.57*	*22.9*	*13.7*	*4.0*
3	3:3:1	644.71	21.8	18.0	9.4
3	3:4:1	645.92	20.1	12.6	2.7
3	**Average**	**–**	**18.1**	**15.7**	**9.0**

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

**) not included in calculation of average stress for Level 3

Table 5-5. Orientations of principal stress as determined by overcoring in borehole KAV04.

Level no	Measurement no (pilot hole no *)	Hole length [m]	σ_1 Trend/Plunge [°]	σ_2 Trend/Plunge [°]	σ_3 Trend/Plunge [°]
1	1:2:2	251.51	144/27	307/62	050/07
1	1:6:1	265.15	113/00	204/43	023/47
1	1:7:2	272.87	255/37	056/51	158/09
1	**Average**	**–**	**275/28**	**151/47**	**023/30**
2	2:1:1	429.66	352/03	257/57	084/32
2	2:4:1	435.36	333/25	234/18	112/58
2:A	**Average**	**–**	**338/22**	**232/35**	**093/47**
2	2:5:2	437.23	294/46	072/35	179/22
2	2:6:1	438.66	070/43	163/03	256/47
2:B	**Average**	**–**	**058/53**	**287/26**	**184/24**
2	2:7:4	455.25	185/13	068/63	280/23
2	2:8:1	456.35	178/38	056/35	299/33
2:C	**Average**	**–**	**183/22**	**058/55**	**284/26**
3	3:1:5	635.03	067/55	166/06	260/35
*3 **)*	*3:2:4 **)*	*639.57*	*348/77*	*258/00*	*168/13*
3	3:3:1	644.71	289/30	145/54	029/17
3	3:4:1	645.92	304/41	155/44	049/16
3	**Average**	**–**	**068/82**	**305/05**	**215/07**

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

**) not included in calculation of average stress for Level 3

Table 5-6. Horizontal and vertical stress components calculated from measured principal stresses in borehole KAV04.

Level no	Measurement no (pilot hole no *)	Hole length [m]	σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
1	1:2:2	251.51	4.2	0.7	3.3	142
1	1:6:1	265.15	4.5	0.3	0.3	113
1	1:7:2	272.87	8.6	3.3	7.0	072
1	**Average**	**–**	**4.8**	**2.4**	**3.5**	**104**
2	2:1:1	429.66	13.9	7.6	9.8	173
2	2:4:1	435.36	15.6	7.1	5.7	158
2:A	**Average**	**–**	**14.7**	**7.5**	**7.7**	**165**
2	2:5:2	437.23	12.3	4.9	12.3	102
2	2:6:1	438.66	13.9	8.9	12.9	069
2:B	**Average**	**–**	**12.6**	**7.4**	**12.6**	**089**
2	2:7:4	455.25	9.1	1.8	3.5	006
2	2:8:1	456.35	10.2	7.6	9.1	007
2:C	**Average**	**–**	**9.6**	**4.7**	**6.3**	**006**
3	3:1:5	635.03	13.2	10.2	20.5	051
*3 **)*	*3:2:4 **)*	*639.57*	*13.7*	*5.0*	*22.0*	*078*
3	3:3:1	644.71	20.8	10.2	18.2	117
3	3:4:1	645.92	16.6	3.6	15.1	135
3	**Average**	**–**	**15.7**	**9.1**	**17.9**	**125**

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

**) not included in calculation of average stress for Level 3

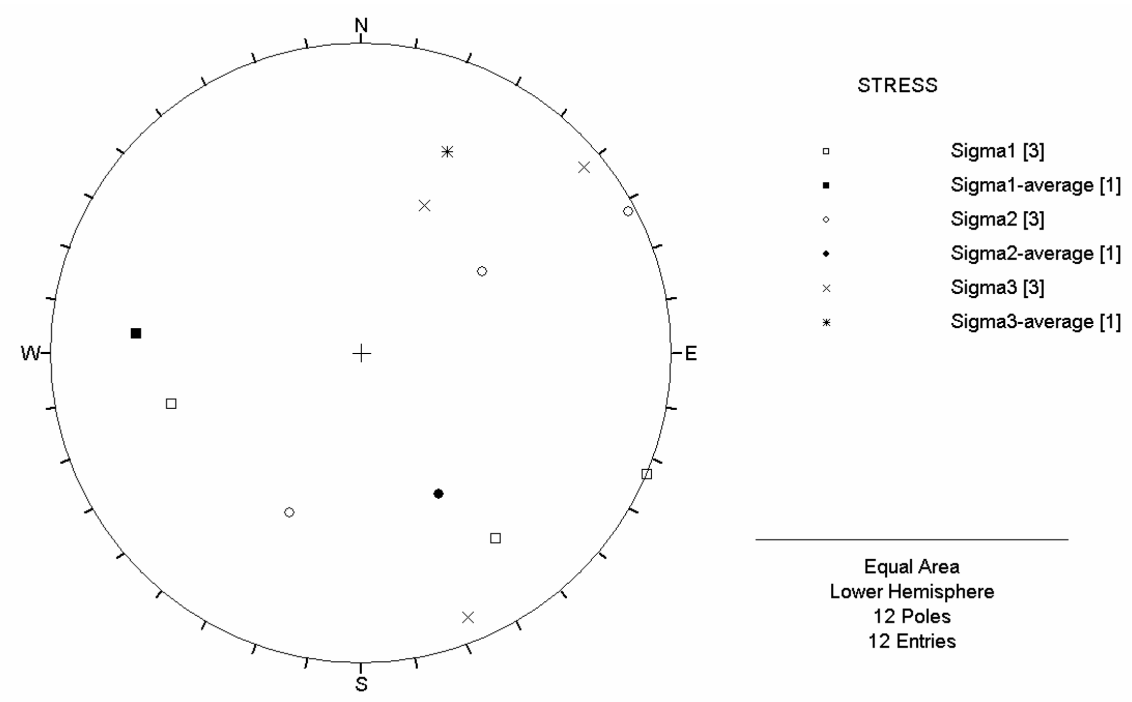


***Figure 5-1.** Orientations of measured principal stresses in borehole KAV04, Level 1, shown in a lower hemisphere projection (test nos 1:2:2, 1:6:1, and 1:7:2).*

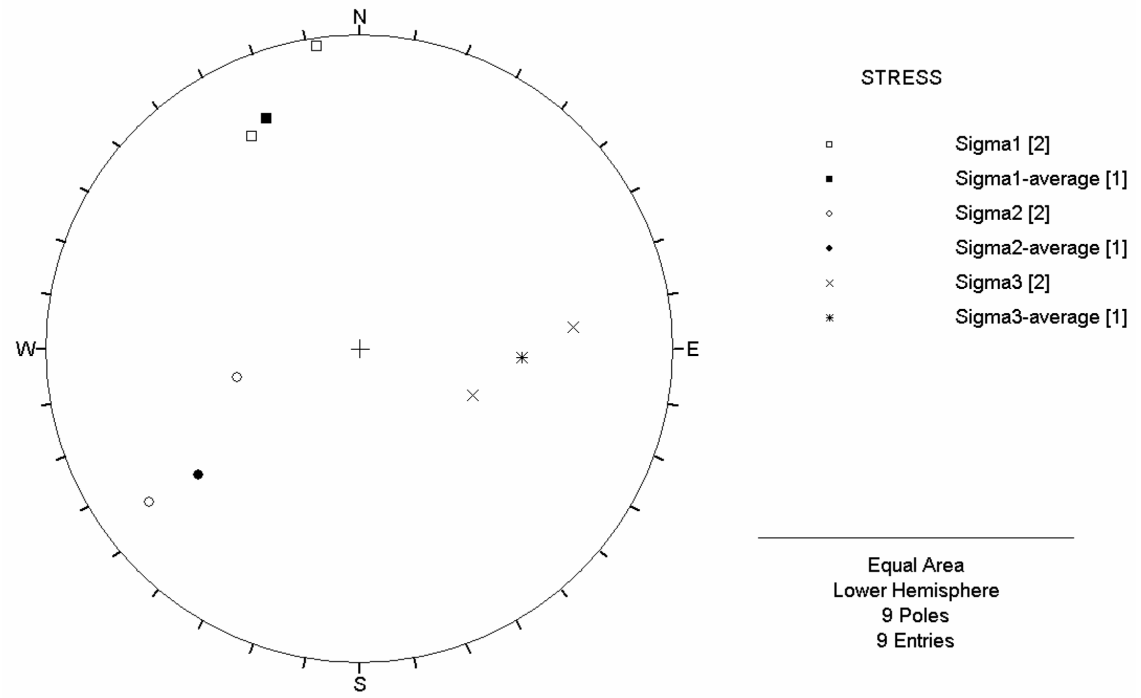


Figure 5-2. *Orientations of measured principal stresses in borehole KAV04, Level 2:A, shown in a lower hemisphere projection (test nos 2:1:1 and 2:4:1).*

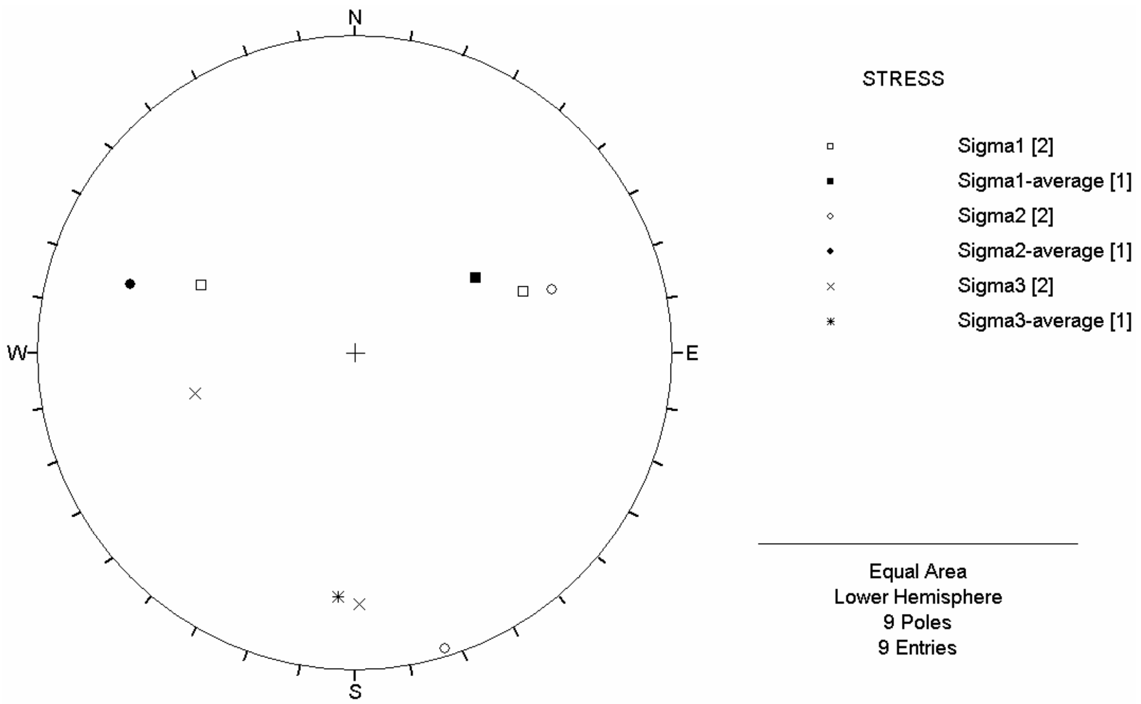


Figure 5-3. *Orientations of measured principal stresses in borehole KAV04, Level 2:B, shown in a lower hemisphere projection (test nos 2:5:2 and 2:6:1).*

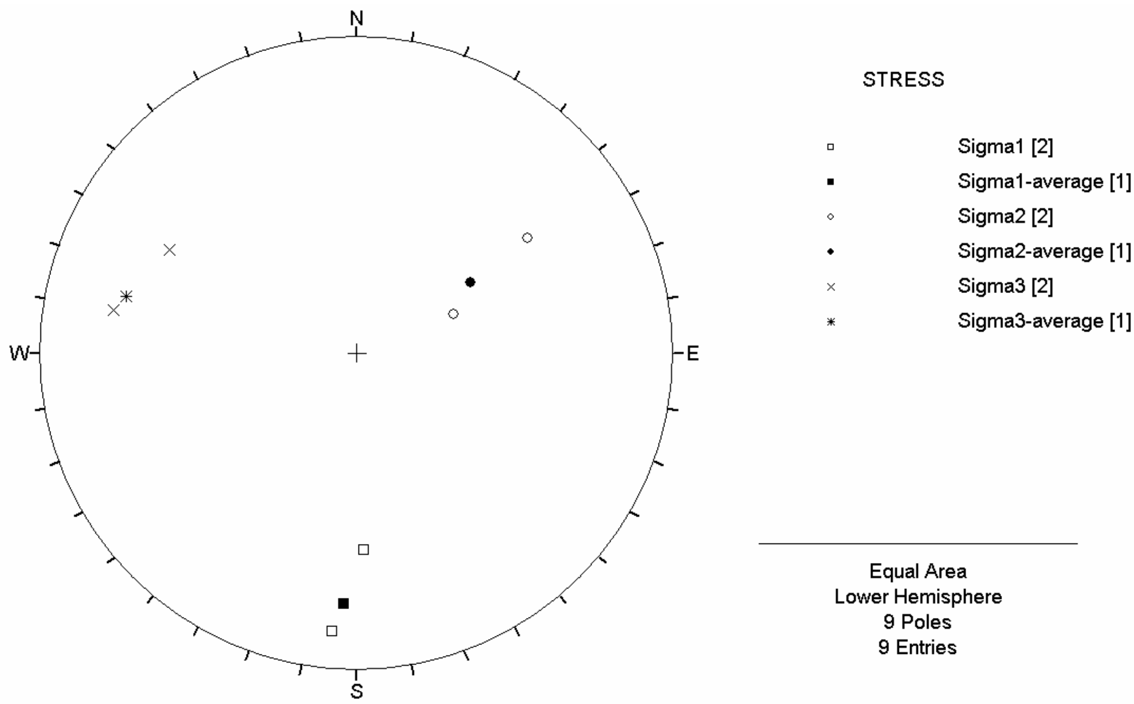


Figure 5-4. *Orientations of measured principal stresses in borehole KAV04, Level 2:C, shown in a lower hemisphere projection (test nos 2:7:4 and 2:8:1).*

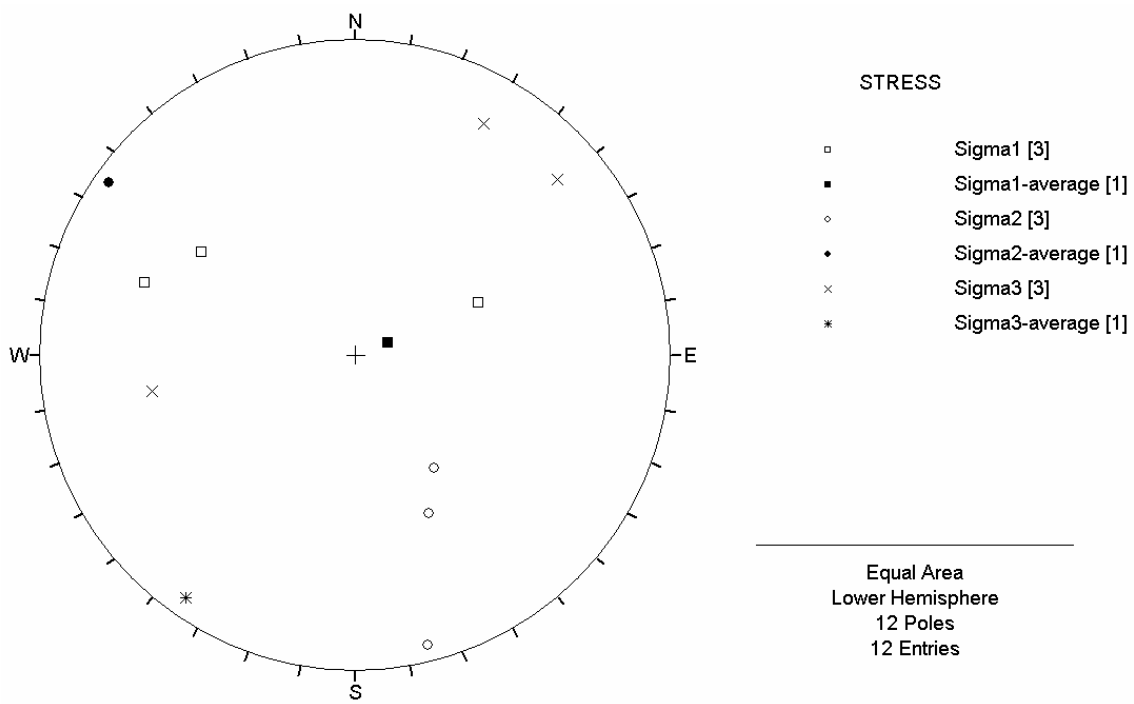


Figure 5-5. *Orientations of measured principal stresses in borehole KAV04, Level 3, shown in a lower hemisphere projection (test nos 3:1:5, 3:3:1, and 3:4:1).*

5.5 Transient strain analysis

5.5.1 Transient strain response

Transient strain analysis was conducted for selected tests from Levels 2 and 3 (see Table 5-1). The resulting calculated strain differences (compared to measured strains), amount of unexplained strain, and maximum tensile stress are shown in Appendix E.

For test no 2:5:2, large relative deviations exist between theoretical and measured strains, in particular for the debonded strain rosette (no 2). Nevertheless, the amount of unexplained strain is only 11% for the final strains (at the end of overcoring), which is fairly acceptable. The analysis clearly showed that low final strain values would have been recorded by the tangential and inclined gauges of rosette no 2, even if they had been properly bonded. This is due to the orientation of those particular gauges relative to the stress field. This situation is very fortunate since a reasonable stress estimate can be obtained through classical overcoring analysis, even when neglecting gauge nos 5 and 6, and by recalculating the axial gauge (no 4), cf Section 5.4.

The axial gauges display large deviation for test 3:1:5, but quite good correlation for test no 3:3:1. The large axial strain deviation of test 3:1:5 may explain the somewhat high value on the vertical stress component obtained from this test. The tangential gauges (with a few exceptions) show the best agreement between measured and theoretical (calculated transient) strains, see e.g. Figure 5-6. Good agreement is also obtained for the inclined gauges, e.g. for test nos 3:1:5 and 3:3:1.

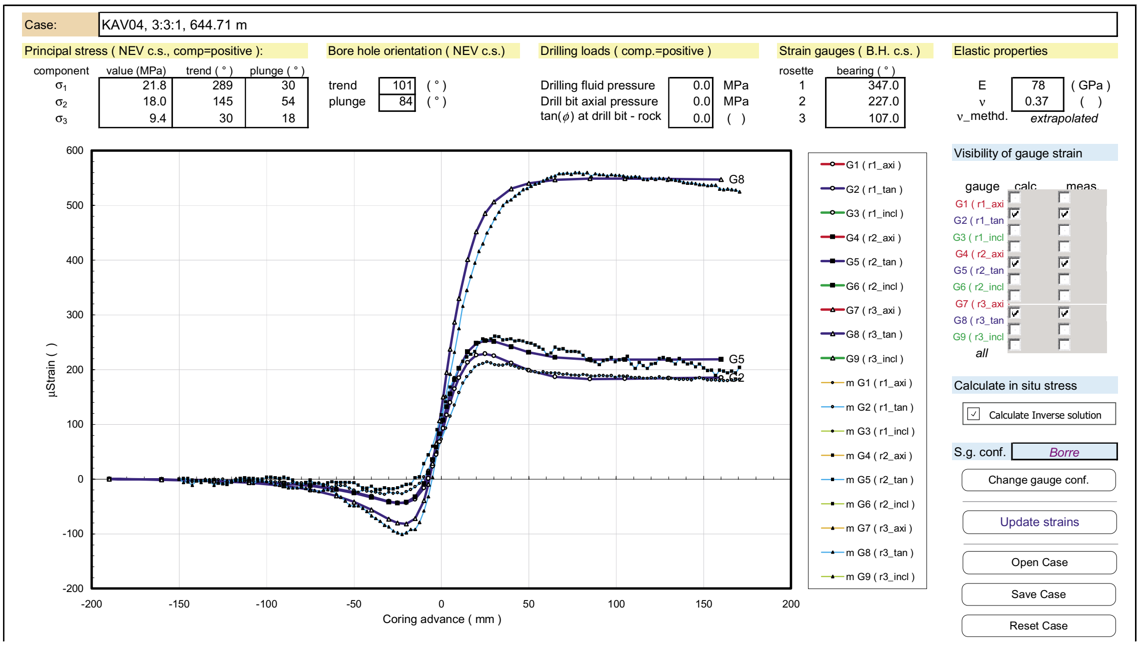


Figure 5-6. *Calculated vs measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no 3:3:1 and all tangential gauges.*

The amount of unexplained strain for final strain values is small for test nos 3:1:5 and 3:4:1 (less than 10%). However, for test 3:2:4 and 3:3:1, small values are also obtained, but not for the final strains. Rather, the strains corresponding to 20–25 cm overcoring length produced the smallest amount of unexplained strain, as shown in Figure 5-7 (see also Appendix E). This finding is not surprising, considering that these tests exhibited large strain drift in the latter portion of the overcoring process. The transient strain analysis thus confirmed that strain differences must be determined for the peak values at 20–25 cm drill bit position.

The calculated value on the maximum tensile stress that develops during overcoring is between 12 and 22 MPa for the analysed measurements. The last test (3:4:1) produced that highest tensile stress (22 MPa; see Figure 5-8). This value is probably high enough to cause some damage/microcracking to the overcore samples. However, the measured axial strain response, which is most susceptible to core damage, is in fair agreement with the theoretical strain response. The potential for tensile damage is significantly lower for the other tests at Level 3.

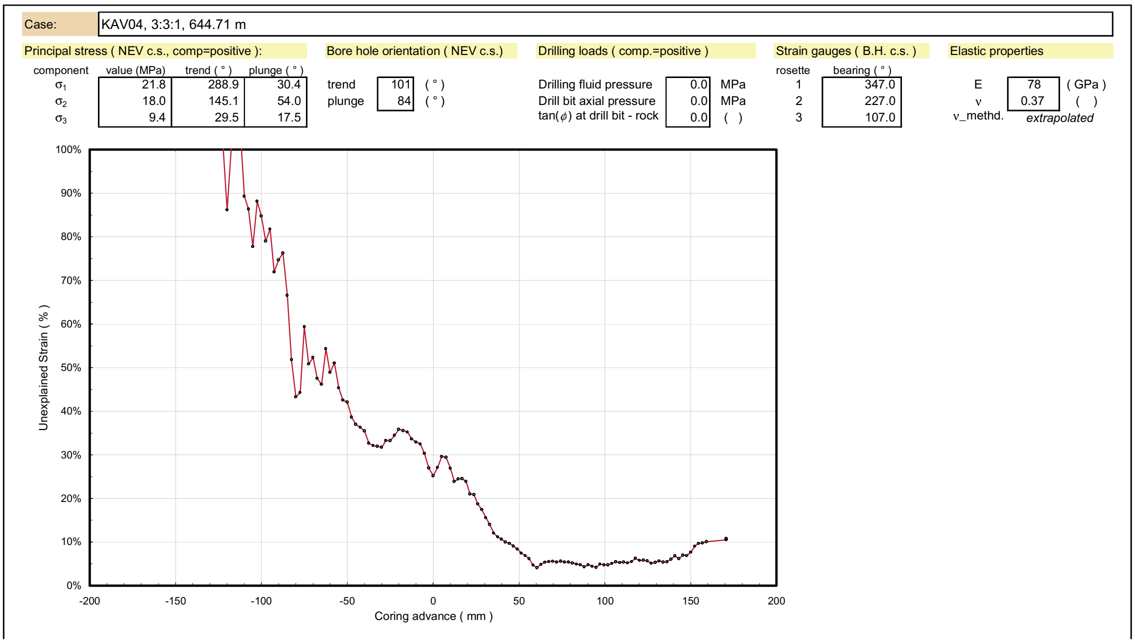


Figure 5-7. *Amount of unexplained strain as a function of coring advance (gauge positions at 0 mm) for test no 3:3:1.*

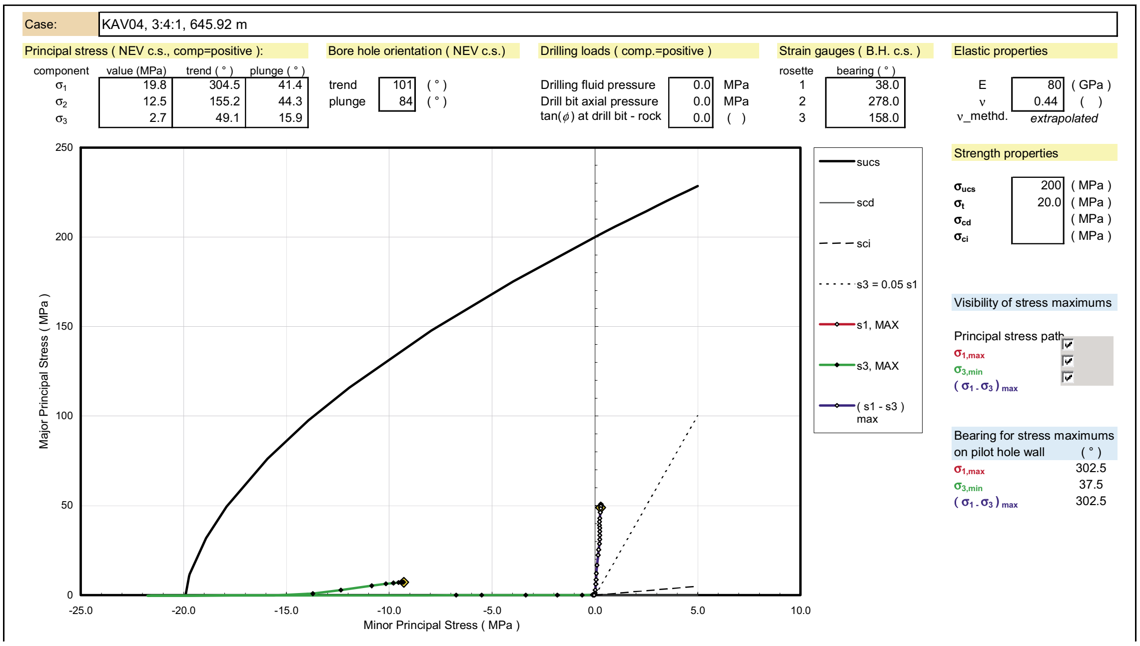


Figure 5-8. Calculated induced stresses in the overcore sample during overcoring for test no 3:4:1.

5.5.2 Inverse solution stress estimate

The inverse solution was used to further confirm (or reject) the inferred stresses from classical analysis, through stress estimation from the early (transient) strain response of the overcoring process. Generally, the stress calculated with the inverse solution varies significantly with coring advance. To obtain a reliable stress estimate, the calculated stresses must be relatively constant over some distance during the early overcoring phase. This requires that the overcoring response during the first few minutes (before passing the strain gauges at 16 cm position) is stable and that the coring advance is accurate. Unfortunately, these two conditions are seldom satisfied simultaneously.

The inverse solution was applied for all tests on Level 3, and test 2:5:2 from Level 2 (cf Table 5-1). Water pressure was not included in the analysis. While this may have some effect on the calculated stresses, it is shadowed by the inaccuracies of coring advance measurements.

The results using the inverse solution were of highly varying quality. Consistent values for the stress state were very difficult to define in the pre-overcoring phase. An example is shown in Figure 5-9. For this case (3:3:1), coring advances of –80 and –70 mm gave fairly similar stresses, which also can be considered realistic. Similarly, test 3:1:5 and 2:5:2 could be evaluated in this manner. For test no 2:5:2, stresses were also calculated for final (post-overcoring) strains, corresponding to a coring advance of 160 mm. The resulting stresses are presented in Table 5-7 through Table 5-9. The obtained stress state from classical analysis is shown for comparison for each test.

For test nos 3:2:4 and 3:4:1, the inverse solution resulted in unrealistic stresses (negative or extremely high), or non-stable stresses in the early overcoring phase. Since the stress state cannot be determined unambiguously for these tests, they were not included in the tables below.

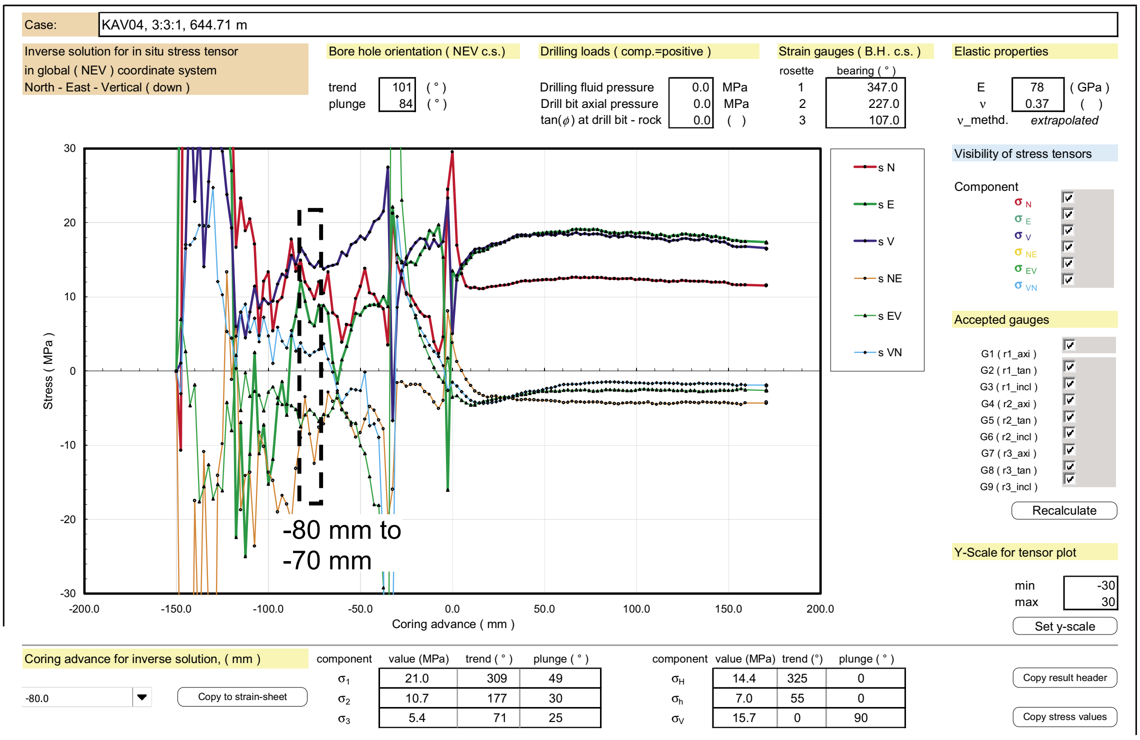


Figure 5-9. Inverse stress solution for test no 3:3:1.

Table 5-7. Magnitudes of principal stress as determined from transient strain analysis (inverse solution). Results from classical analysis shown for comparison.

Measurement no (pilot hole no *)	Coring advance [mm]	σ_1 [MPa]	σ_2 [MPa]	σ_3 [MPa]
2:5:2 (inverse)	–90	20.4	12.2	–0.6
	–80	17.4	13.9	0.2
	–70	14.1	13.6	0.1
	+160	17.0	7.7	3.7
2:5:2 (classical)	–	17.1	8.6	3.9
3:1:5 (inverse)	–101	35.4	17.6	6.8
	–90	25.2	12.9	5.6
	–79	10.0	10.1	–1.8
3:1:5 (classical)	–	28.1	10.2	5.2
3:3:1 (inverse)	–80	21.0	10.7	5.4
	–70	22.2	8.8	2.1
3:3:1 (classical)	–	21.8	18.0	9.4

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

Table 5-8. Orientations of principal stress as determined from transient strain analysis (inverse solution). Results from classical analysis shown for comparison.

Measurement no (pilot hole no *)	Coring advance [mm]	σ_1 Trend/Plunge [°]	σ_2 Trend/Plunge [°]	σ_3 Trend/Plunge [°]
2:5:2 (inverse)	–90	215/24	322/34	097/46
	–80	224/27	330/29	099/49
	–70	265/41	000/07	098/48
	+160	291/39	064/39	177/26
2:5:2 (classical)	–	294/46	072/35	179/22
3:1:5 (inverse)	–101	167/05	281/79	076/10
	–90	184/16	358/74	094/02
	–79	197/16	031/74	288/04
3:1:5 (classical)	–	067/55	166/06	260/35
3:3:1 (inverse)	–80	309/49	177/30	071/25
	–70	314/39	158/49	054/12
3:3:1 (classical)	–	289/30	145/54	029/17

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

Table 5-9. Horizontal and vertical stress components as determined from transient strain analysis (inverse solution). Results from classical analysis shown for comparison.

Measurement no (pilot hole no *)	Coring advance [mm]	σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
2:5:2 (inverse)	–90	18.4	6.8	6.9	022
	–80	16.0	8.6	6.9	019
	–70	13.7	7.8	6.4	008
	+160	12.9	4.9	10.7	103
2:5:2 (classical)	–	12.3	4.9	12.3	102
3:1:5 (inverse)	–101	35.3	7.1	17.4	167
	–90	24.3	5.6	13.9	004
	–79	19.3	0.0	10.7	018
3:1:5 (classical)	–	13.2	10.2	20.5	051
3:3:1 (inverse)	–80	14.4	7.0	15.7	145
	–70	16.9	2.5	13.7	138
3:3:1 (classical)	–	20.8	10.2	18.2	117

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

Comparing the values of the inverse solution with those of the classical analysis, some differences can be noted. For test 2:5:2, a significantly higher maximum horizontal stress is inferred from the inverse solution for pre-overcoring strains (before passing the gauges), whereas the vertical stress is lower in the inverse solution compared to classical analysis. The vertical stress from the inverse solution is about half of the theoretical value corresponding to the overburden pressure. However, the resulting stresses for final strains (+160 mm) are very similar to those obtained from classical analysis. Consequently, test 2:5:2 is regarded as fairly confident for final overcoring strains, despite the fact that one strain rosette malfunctioned.

For test 3:1:5, dramatically higher maximum horizontal stress is indicated from the inverse solution, whereas the vertical stress is lower, but fairly realistic. Stress orientations of the major horizontal stress are also markedly different (N-S rather than NE-SW). For test 3:3:1, fairly similar stress orientations are obtained through both classical and inverse stress calculation. Stress magnitudes are lower for all stress components in the inverse solution.

The variation between the results for the presented coring advances in the pre-overcoring phase is significant – thus, stresses cannot be said to unequivocally determined through this analysis. The large variation also makes averaging futile, and possibly misleading.

In conclusion, the inverse solution can be said to confirm the stress state obtained through classical analysis for test no 3:3:1. For test 2:5:2, a similar, but improved stress estimate was obtained through the inverse solution using final strains. These values can be used instead of those from classical analysis as representative for this test.

For 3:1:5, larger uncertainties exist, but it is possible that the maximum horizontal stress component can be somewhat higher than what the classical analysis indicates. However, based on the large variation of the results with respect to coring advance in the inverse solution, the obtained values from the inverse solution cannot be regarded reliable and should not be used in place of those from classical analysis for test no 3:1:5.

5.6 Summary and discussion

Based on the results and findings presented above, a summary of the stress state in borehole KAV04 is presented in Table 5-10 and Table 5-11 – based on both classical and transient strain analysis.

The measured stress state in borehole KAV04 indicates relatively low stresses even at large depths. For Level 1, the obtained stress magnitudes are close to the achievable precision of the measurement method as such. Considering this, the obtained values must be regarded as quite consistent. The average major principal stress is subhorizontal and striking nearly east-west. Measured magnitudes are only between 5 and 10 MPa for the major stress. The vertical stress component is also low, although test no 1:7:4 indicates a vertical stress that is nearly identical to the theoretical value corresponding to overburden pressure.

Table 5-10. Magnitudes and orientations of principal stresses as determined from overcoring and transient strain analysis (marked * and in *italic*) in borehole KAV04.

Test no	Hole length [m]	Magnitude and Trend/Plunge of principal stresses					
		σ_1		σ_2		σ_3	
		[MPa]	[°]	[MPa]	[°]	[MPa]	[°]
1:2:2	251.51	4.5	144/27	3.0	307/62	0.7	050/07
1:6:1	265.15	4.5	113/00	0.9	204/43	–0.3	023/47
1:7:2	272.87	10.7	255/37	5.0	056/51	3.2	158/09
Average Level 1		**5.2**	**275/28**	**3.6**	**151/47**	**2.0**	**023/30**
2:1:1	429.66	14.0	352/03	11.2	257/57	6.1	084/32
2:4:1	435.36	18.3	333/25	7.8	234/18	2.3	112/58
Average Level 2:A		**15.8**	**338/22**	**9.4**	**232/35**	**4.6**	**093/47**
*2:5:2 *)*	*437.23*	*17.0*	*291/39*	*7.7*	*064/39*	*3.7*	*177/26*
2:6:1	438.66	20.1	070/43	8.9	163/03	6.7	256/47
Average Level 2:B **)		**13.9**	**066/44**	**12.1**	**294/35**	**6.1**	**184/26**
2:7:4	455.25	9.4	185/13	3.6	068/63	1.5	280/23
2:8:1	456.35	11.6	178/38	8.3	056/35	7.0	299/33
Average Level 2:C		**10.3**	**183/22**	**6.1**	**058/55**	**4.3**	**284/26**
3:1:5	635.03	28.1	067/55	10.2	166/06	5.2	260/35
3:3:1	644.71	21.8	289/30	18.0	145/54	9.4	029/17
3:4:1	645.92	20.1	304/41	12.6	155/44	2.7	049/16
Average Level 3		**18.1**	**068/82**	**15.7**	**305/05**	**9.0**	**215/07**

*) data from transient strain analysis (inverse solution)

**) average based on inverse solution of 2:5:2 and classical analysis of 2:6:1

Table 5-11. Horizontal and vertical stress components calculated from principal stresses from overcoring and transient strain analysis (marked * and in italic) in borehole KAV04.

Test no	Hole length [m]	σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
1:2:2	251.51	4.2	0.7	3.3	142
1:6:1	265.15	4.5	0.3	0.3	113
1:7:2	272.87	8.6	3.3	7.0	072
Average Level 1		**4.8**	**2.4**	**3.5**	**104**
2:1:1	429.66	13.9	7.6	9.8	173
2:4:1	435.36	15.6	7.1	5.7	158
Average Level 2:A		**14.7**	**7.5**	**7.7**	**165**
2:5:2 *)	437.23	12.9	4.9	10.7	103
2:6:1	438.66	13.9	8.9	12.9	069
Average Level 2:B **)		**12.9**	**7.4**	**11.8**	**090**
2:7:4	455.25	9.1	1.8	3.5	006
2:8:1	456.35	10.2	7.6	9.1	007
Average Level 2:C		**9.6**	**4.7**	**6.3**	**006**
3:1:5	635.03	13.2	10.2	20.5	051
3:3:1	644.71	20.8	10.2	18.2	117
3:4:1	645.92	16.6	3.6	15.1	135
Average Level 3		**15.7**	**9.1**	**17.9**	**125**

*) data from transient strain analysis (inverse solution)

**) average based on inverse solution of 2:5:2 and classical analysis of 2:6:1

For Level 2, slightly higher stresses were deduced. However, a consistent average stress state was more difficult to determine. The varying rock conditions (partly fractured rock inhibiting measurements) probably affected the measurement results in that the obtained stresses varied significantly depending on measurement location. For the measurements above and below the most fractured rock, a major principal stress oriented subhorizontally and trending nearly NNW–SSE to N-S was found. Stress magnitudes were higher above the fracture zone, with the maximum horizontal stress being around 15 MPa. The vertical stress is lower than the theoretical value from overburden depth for all measurements. Orientations were very consistent for both these groups of tests. The third group of tests comprising test nos 2:5:2 and 2:6:2 also displayed consistency between the two measurements, but with an E-W orientation of the maximum horizontal stress. Consequently, all these three groups of tests are presented in Table 5-10 and Table 5-11.

Slightly higher stresses were obtained from Level 3, indicating an average maximum horizontal stress of around 16 MPa, oriented WNW-ESE. The average vertical stress is close to the theoretical value (17.9 vs 17 MPa). Interestingly, the vertical stress is of the same magnitude as the maximum horizontal stress (the major principal stress is also steeply dipping as a result of this), indicating a possible change in stress regime compared to the upper levels. However, the existence of fractured rock for more than 30 m directly above the measurement levels, as well as the presence of single fractures close to the test locations, may have some influence on the deduced stress state.

The high values on Poisson's ratios obtained from Levels 1 and 3 may indicate some core damage; however, the transient strain analysis showed that only moderately high tensile stresses develop during the overcoring process. Furthermore, axial strain response was (with a few exceptions) reasonably close to the theoretically expectable values. These signs point to low potential for core damage in the conducted measurements, with little influence on the recorded strain response.

Using the inverse solution of transient strain analysis, the obtained stress states from measurement nos 2:5:2 and 3:3:1 were confirmed, whereas a somewhat higher maximum horizontal stress component may be possible for test 3:1:5. However, in light of the large variations and the difficulty in finding stable values in the inverse solution, the obtained values from the inverse solution for the pre-overcoring strains cannot be regarded as particularly confident.

In conclusion, the stress state in borehole KAV04 is characterized by low to moderate stresses, reaching at the most 20 MPa at 640 m depth below the ground surface. The maximum horizontal stress appears to be oriented E-W to WNW-ESE, with the exception of measurement Level 2, where both a N-S orientation, as well as an E-W orientation prevailed. The latter may be an effect of the fracture zones near the measurement locations at this level. The test results should be evaluated further, particularly with respect to geological context, and compared to measurements in nearby areas, such as the Äspö HRL.

6 References

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

Fouial K, Alheib M, Baroudi H, Trentsaux C, 1998. Improvement in the interpretation of stress measurements by use of the overcoring method: development of a new approach. *Engineering Geology*, *49*, pp. 239–252.

Hakala M, Hudson J A, Christiansson R, 2003. Quality control of overcoring stress measurement data. *Int. J. Rock Mech. Min. Sci.*, *40*, No 7–8, pp. 1141–1159.

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

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.

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.

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

Key measurement data

Table A1. Key measurement data for test no. 1:2:2, 251.51 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-01-14	18:45:00
Mixing of glue	04-01-14	18:49:00
Application of glue to gauges	04-01-14	18:55:00
Probe installation in pilot hole	04-01-14	19:05:00
Start time for dense sampling (5 s interval)	04-01-15	07:30:00
Adapter retrieved	04-01-15	08:45:00
Drill string fed down the hole	04-01-15	08:50:00
Drill string in place	04-01-15	10:50:00
Flushing start	04-01-15	10:50:00
Rotation start	04-01-15	11:06:10
Overcoring start	04-01-15	11:07:50
Overcoring 3 cm	04-01-15	11:09:00
Overcoring 6 cm	04-01-15	11:10:05
Overcoring 9 cm	04-01-15	11:11:20
Overcoring 12 cm	04-01-15	11:12:00
Overcoring 16 cm	04-01-15	11:13:00
Overcoring 24 cm	04-01-15	11:15:55
Overcoring 30 cm	04-01-15	11:17:45
Overcoring stop	04-01-15	11:30:00
Flushing off	04-01-15	11:45:00
Core break	04-01-15	12:07:00
Core retrieval start	04-01-15	12:20:00
Core & probe on surface	04-01-15	13:15:00
End of strain registration	04-01-15	14:19:40
Calculation of strain difference: OC Start	04-01-15	11:08:00
Calculation of strain difference: OC Stop	04-01-15	11:29:45
Overcoring advance	**Overcoring rate [cm/min]**	
0 – 16 cm	3.1	
16 – 30 cm	2.9	
30 cm – overcoring stop	5.6	

Table A2. Key measurement data for test no. 1:6:1, 265.15 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-01-21	20:30:00
Mixing of glue	04-01-21	20:54:00
Application of glue to gauges	04-01-21	20:59:00
Probe installation in pilot hole	04-01-21	21:10:00
Start time for dense sampling (5 s interval)	04-01-22	07:30:00
Adapter retrieved	04-01-22	08:10:00
Drill string fed down the hole	04-01-22	08:15:00
Drill string in place	04-01-22	09:48:00
Flushing start	04-01-22	09:53:00
Rotation start	04-01-22	10:15:00
Overcoring start	04-01-22	10:15:30
Overcoring 4 m	04-01-22	10:17:00
Overcoring 8 cm	04-01-22	10:18:00
Overcoring 12 cm	04-01-22	10:19:30
Overcoring 16 cm	04-01-22	10:21:00
Overcoring 30 cm	04-01-22	10:24:00
Overcoring stop (106 cm)	04-01-22	10:34:00
Flushing off	04-01-22	10:49:00
Core break	04-01-22	11:36:30
Core retrieval start	04-01-22	11:50:00
Core & probe on surface	04-01-22	12:37:00
End of strain registration	04-01-22	12:55:35
Calculation of strain difference: OC Start	04-01-22	10:15:30
Calculation of strain difference: OC Stop	04-01-22	10:28:00

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.9
16 – 30 cm	4.5
30 cm – overcoring stop	7

Table A3. Key measurement data for test no. 1:7:2, 272.87 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-01-23	16:15:00
Mixing of glue	04-01-23	16:28:00
Application of glue to gauges	04-01-23	16:36:00
Probe installation in pilot hole	04-01-23	16:48:00
Start time for dense sampling (5 s interval)	04-01-24	07:30:00
Adapter retrieved	04-01-24	08:06:45
Drill string fed down the hole	04-01-24	08:28:00
Drill string in place	04-01-24	09:10:00
Flushing start	04-01-24	09:36:00
Rotation start	04-01-24	09:59:50
Overcoring start	04-01-24	10:00:40
Overcoring 4 cm	04-01-24	10:02:00
Overcoring 8 cm	04-01-24	10:03:20
Overcoring 12 cm	04-01-24	10:04:20
Overcoring 16 cm	04-01-24	10:05:12
Overcoring 30 cm	04-01-24	10:08:00
Overcoring stop (100 cm)	04-01-24	10:19:20
Flushing off	04-01-24	10:36:00
Core break	04-01-24	11:52:15
Core retrieval start	04-01-24	12:10:00
Core & probe on surface	04-01-24	12:55:00
End of strain registration	04-01-24	13:20:05
Calculation of strain difference: OC Start	04-01-24	10:00:40
Calculation of strain difference: OC Stop	04-01-24	10:13:20

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	3.5
16 – 30 cm	5.0
30 cm – overcoring stop	6

Table A4. Key measurement data for test no. 2:1:1, 429.66 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-02-06	10:30:00
Mixing of glue	04-02-06	10:38:00
Application of glue to gauges	04-02-06	10:43:00
Probe installation in pilot hole	04-02-06	11:00:00
Start time for dense sampling (5 s interval)	04-02-07	06:30:00
Adapter retrieved	04-02-07	07:30:00
Drill string fed down the hole	04-02-07	08:00:00
Drill string in place	04-02-07	09:40:00
Flushing start	04-02-07	09:45:00
Rotation start	04-02-07	10:15:00
Overcoring start	04-02-07	10:18:00
Overcoring 16 cm	04-02-07	10:25:30
Overcoring 30 cm	04-02-07	10:29:30
Overcoring stop	04-02-07	10:39:40
Flushing off	04-02-07	10:56:20
Core break	04-02-07	11:09:40
Core retrieval start	04-02-07	11:26:00
Core & probe on surface	04-02-07	12:45:00
End of strain registration	04-02-07	13:20:05
Calculation of strain difference: OC Start	04-02-07	10:18:00
Calculation of strain difference: OC Stop	04-02-07	10:39:40

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.1
16 – 30 cm	3.5
30 cm – overcoring stop	6.9

Table A5. Key measurement data for test no. 2:4:1, 435.36 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-02-10	19:00:00
Mixing of glue	04-02-10	19:04:00
Application of glue to gauges	04-02-10	19:10:00
Probe installation in pilot hole	04-02-10	19:25:00
Start time for dense sampling (5 s interval)	04-02-11	07:00:00
Adapter retrieved	04-02-11	08:34:50
Drill string fed down the hole	04-02-11	09:00:00
Drill string in place	04-02-11	10:15:00
Flushing start	04-02-11	10:30:00
Rotation start	04-02-11	10:57:00
Overcoring start	04-02-11	10:57:30
Overcoring 16 cm	04-02-11	11:02:45
Overcoring 30 cm	04-02-11	11:07:15
Overcoring stop	04-02-11	11:16:15
Flushing off	04-02-11	11:31:00
Core break	04-02-11	11:46:15
Core retrieval start	04-02-11	12:42:00
Core & probe on surface	04-02-11	13:52:00
End of strain registration	04-02-11	14:32:00
Calculation of strain difference: OC Start	04-02-11	10:57:30
Calculation of strain difference: OC Stop	04-02-11	11:05:00
Overcoring advance	**Overcoring rate [cm/min]**	
0 – 16 cm	3.0	
16 – 30 cm	3.1	
30 cm – overcoring stop	7.8	

Table A6. Key measurement data for test no. 2:5:2, 437.23 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-02-12	18:00:00
Mixing of glue	04-02-12	18:22:00
Application of glue to gauges	04-02-12	18:28:00
Probe installation in pilot hole	04-02-12	18:46:00
Start time for dense sampling (5 s interval)	04-02-13	07:30:00
Adapter retrieved	04-02-13	08:05:00
Drill string fed down the hole	04-02-13	08:30:00
Drill string in place	04-02-13	09:42:00
Flushing start	04-02-13	09:58:00
Rotation start	04-02-13	10:18:10
Overcoring start	04-02-13	10:18:55
Overcoring 4 cm	04-02-13	10:20:20
Overcoring 8 cm	04-02-13	10:21:45
Overcoring 12 cm	04-02-13	10:22:55
Overcoring 16 cm	04-02-13	10:24:15
Overcoring 30 cm	04-02-13	10:30:00
Overcoring stop (104 cm)	04-02-13	10:39:15
Flushing off	04-02-13	10:54:00
Core break	04-02-13	11:49:30
Core retrieval start	04-02-13	12:06:00
Core & probe on surface	04-02-13	13:10:00
End of strain registration	04-02-13	13:35:05
Calculation of strain difference: OC Start	04-02-13	10:18:55
Calculation of strain difference: OC Stop	04-02-13	10:39:15

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	3.0
16 – 30 cm	3.0
30 cm – overcoring stop	7.5

Table A7. Key measurement data for test no. 2:6:1, 438.66 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-02-13	20:45:00
Mixing of glue	04-02-13	21:19:00
Application of glue to gauges	04-02-13	21:25:50
Probe installation in pilot hole	04-02-13	21:40:50
Start time for dense sampling (5 s interval)	04-02-14	08:00:00
Adapter retrieved	04-02-14	08:39:00
Drill string fed down the hole	04-02-14	08:57:00
Drill string in place	04-02-14	10:00:00
Flushing start	04-02-14	10:03:00
Rotation start	04-02-14	10:22:00
Overcoring start	04-02-14	10:23:10
Overcoring 4 cm	04-02-14	10:24:30
Overcoring 8 cm	04-02-14	10:26:10
Overcoring 12 cm	04-02-14	10:27:30
Overcoring 16 cm	04-02-14	10:28:55
Overcoring 30 cm	04-02-14	10:34:00
Overcoring stop (100 cm)	04-02-14	10:43:50
Flushing off	04-02-14	10:57:45
Core break	04-02-14	11:12:40
Core retrieval start	04-02-14	12:10:00
Core & probe on surface	04-02-14	13:12:00
End of strain registration	04-02-14	13:30:05
Calculation of strain difference: OC Start	04-02-14	10:23:10
Calculation of strain difference: OC Stop	04-02-14	10:31:00

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.8
16 – 30 cm	2.8
30 cm – overcoring stop	7.1

Table A8. Key measurement data for test no. 2:7:4, 455.25 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-02-16	15:30:00
Mixing of glue	04-02-16	15:45:00
Application of glue to gauges	04-02-16	15:56:00
Probe installation in pilot hole	04-02-16	16:09:00
Start time for dense sampling (5 s interval)	04-02-17	07:00:00
Adapter retrieved	04-02-17	07:40:00
Drill string fed down the hole	04-02-17	08:05:00
Drill string in place	04-02-17	09:09:00
Flushing start	04-02-17	09:11:00
Rotation start	04-02-17	09:35:55
Overcoring start	04-02-17	09:37:25
Overcoring 4 cm	04-02-17	09:38:50
Overcoring 8 cm	04-02-17	09:40:00
Overcoring 12 cm	04-02-17	09:41:20
Overcoring 16 cm	04-02-17	09:42:35
Overcoring 30 cm	04-02-17	09:47:30
Overcoring stop	04-02-17	09:59:00
Flushing off	04-02-17	10:17:00
Core break	04-02-17	10:37:00
Core retrieval start	04-02-17	10:52:40
Core & probe on surface	04-02-17	11:56:00
End of strain registration	04-02-17	12:17:00
Calculation of strain difference: OC Start	04-02-17	09:37:25
Calculation of strain difference: OC Stop	04-02-17	09:47:30

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	3.1
16 – 30 cm	2.9
30 cm – overcoring stop	6.1

Table A9. Key measurement data for test no. 2:8:1, 456.35 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-02-17	19:00:00
Mixing of glue	04-02-17	19:12:00
Application of glue to gauges	04-02-17	19:20:00
Probe installation in pilot hole	04-02-17	19:34:05
Start time for dense sampling (5 s interval)	04-02-18	07:00:00
Adapter retrieved	04-02-18	07:36:00
Drill string fed down the hole	04-02-18	07:53:40
Drill string in place	04-02-18	08:56:00
Flushing start	04-02-18	09:06:30
Rotation start	04-02-18	09:19:00
Overcoring start	04-02-18	09:20:55
Overcoring 4 cm	04-02-18	09:22:00
Overcoring 8 cm	04-02-18	09:23:30
Overcoring 12 cm	04-02-18	09:24:50
Overcoring 16 cm	04-02-18	09:26:00
Overcoring 30 cm	04-02-18	09:30:55
Overcoring stop	04-02-18	09:42:45
Flushing off	04-02-18	09:58:00
Core break	04-02-18	10:13:45
Core retrieval start	04-02-18	10:29:35
Core & probe on surface	04-02-18	-
End of strain registration	04-02-18	11:49:55
Calculation of strain difference: OC Start	04-02-18	09:20:55
Calculation of strain difference: OC Stop	04-02-18	09:42:45

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	3.1
16 – 30 cm	2.9
30 cm – overcoring stop	5.9

Table A10. Key measurement data for test no. 3:1:5, 635.03 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-03-02	14:35:00
Mixing of glue	04-03-02	15:01:00
Application of glue to gauges	04-03-02	15:07:00
Probe installation in pilot hole	04-03-02	15:17:00
Start time for dense sampling (5 s interval)	04-03-03	06:40:00
Adapter retrieved	04-03-03	07:45:00
Adapter on surface	04-03-03	07:55:00
Drill string fed down the hole	04-03-03	08:10:00
Drill string in place	04-03-03	10:05:00
Flushing start	04-03-03	10:20:00
Rotation start	04-03-03	10:41:00
Overcoring start	04-03-03	10:44:00
Overcoring 16 cm	04-03-03	10:49:00
Overcoring 30 cm	04-03-03	10:53:00
Overcoring stop	04-03-03	11:01:00
Flushing off	04-03-03	11:16:00
Core break	04-03-03	11:31:00
Core retrieval start	04-03-03	12:50:00
Core & probe on surface	04-03-03	14:25:00
End of strain registration	04-03-03	14:57:10
Calculation of strain difference: OC Start	04-03-03	10:42:00
Calculation of strain difference: OC Stop	04-03-03	10:55:00
Overcoring advance	**Overcoring rate [cm/min]**	
0 – 16 cm	3.0	
16 – 30 cm	3.5	
30 cm – overcoring stop	7.5	

Table A11. Key measurement data for test no. 3:2:4, 639.57 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-03-06	15:05:00
Mixing of glue	04-03-06	15:30:00
Application of glue to gauges	04-03-06	15:36:00
Probe installation in pilot hole	04-03-06	15:49:00
Start time for dense sampling (5 s interval)	04-03-07	07:00:00
Adapter retrieved	04-03-07	08:06:00
Adapter on surface	04-03-03	08:16:00
Drill string fed down the hole	04-03-07	08:55:00
Drill string in place	04-03-07	10:50:00
Flushing start	04-03-07	10:55:00
Rotation start	04-03-07	11:21:00
Overcoring start	04-03-07	11:22:00
Overcoring 16 cm	04-03-07	11:30:00
Overcoring 30 cm	04-03-07	11:34:00
Overcoring stop (88 cm)	04-03-07	11:41:00
Flushing off	04-03-07	11:56:00
Core break	04-03-07	12:16:00
Core retrieval start	04-03-07	-
Core & probe on surface	04-03-07	14:55:00
End of strain registration	04-03-07	15:22:45
Calculation of strain difference: OC Start	04-03-07	11:23:00
Calculation of strain difference: OC Stop	04-03-07	11:32:00

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.0
16 – 30 cm	3.5
30 cm – overcoring stop	8.3

Table A12. Key measurement data for test no. 3:3:1, 644.71 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-03-12	15:45:00
Mixing of glue	04-03-12	16:08:00
Application of glue to gauges	04-03-12	16:15:00
Probe installation in pilot hole	04-03-12	16:37:00
Start time for dense sampling (5 s interval)	04-03-13	07:30:00
Adapter retrieved	04-03-13	08:05:00
Adapter on surface	04-03-13	08:25:00
Drill string fed down the hole	04-03-13	08:29:00
Drill string in place	04-03-13	10:14:40
Flushing start	04-03-13	10:15:00
Rotation start	04-03-13	10:24:20
Overcoring start	04-03-13	10:25:10
Overcoring 16 cm	04-03-13	10:30:30
Overcoring 30 cm	04-03-13	10:35:35
Overcoring stop	04-03-13	10:46:30
Flushing off	04-03-13	10:59:05
Core break	04-03-13	11:42:00
Core retrieval start	04-03-13	11:56:15
Core & probe on surface	04-03-13	13:28:45
End of strain registration	04-03-13	13:57:55
Calculation of strain difference: OC Start	04-03-13	10:25:10
Calculation of strain difference: OC Stop	04-03-13	10:33:30
Overcoring advance	Overcoring rate [cm/min]	
0 – 16 cm	3.0	
16 – 30 cm	2.8	
30 cm – overcoring stop	7.9	

Table A13. Key measurement data for test no. 3:4:1, 645.92 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-03-14	16:15:00
Mixing of glue	04-03-14	16:58:45
Application of glue to gauges	04-03-14	17:08:00
Probe installation in pilot hole	04-03-14	17:20:00
Start time for dense sampling (5 s interval)	04-03-15	07:30:00
Adapter retrieved	04-03-15	08:04:00
Adapter on surface	04-03-15	08:13:00
Drill string fed down the hole	04-03-15	08:30:00
Drill string in place	04-03-15	10:18:00
Flushing start	04-03-15	10:00:00
Rotation start	04-03-15	10:28:00
Overcoring start	04-03-15	10:31:00
Overcoring 16 cm	04-03-15	10:35:30
Overcoring 30 cm	04-03-15	10:40:20
Overcoring stop	04-03-15	10:50:05
Flushing off	04-03-15	11:05:00
Core break	04-03-15	12:03:10
Core retrieval start	04-03-15	12:18:25
Core & probe on surface	04-03-15	13:03:00
End of strain registration	04-03-15	14:17:20
Calculation of strain difference: OC Start	04-03-15	10:31:00
Calculation of strain difference: OC Stop	04-03-15	10:39:00

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	3.5
16 – 30 cm	2.9
30 cm – overcoring stop	7.2

Appendix B

Overcoring strain data and graphs

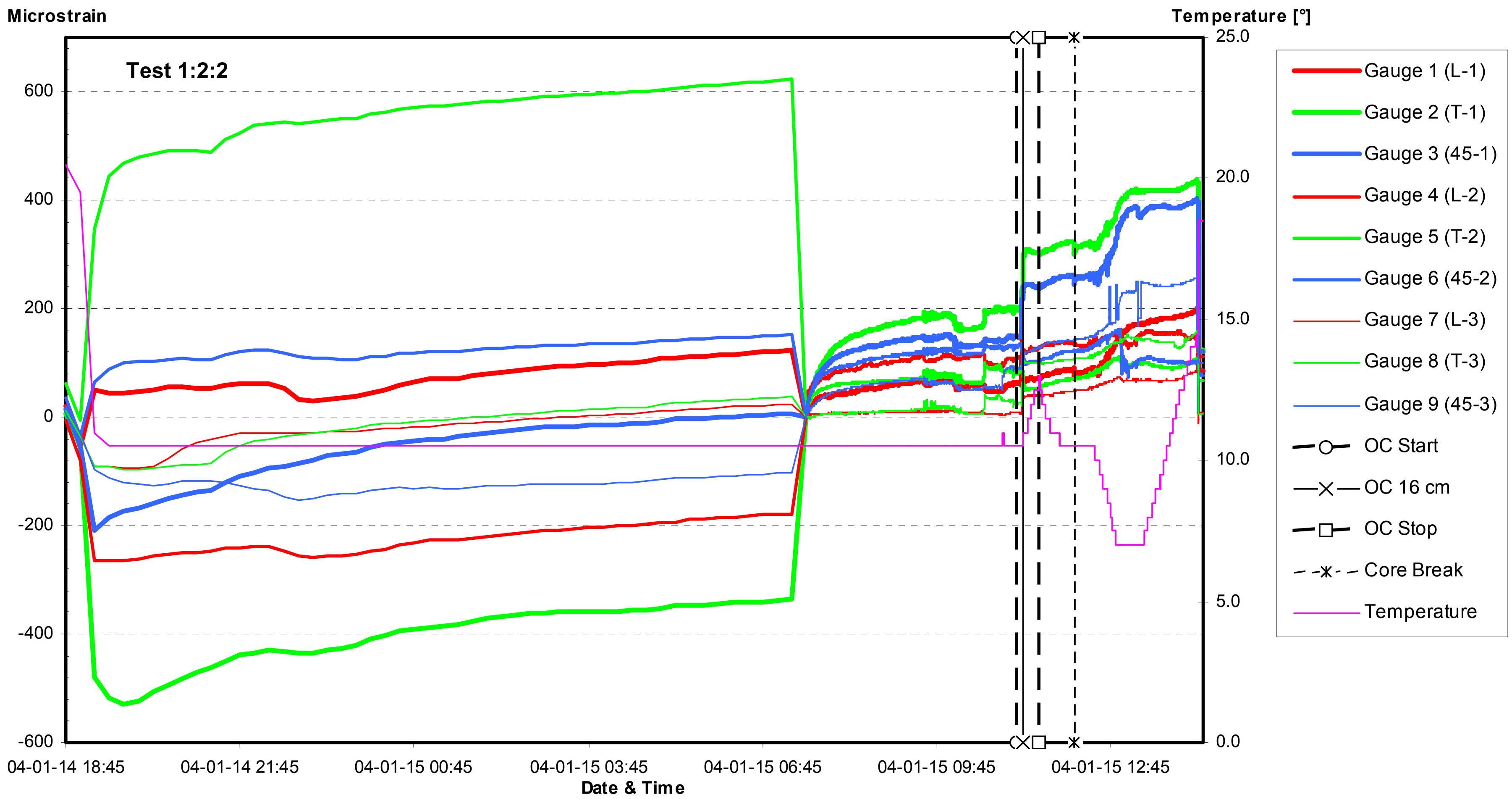


Figure B1. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:2:2, 251.51 m borehole length.*

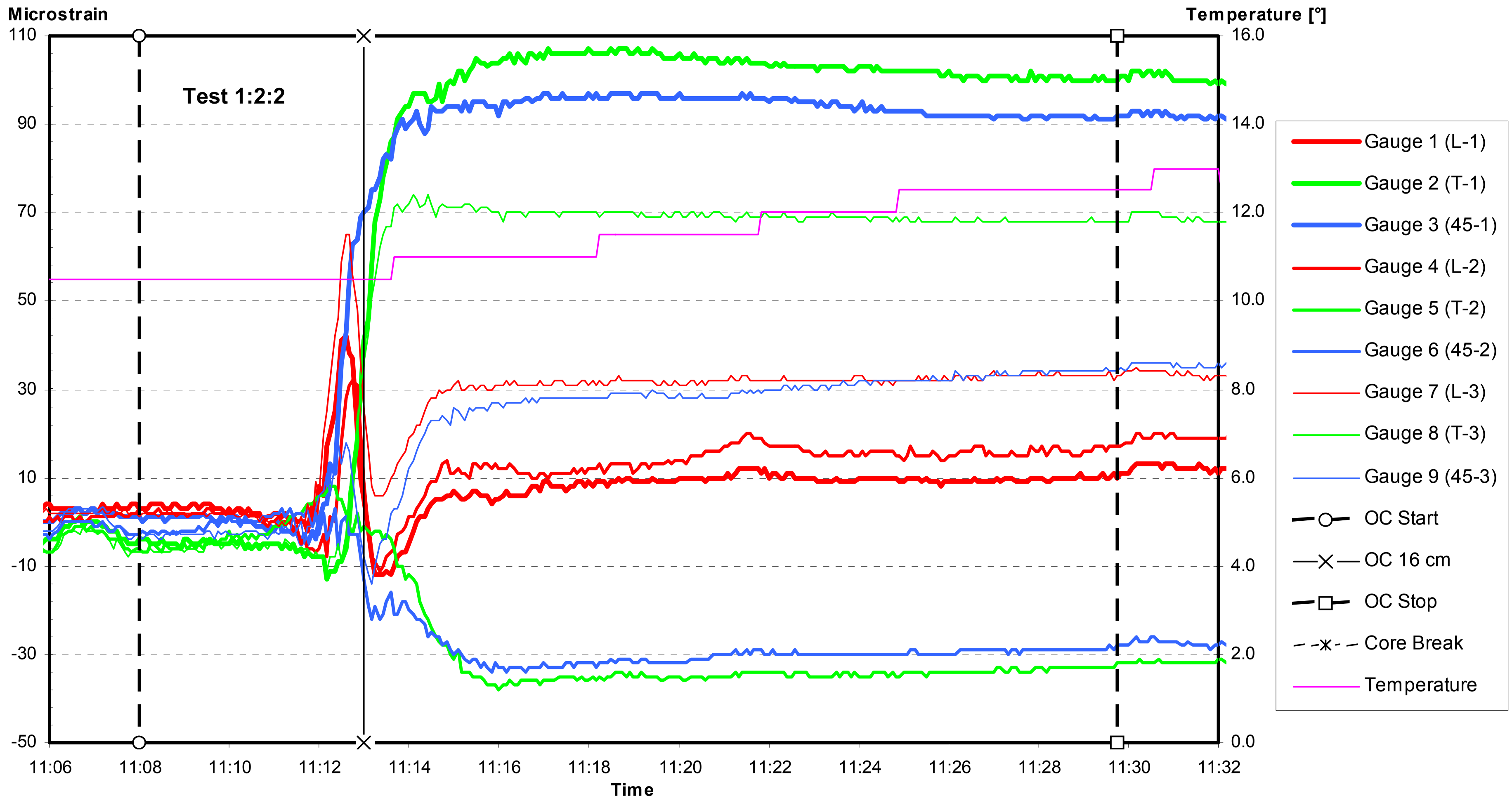


Figure B2. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:2:2, 251.51 m borehole length. Strain values reset to zero at 11:00.*

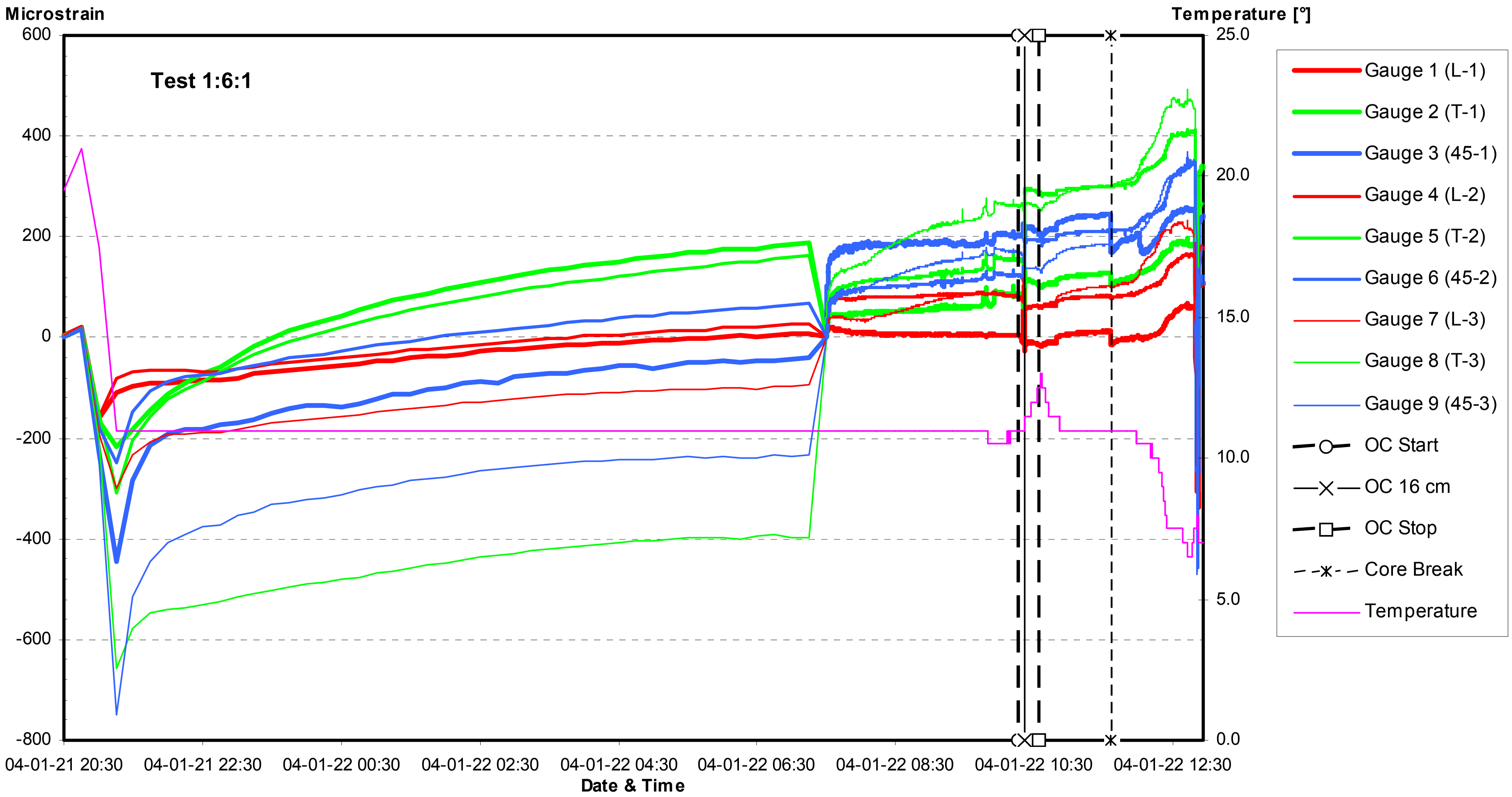


Figure B3. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:6:1, 265.15 m borehole length.*

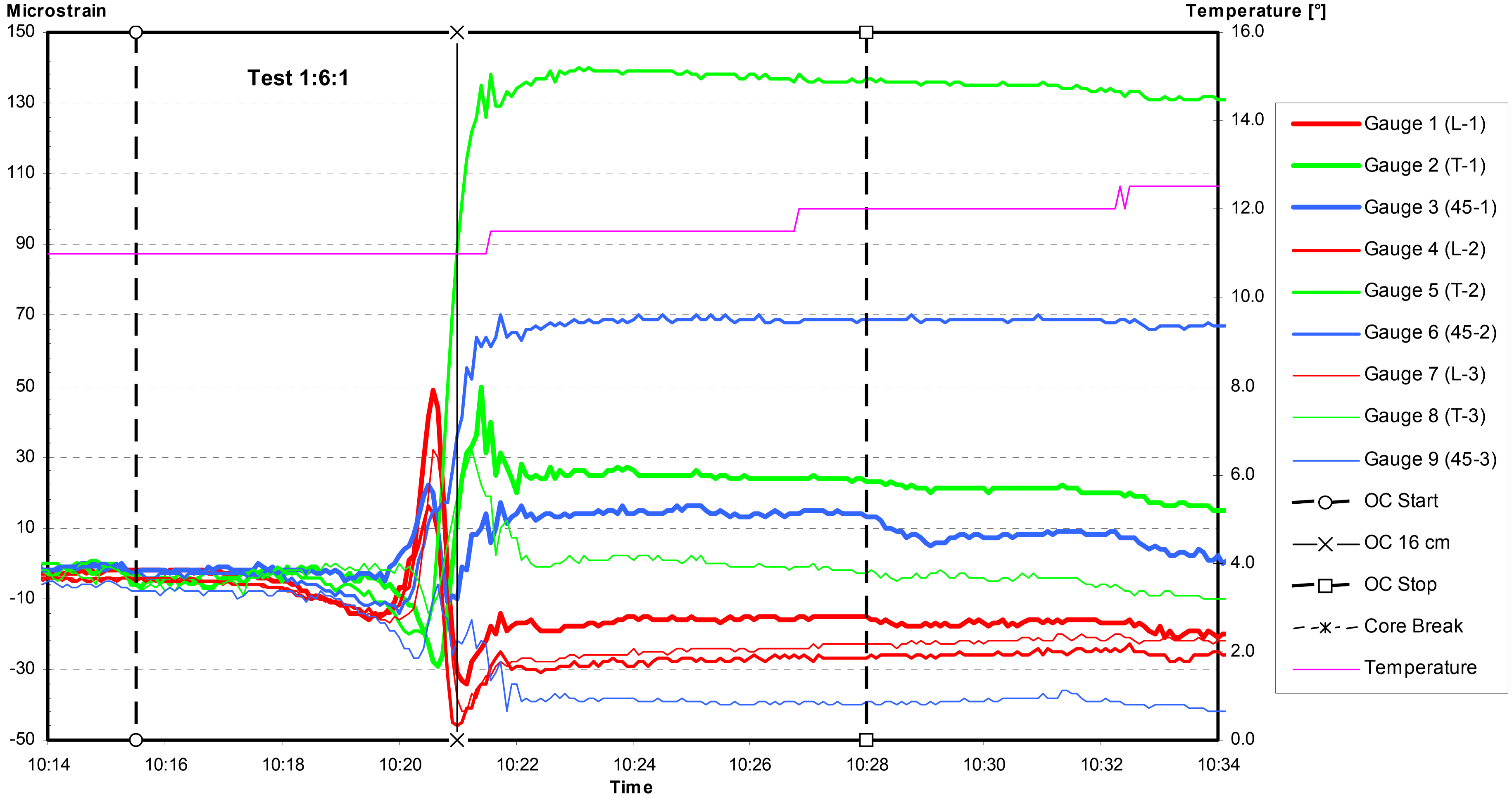


Figure B4. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:6:1, 265.15 m borehole length. Strain values reset to zero at 10:00.*

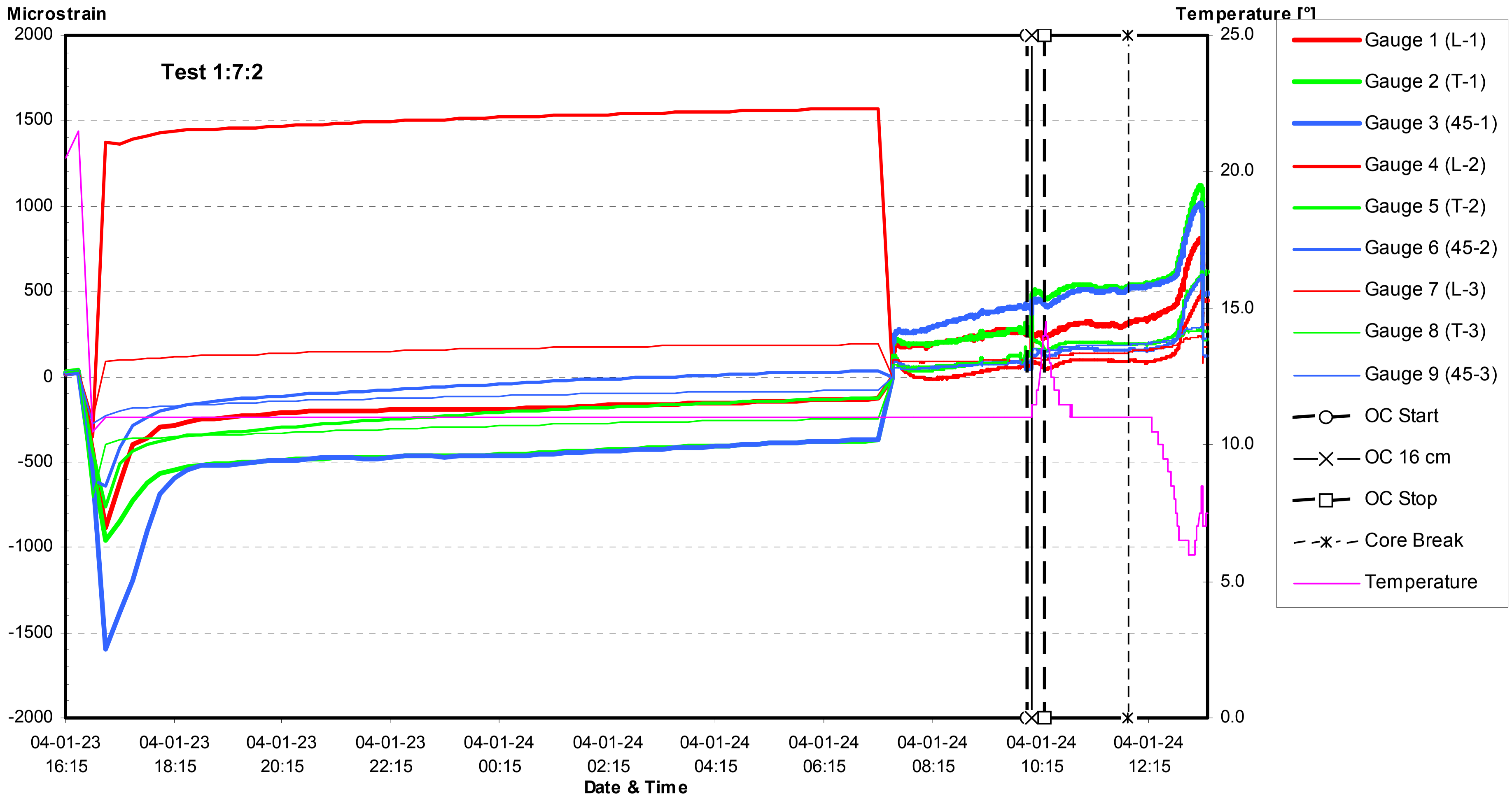


Figure B5. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:7:2, 272.87 m borehole length.*

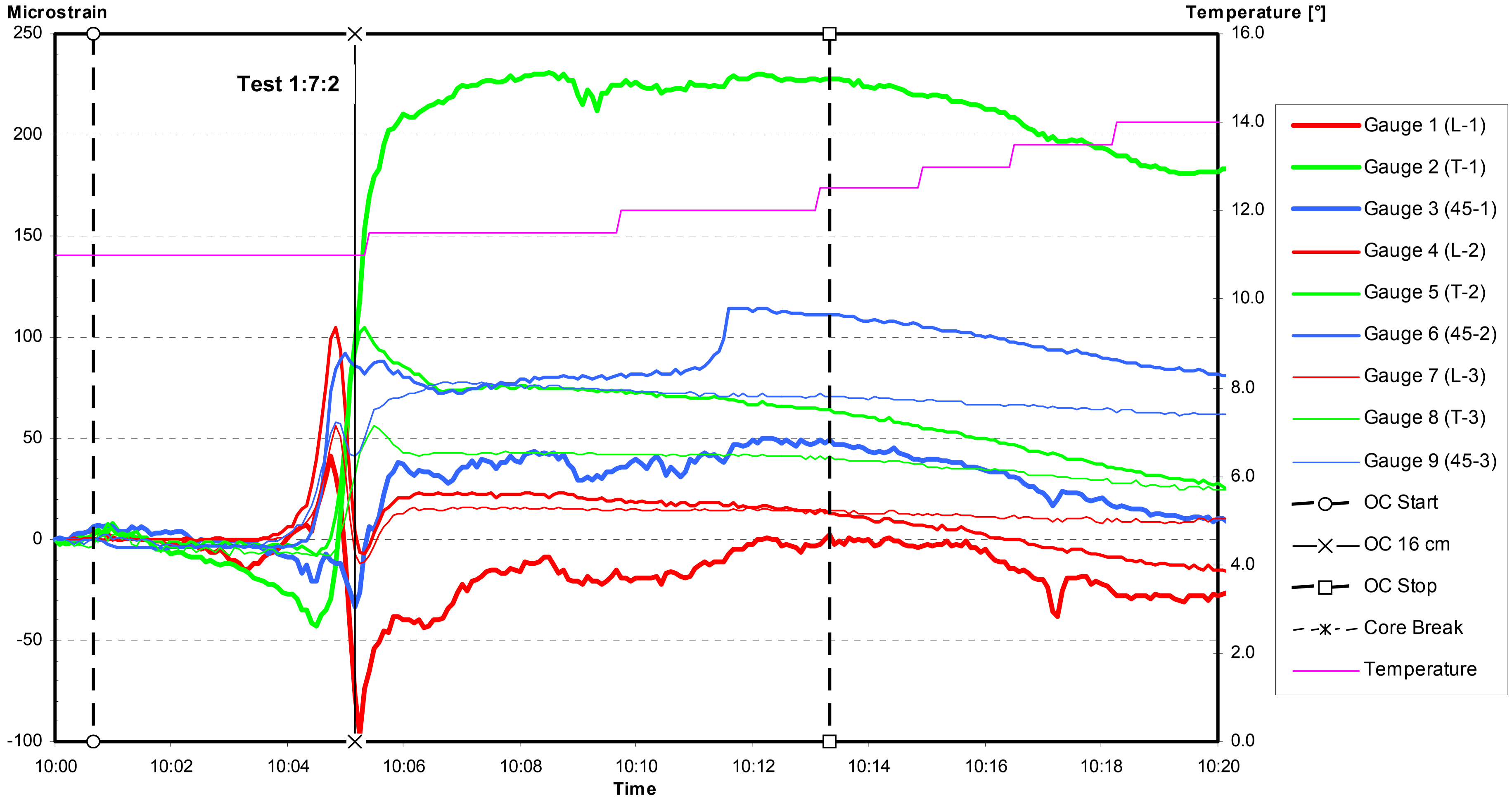


Figure B6. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:7:2, 272.87 m borehole length. Strain values reset to zero at 10:00.*

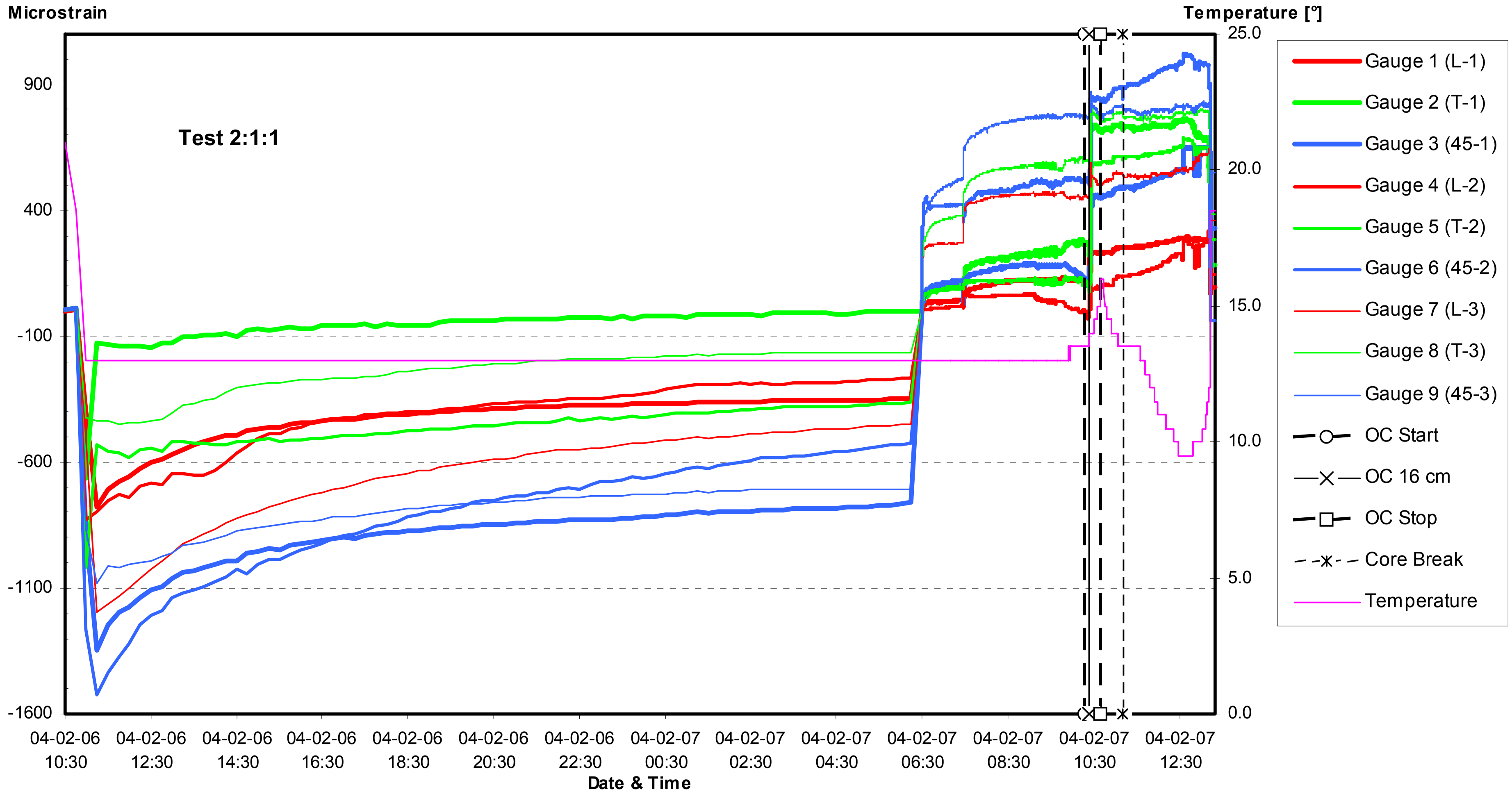


Figure B7. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:1:1, 429.66 m borehole length.*

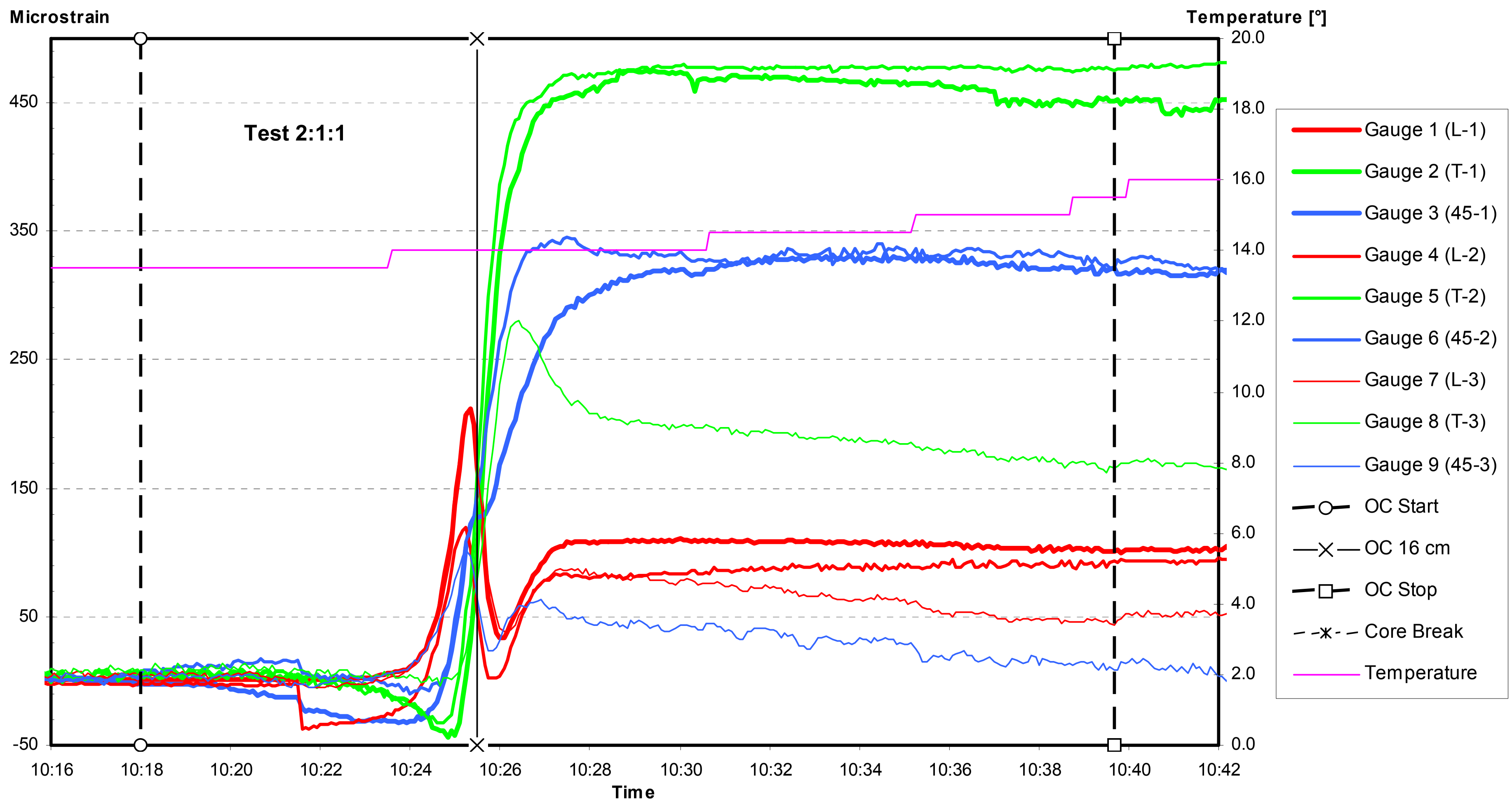


Figure B8. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:1:1, 429.66 m borehole length. Strain values reset to zero at 10:15.*

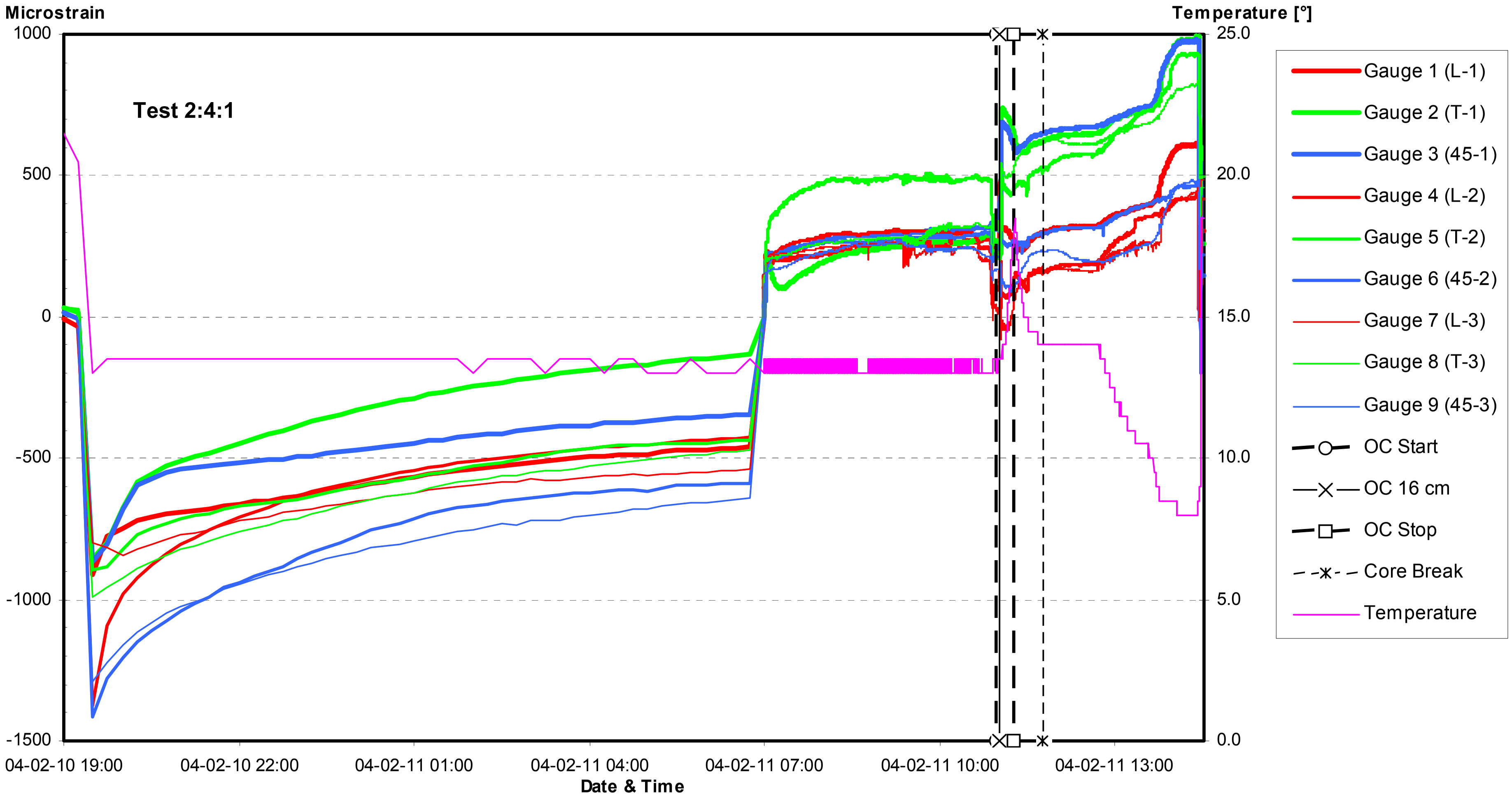


Figure B9. All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:4:1, 435.36 m borehole length.

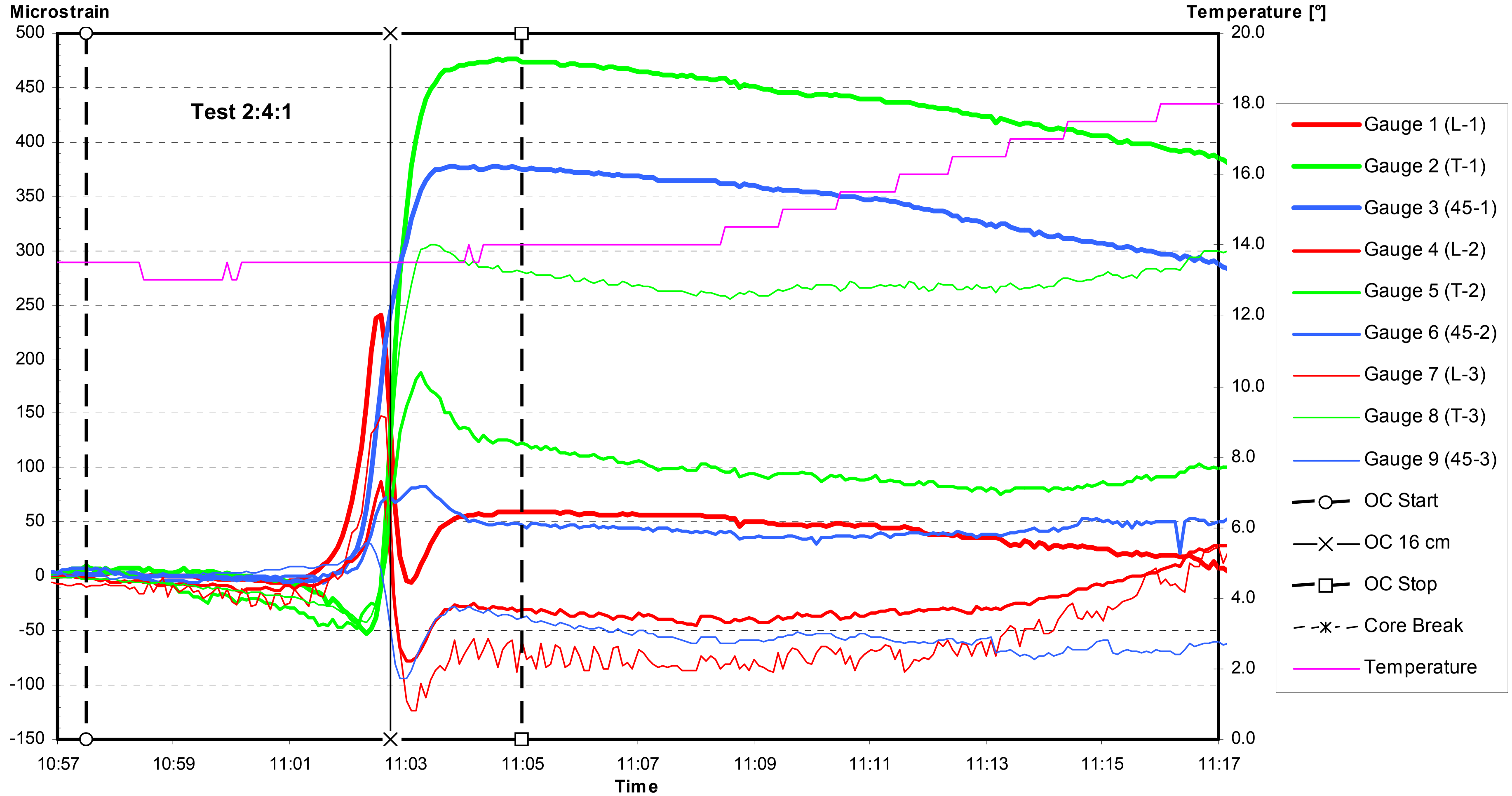


Figure B10. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:4:1, 435.36 m borehole length. Strain values reset to zero at 10:56.*

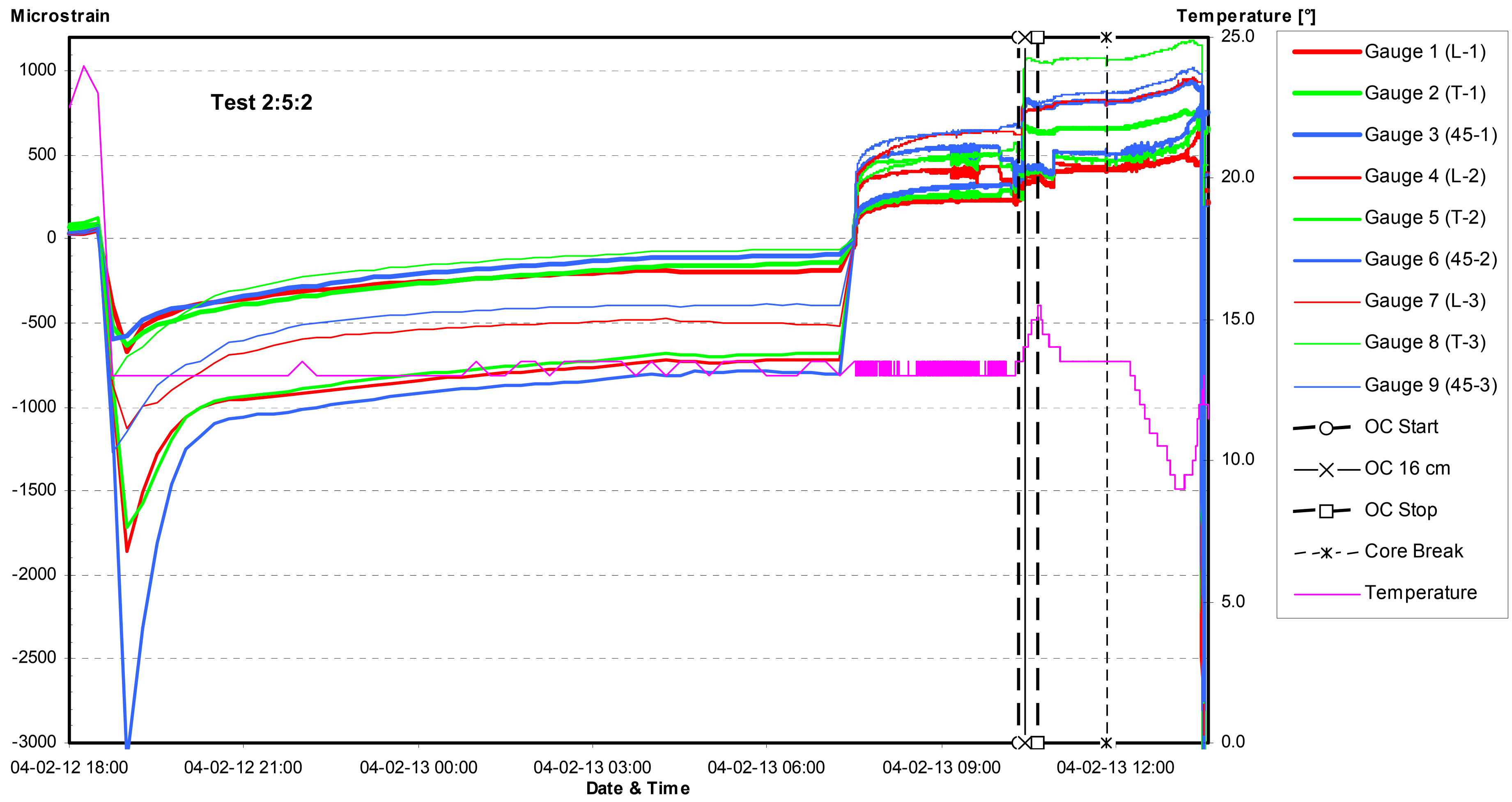


Figure B11. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:5:2, 437.23 m borehole length.*

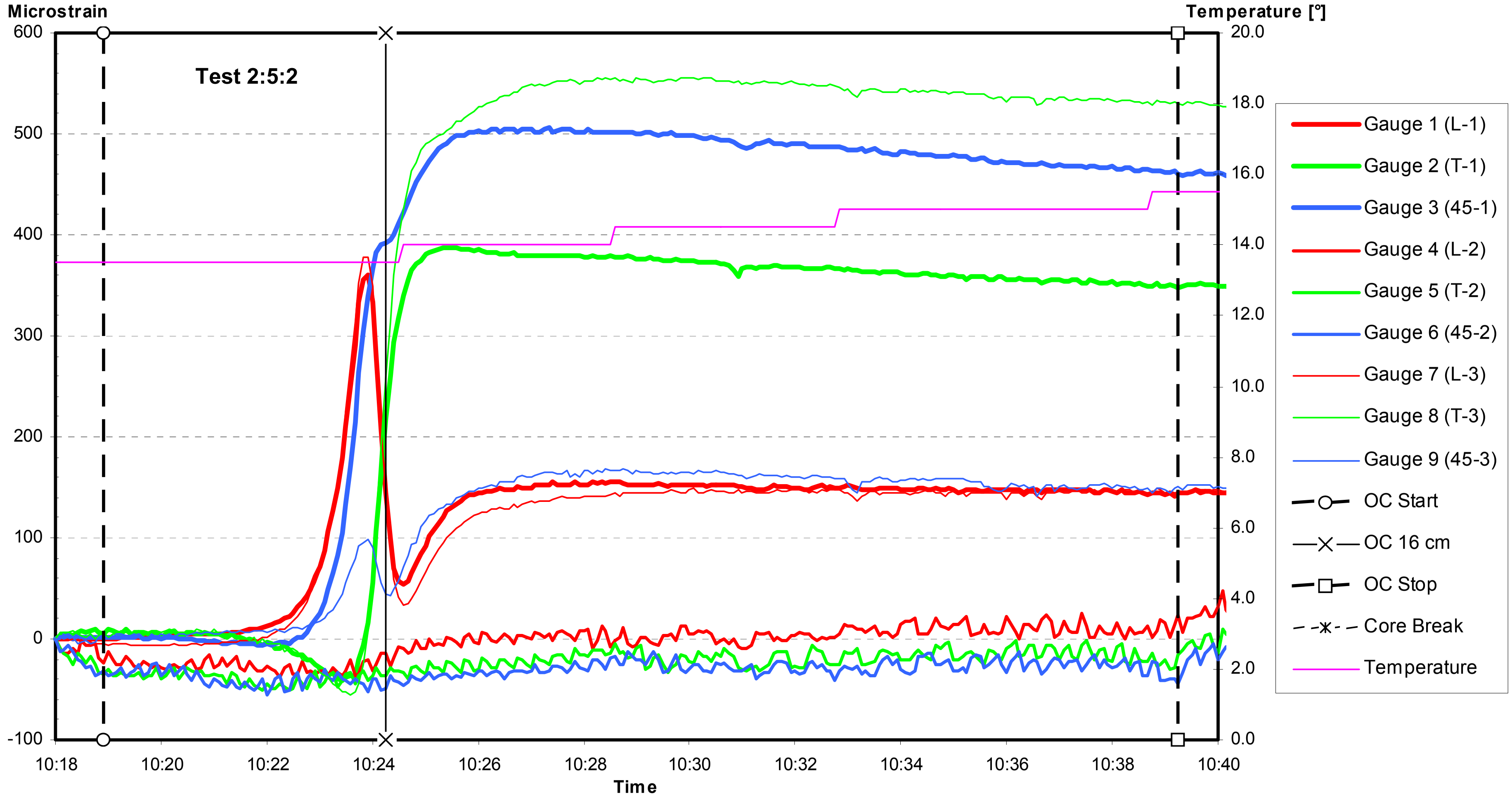


Figure B12. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:5:2, 437.23 m borehole length. Strain values reset to zero at 10:18.*

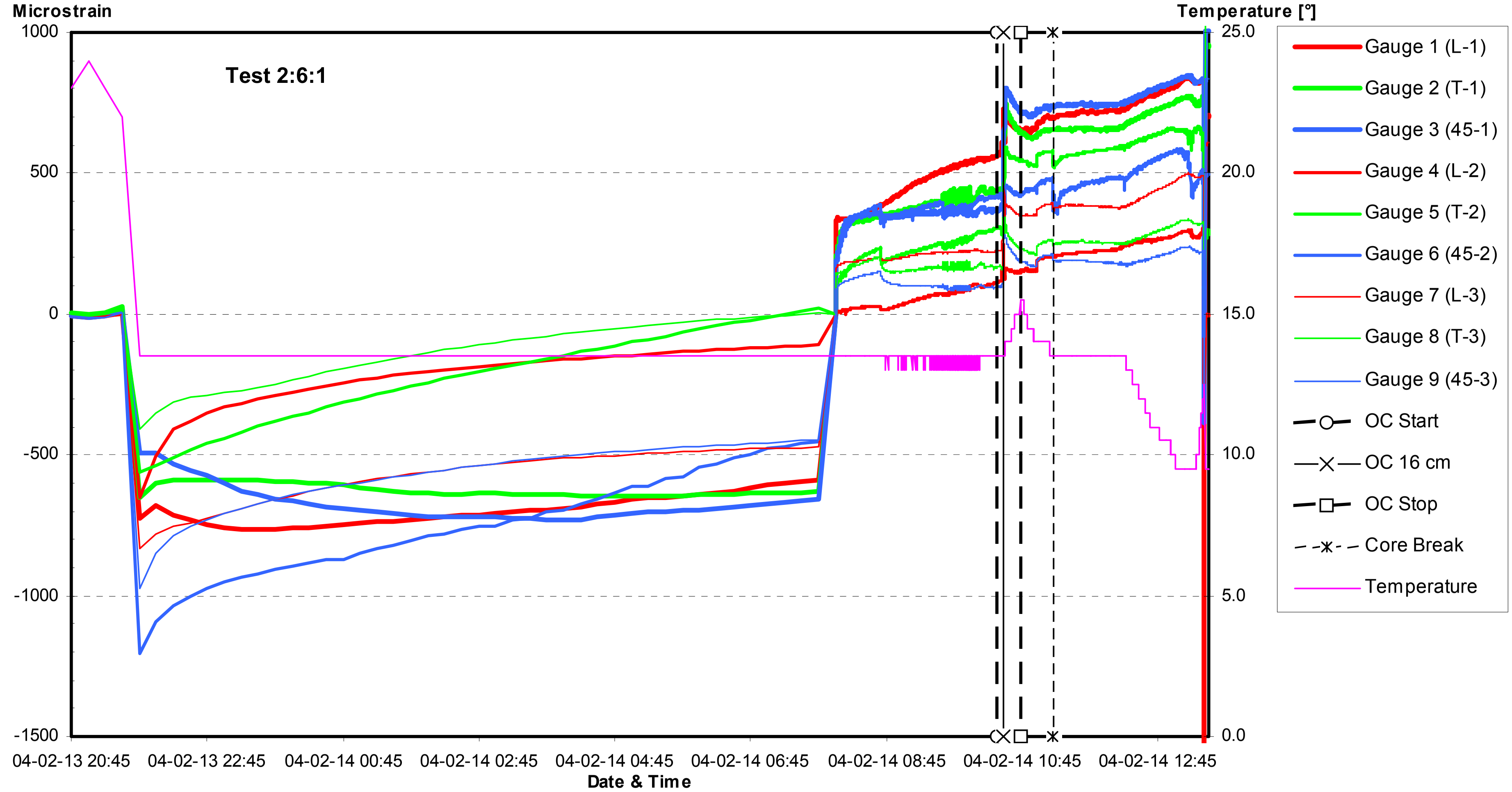


Figure B13. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:6:1, 438.66 m borehole length.*

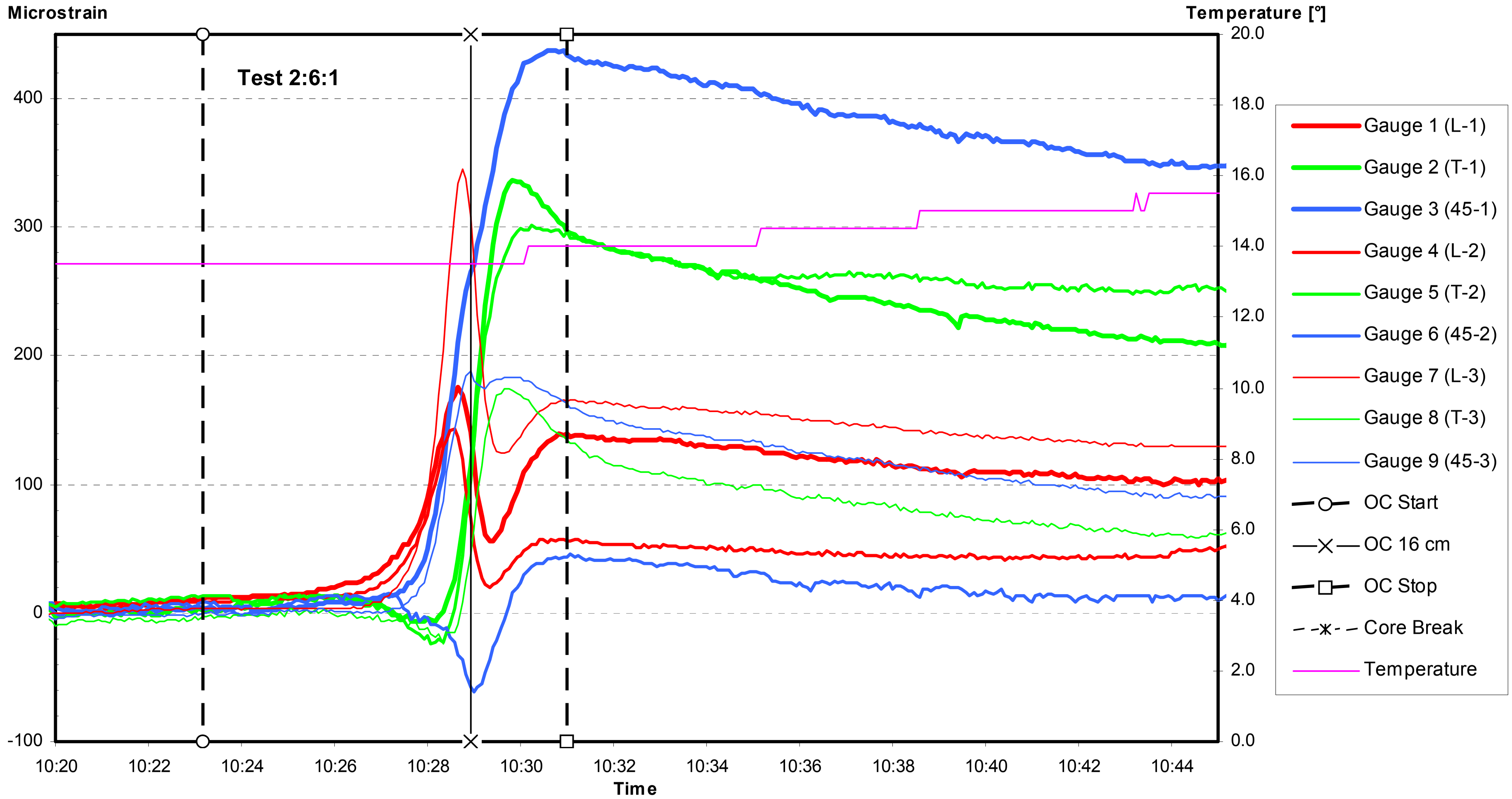


Figure B14. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:6:1, 438.66 m borehole length. Strain values reset to zero at 10:15.*

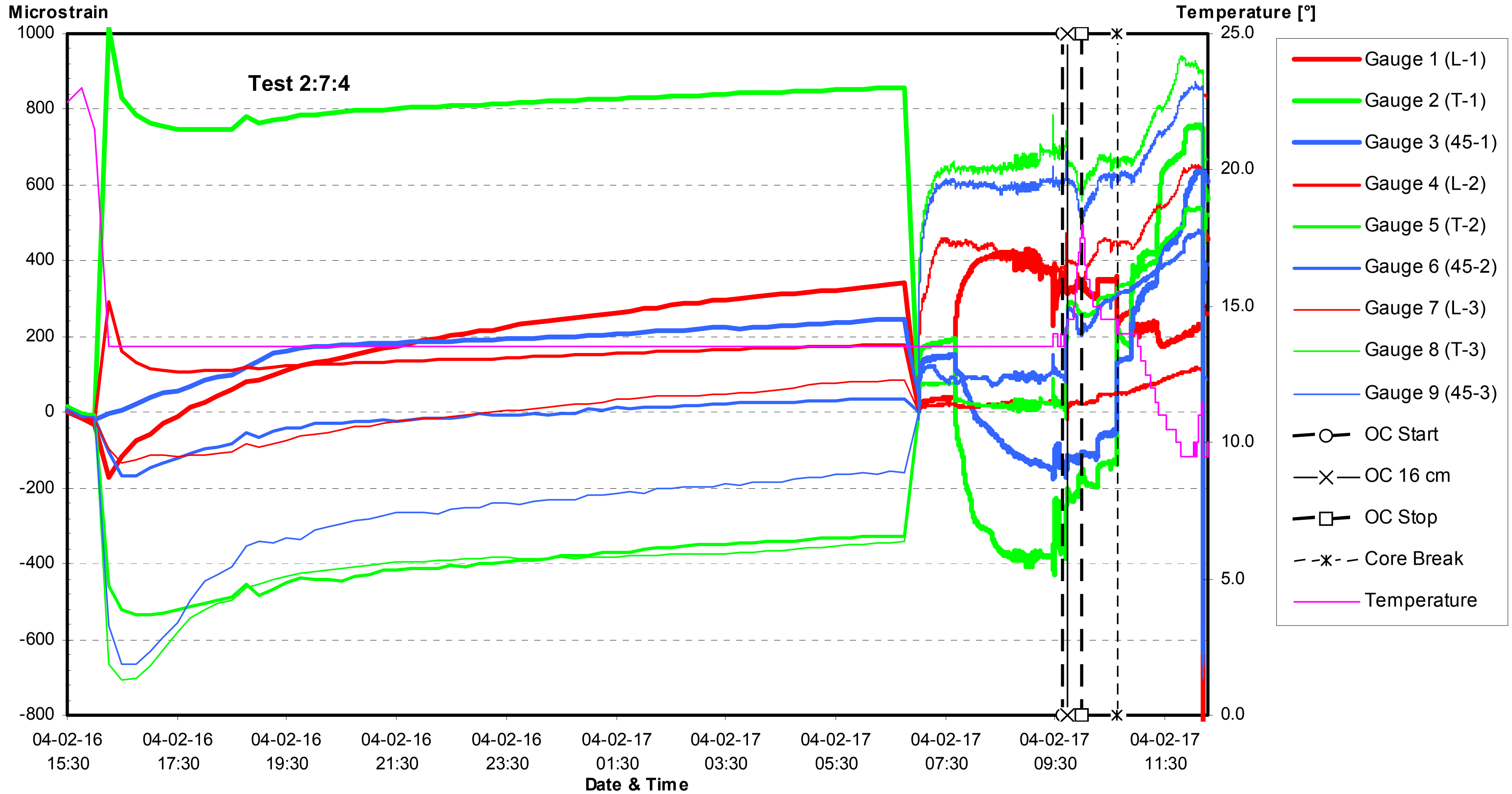


Figure B15. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:7:4, 455.25 m borehole length.*

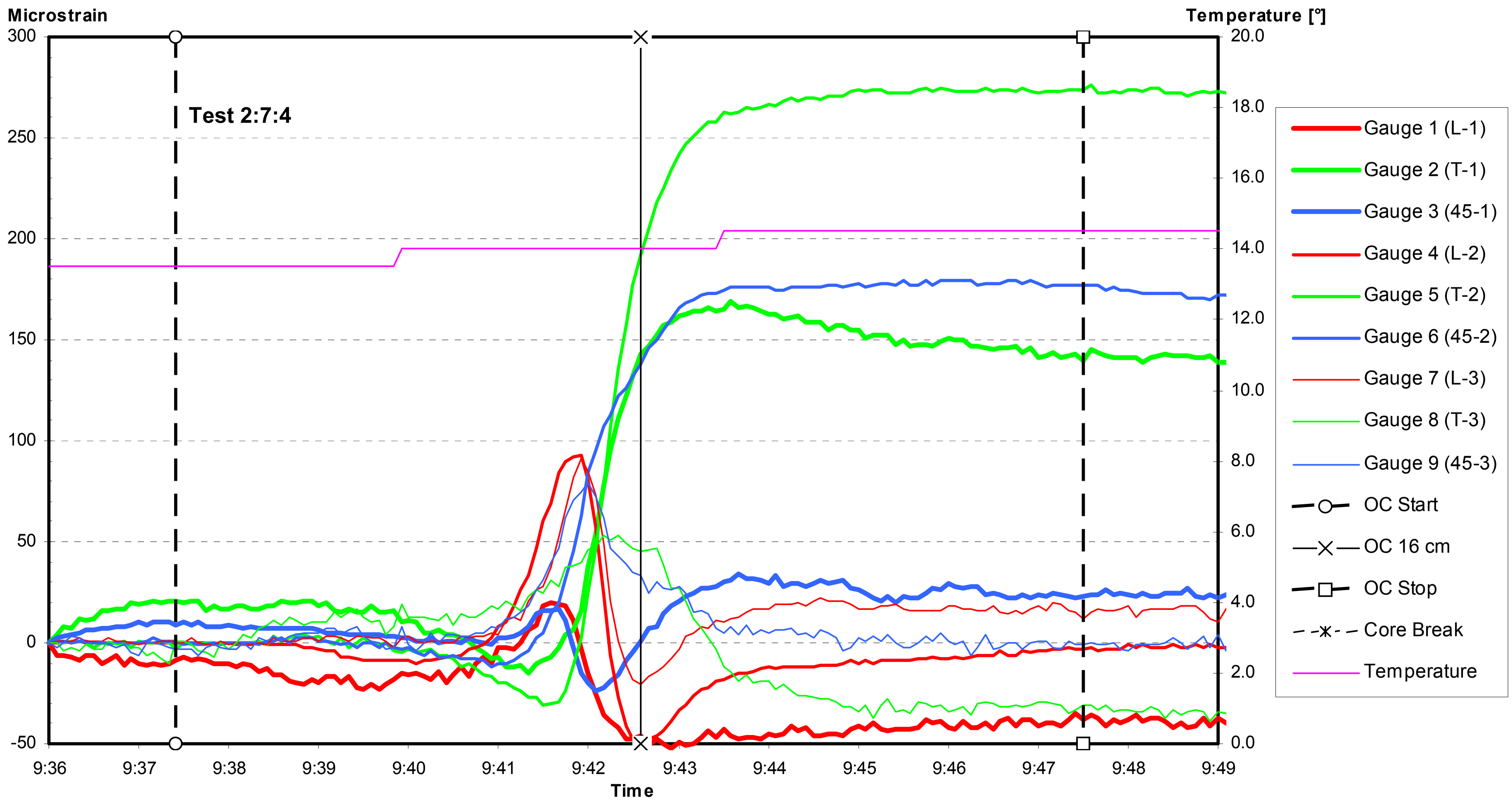


Figure B16. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:7:4, 455.25 m borehole length. Strain values reset to zero at 09:36.*

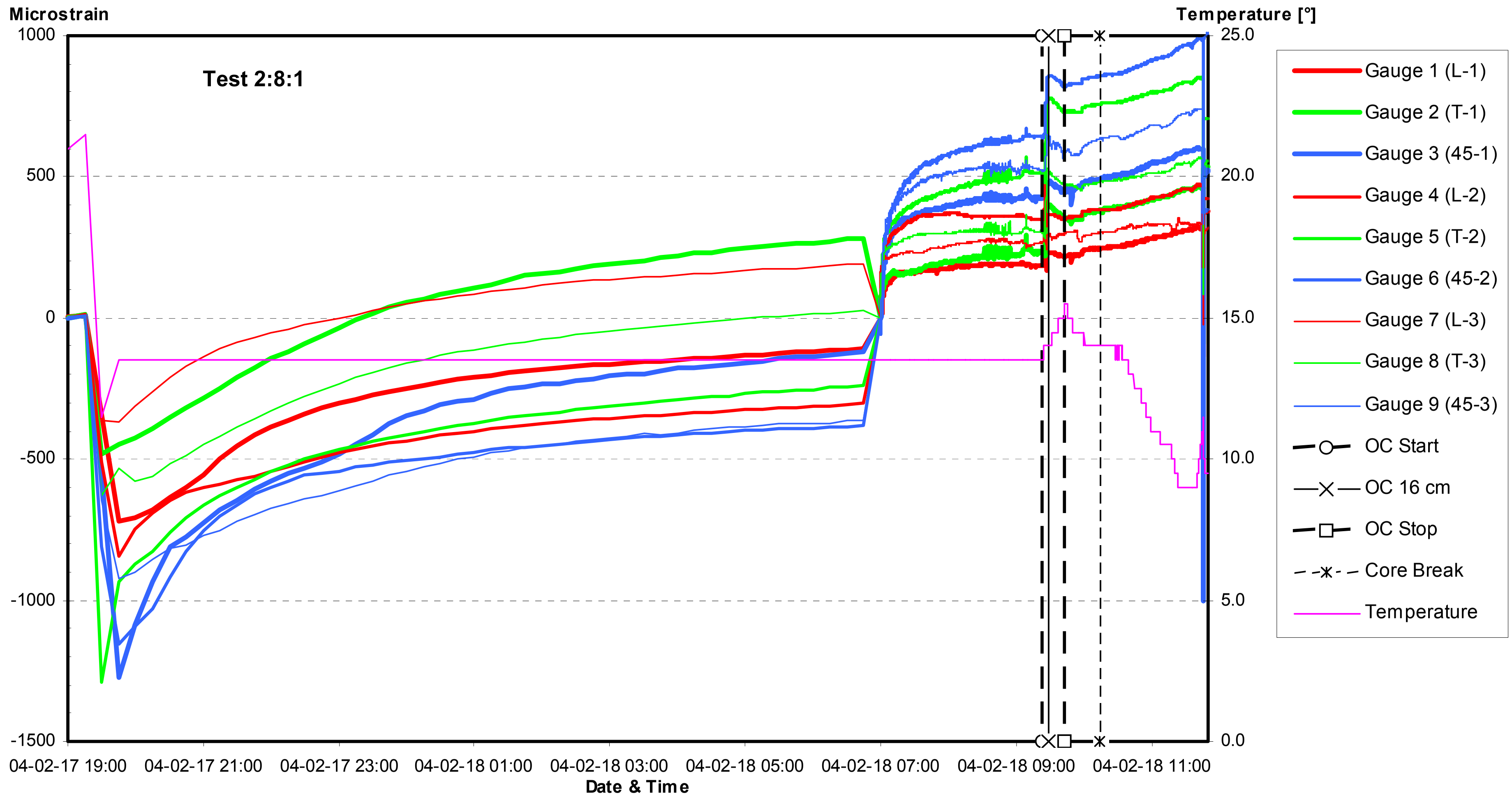


Figure B17. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:8:1, 456.35 m borehole length.*

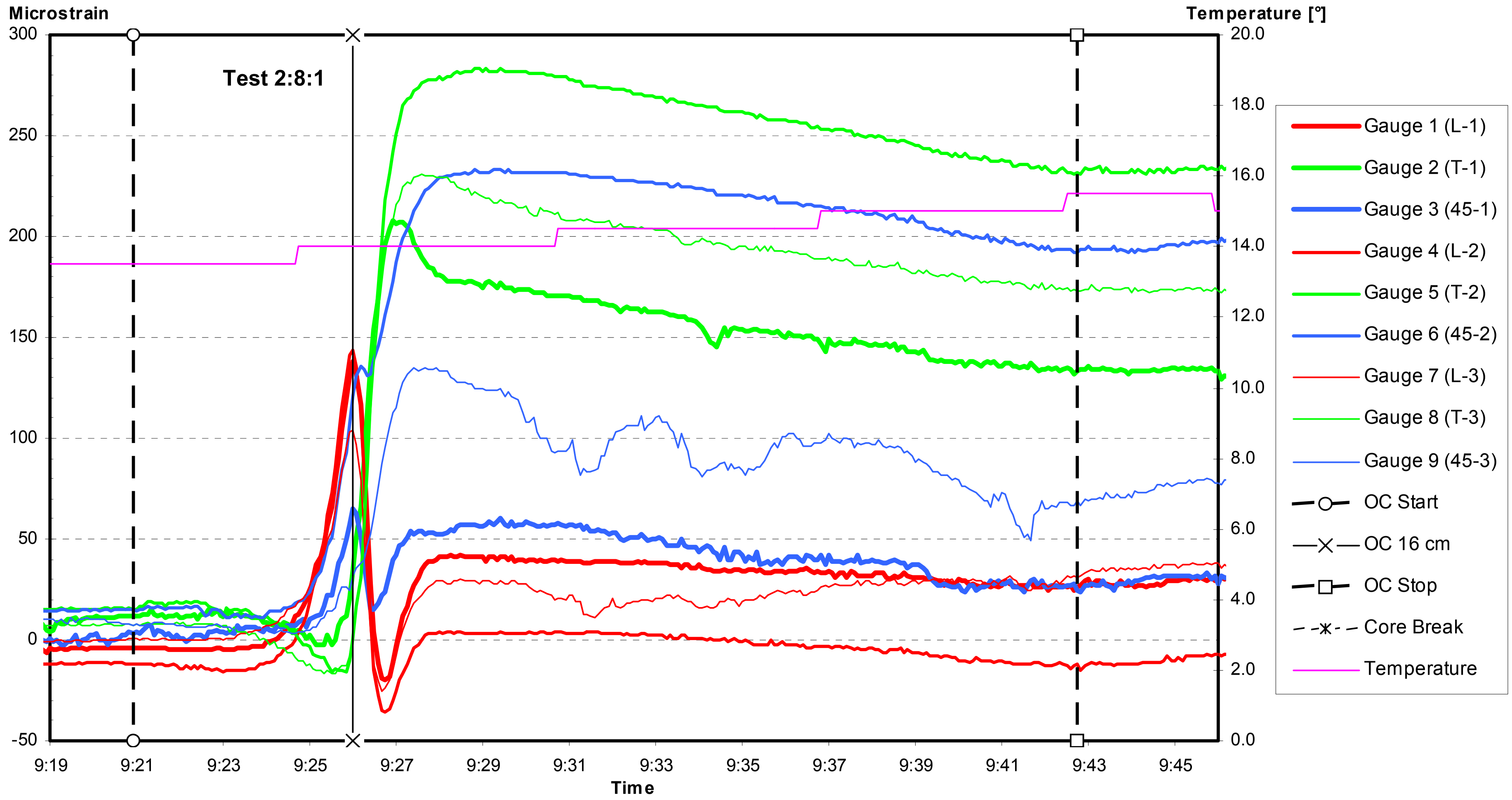


Figure B18. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:8:1, 456.35 m borehole length. Strain values reset to zero at 09:00.*

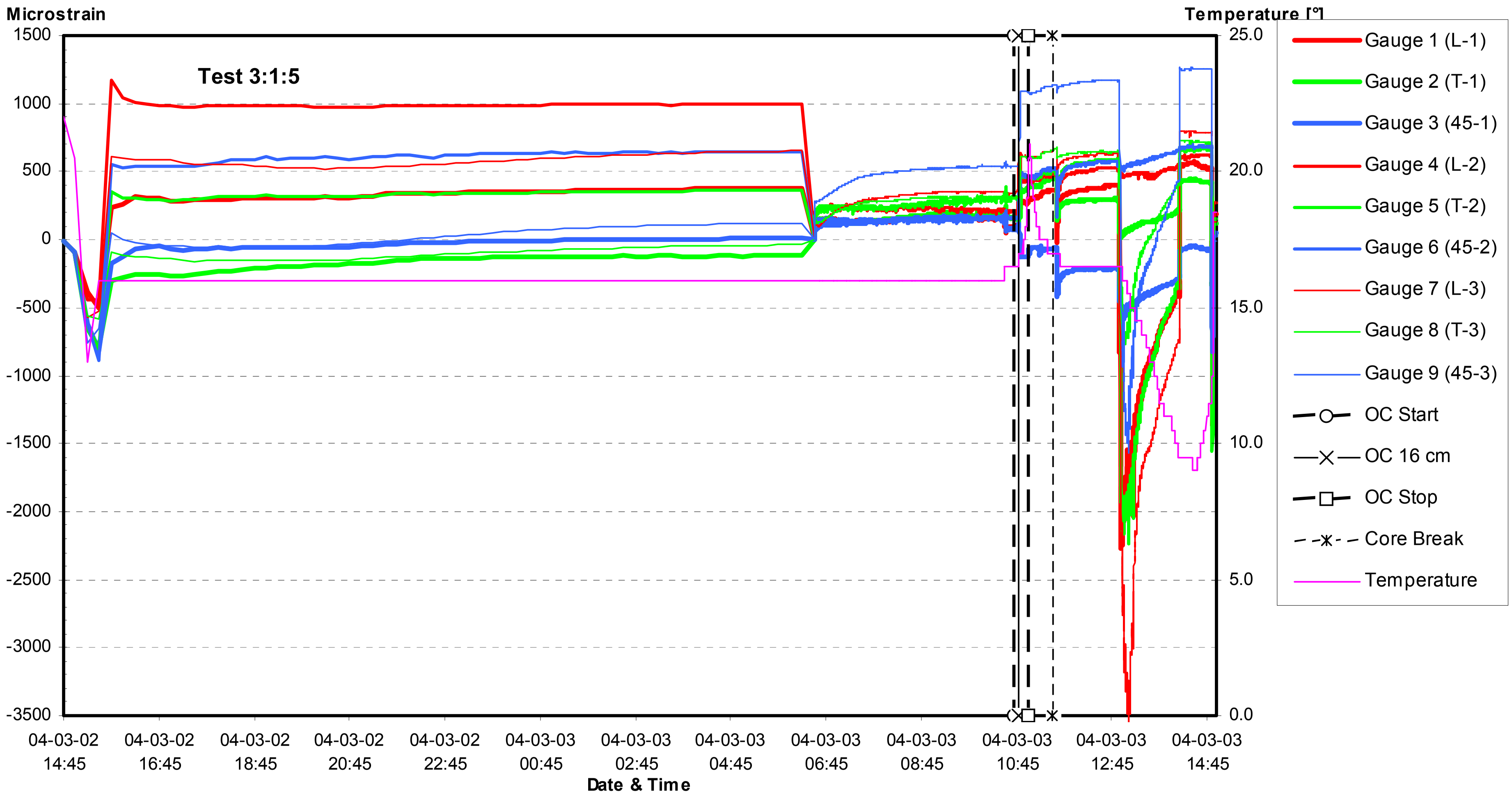


Figure B19. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:1:5, 635.03 m borehole length.*

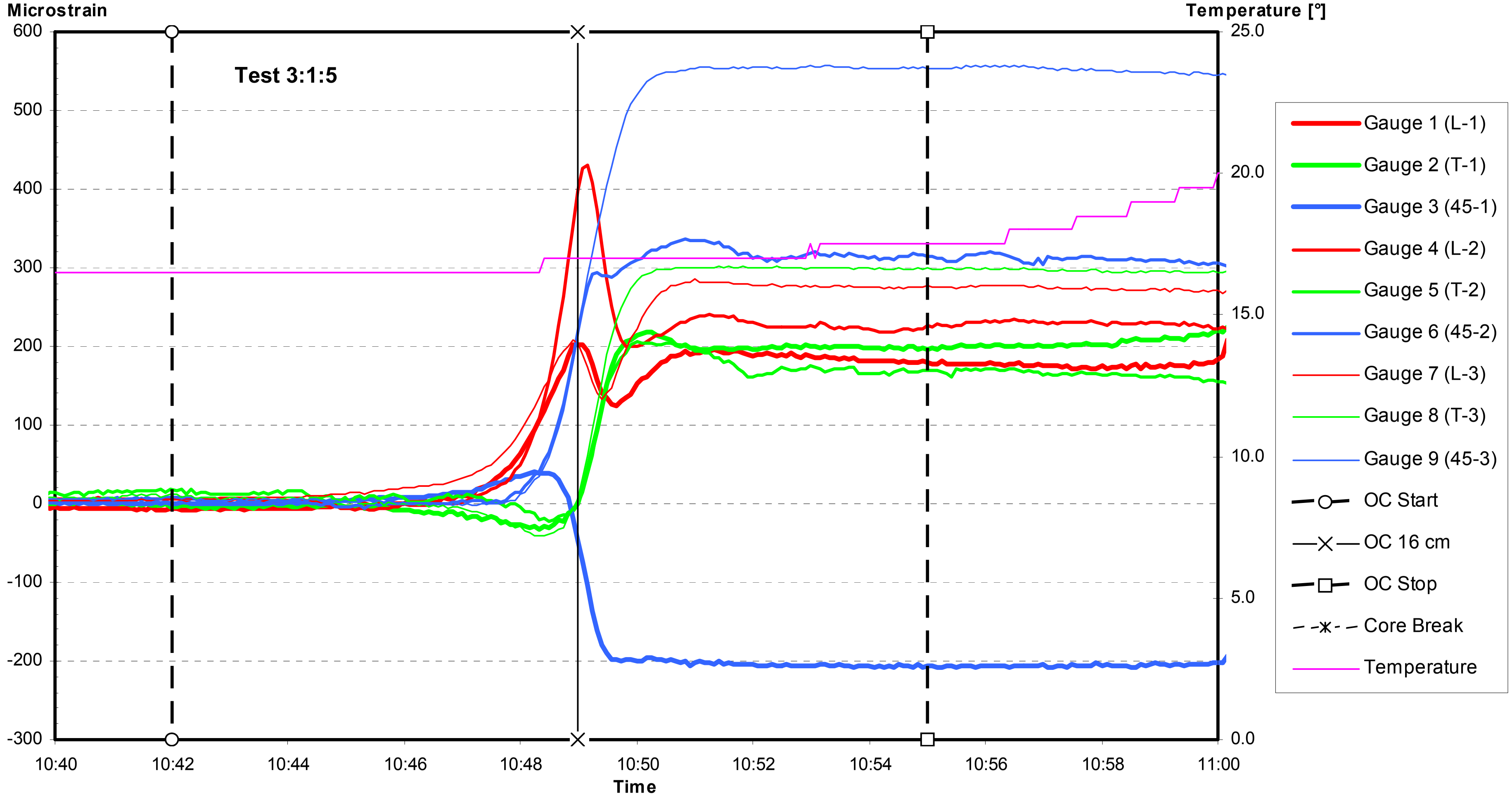


Figure B20. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 3:1:5, 635.03 m borehole length. Strain values reset to zero at 10:35.*

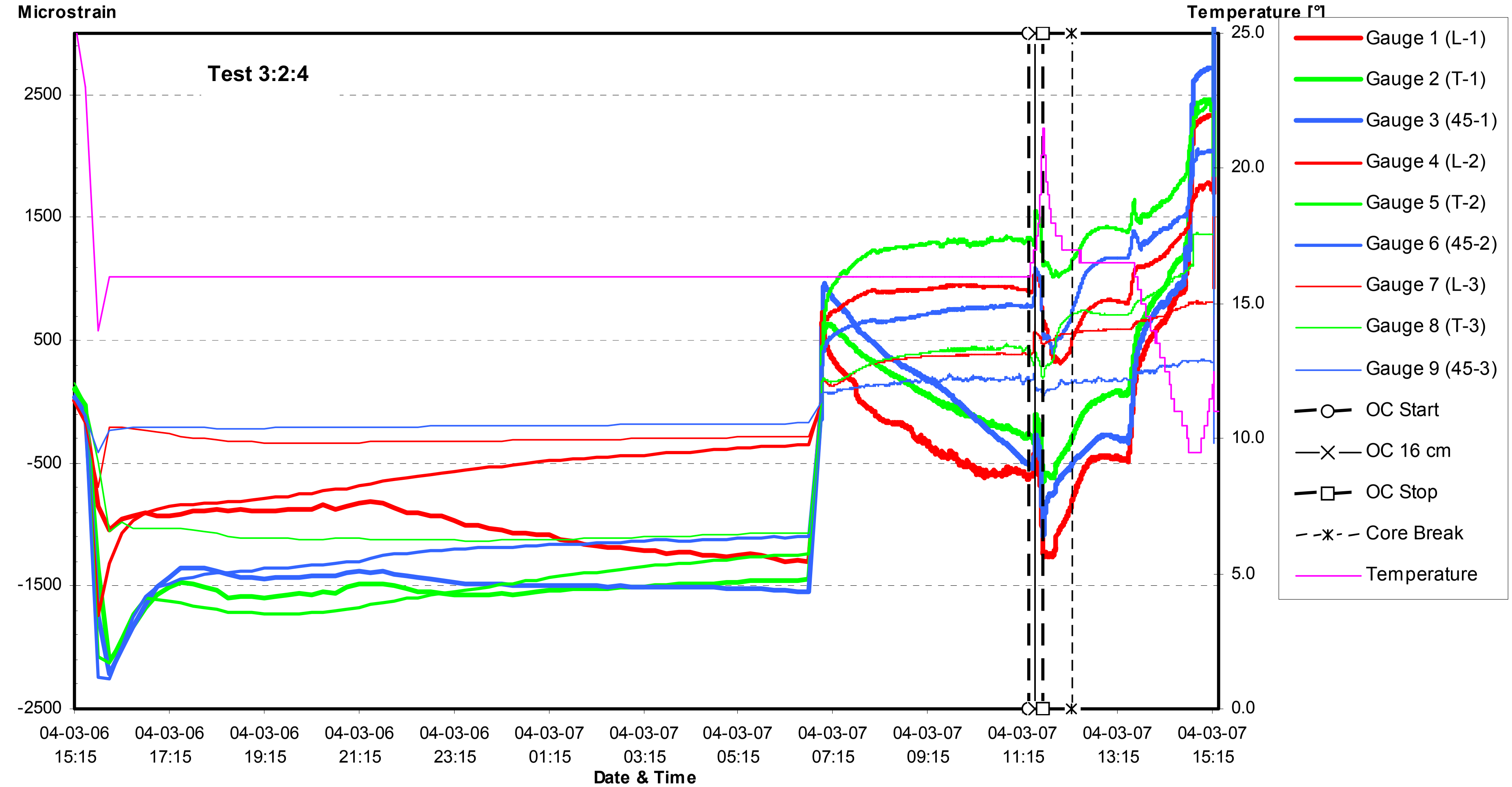


Figure B21. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:2:4, 639.57 m borehole length.*

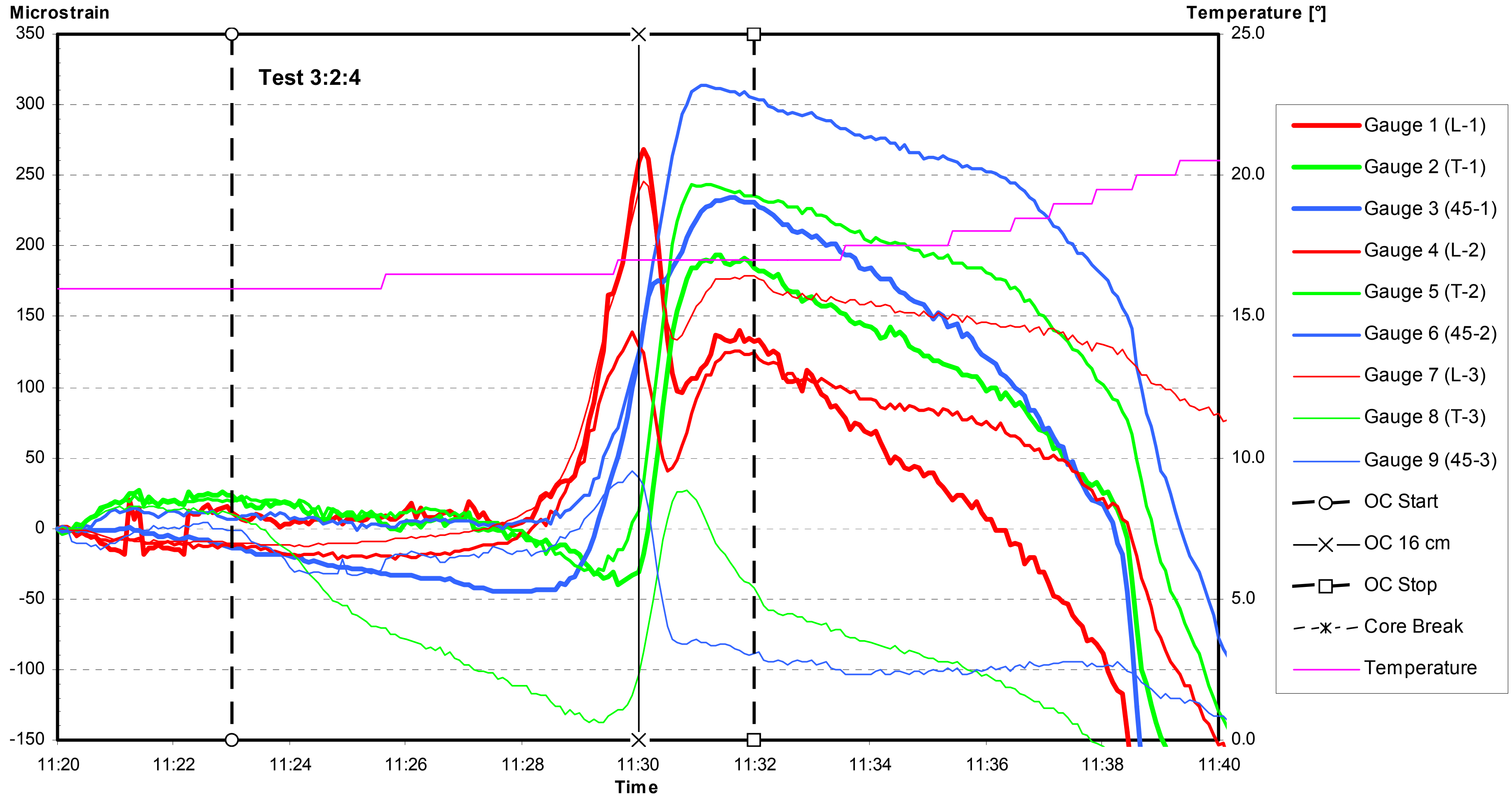


Figure B22. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 3:2:4, 639.57 m borehole length. Strain values reset to zero at 11:20.*

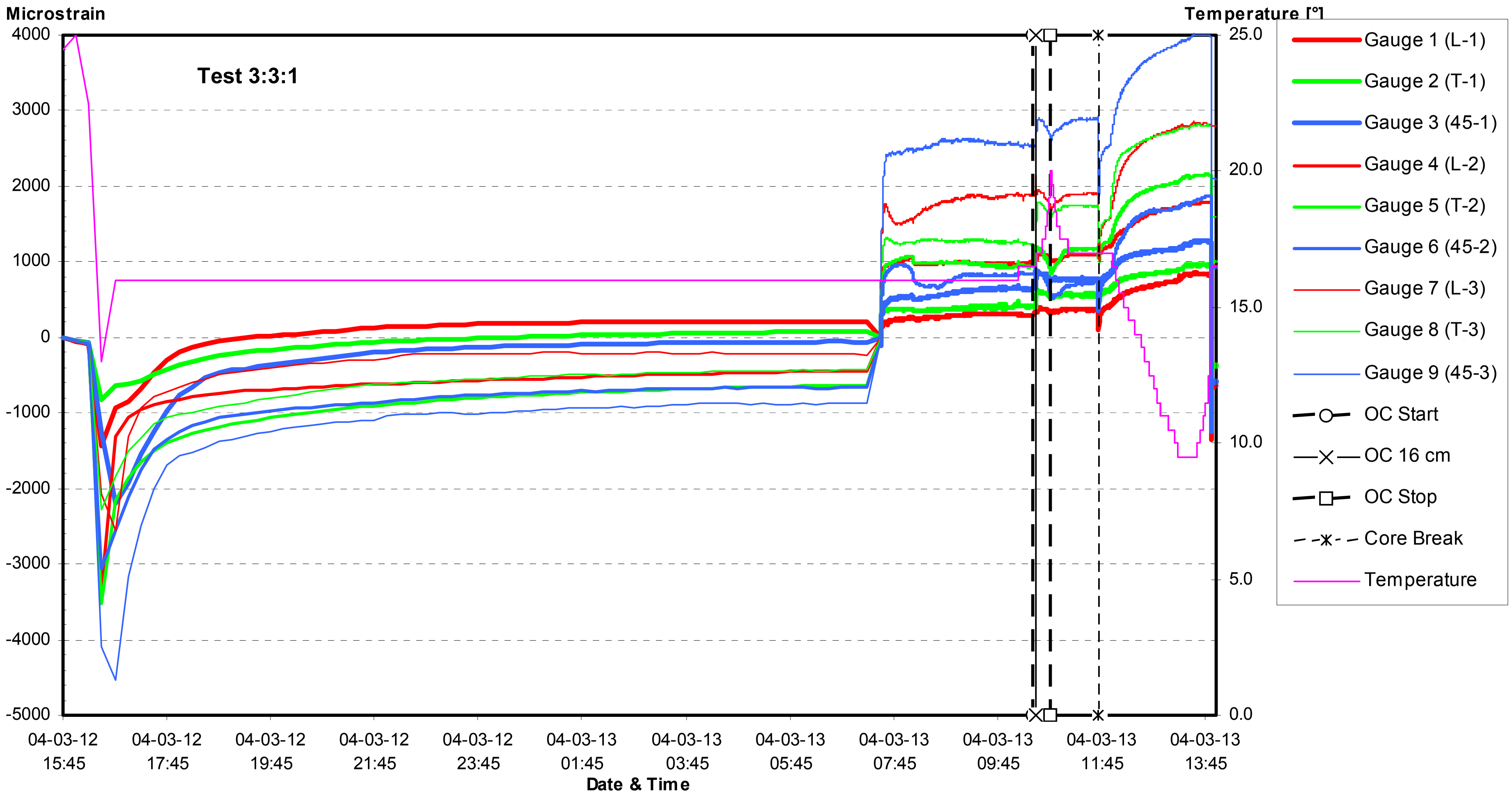


Figure B23. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:3:1, 644.71 m borehole length.*

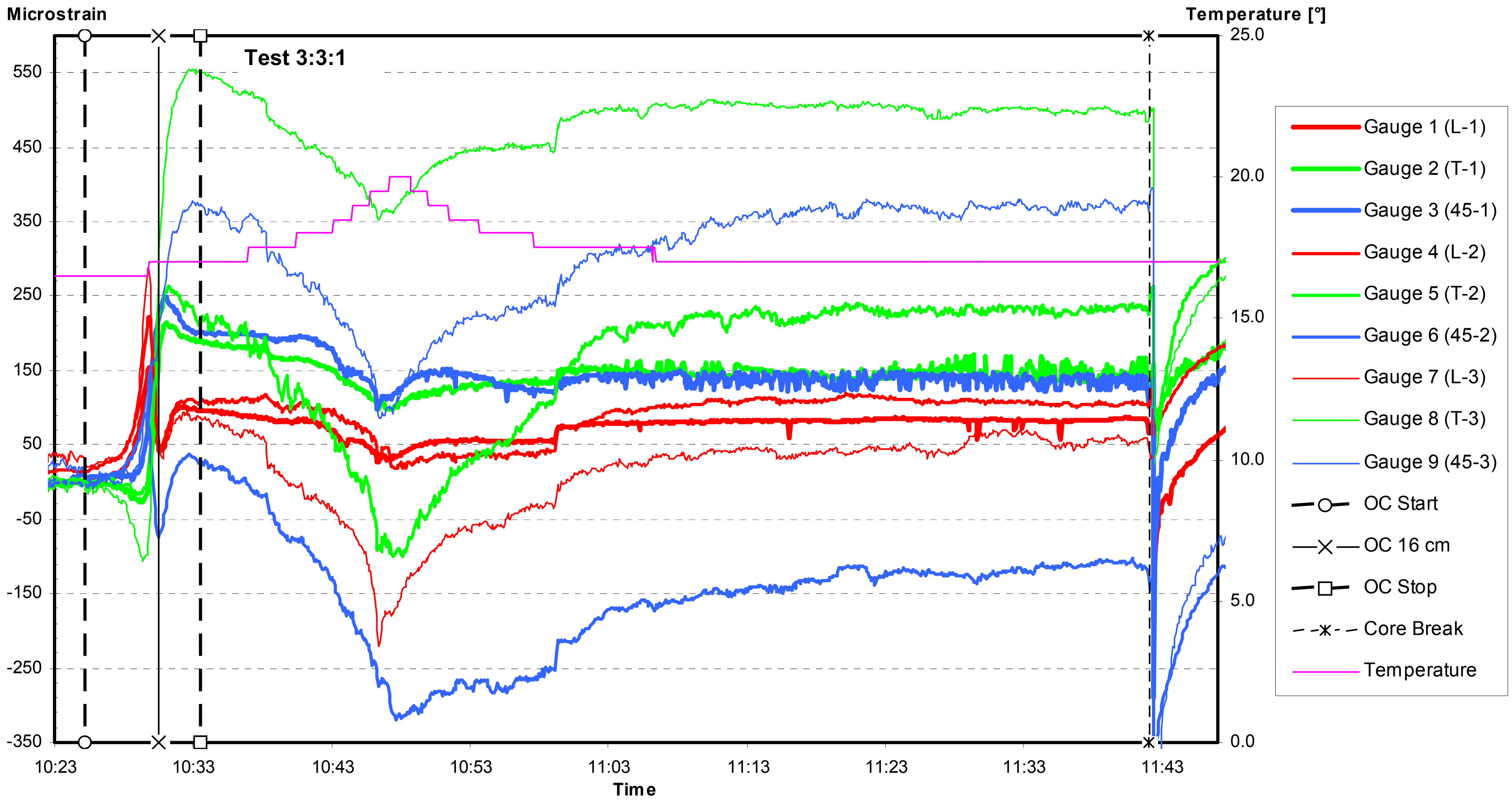


Figure B24. *Recorded strain data and temperature during overcoring (from overcoring start to core break) for test no. 3:3:1, 644.71 m borehole length. Strain values reset to zero at 10:15.*

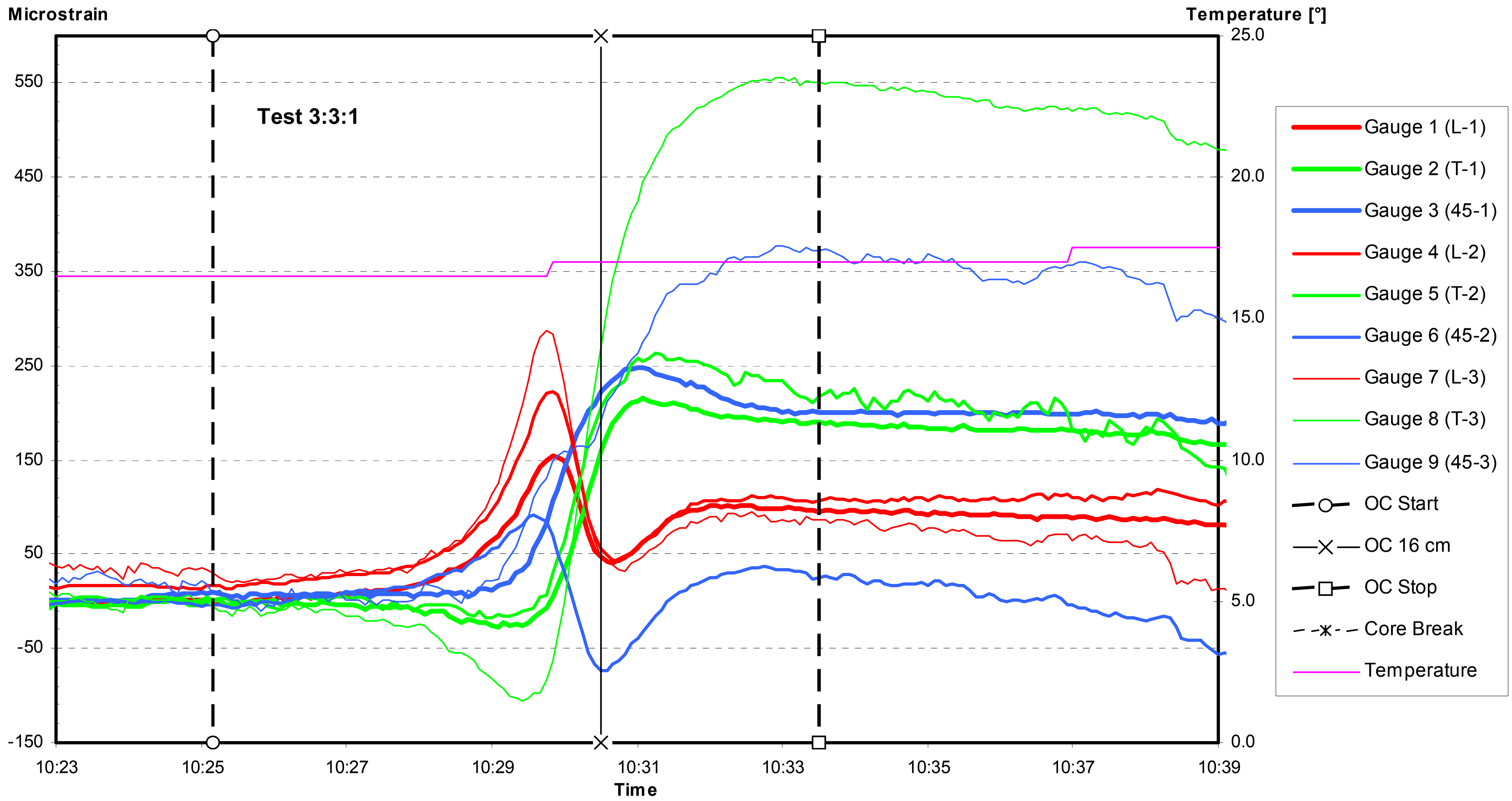


Figure B25. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 3:3:1, 644.71 m borehole length. Strain values reset to zero at 10:15.*

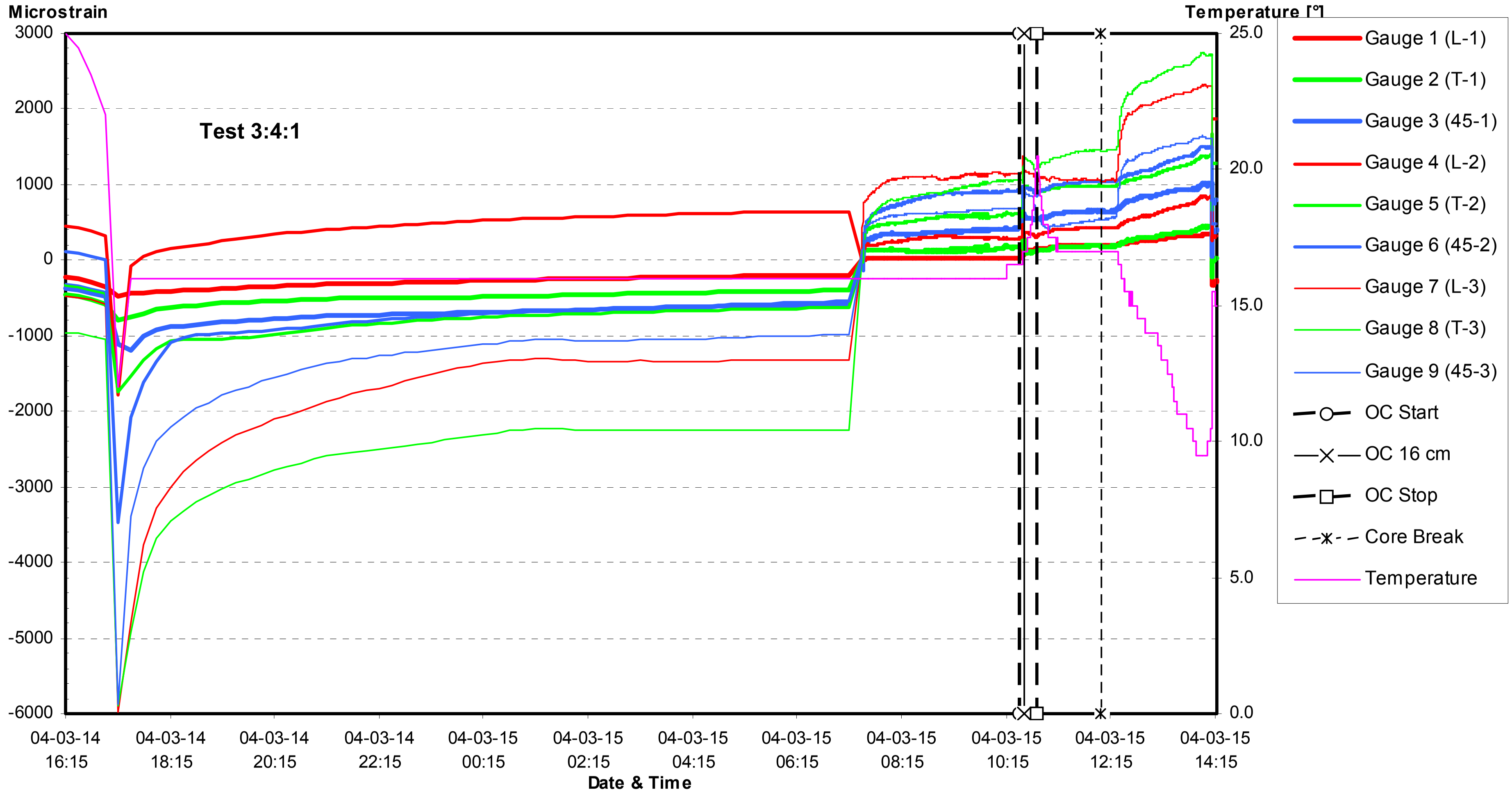


Figure B26. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:4:1, 645.92 m borehole length.*

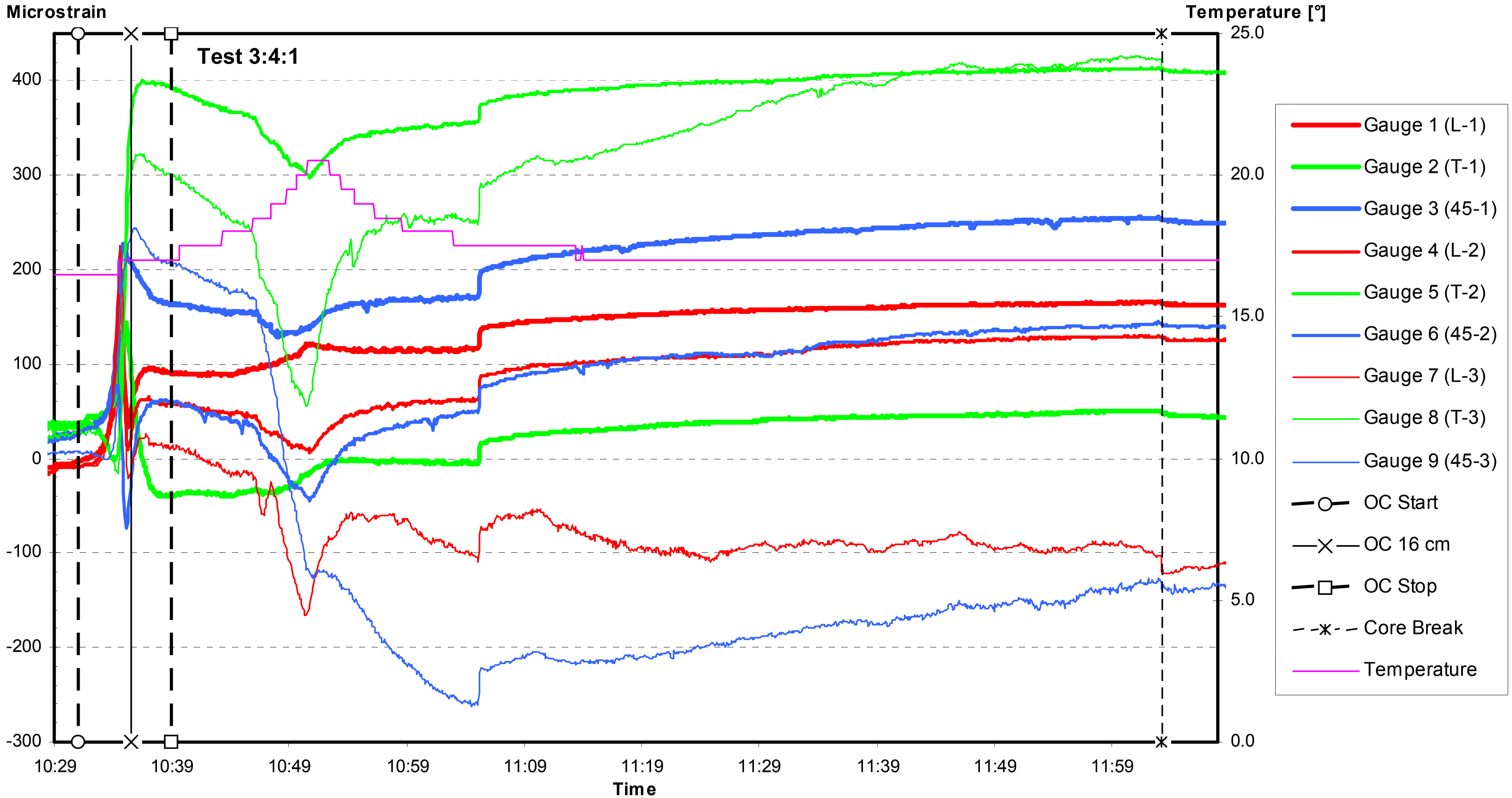


Figure B27. *Recorded strain data and temperature during overcoring (from overcoring start to core break) for test no. 3:4:1, 645.92 m borehole length. Strain values reset to zero at 10:00.*

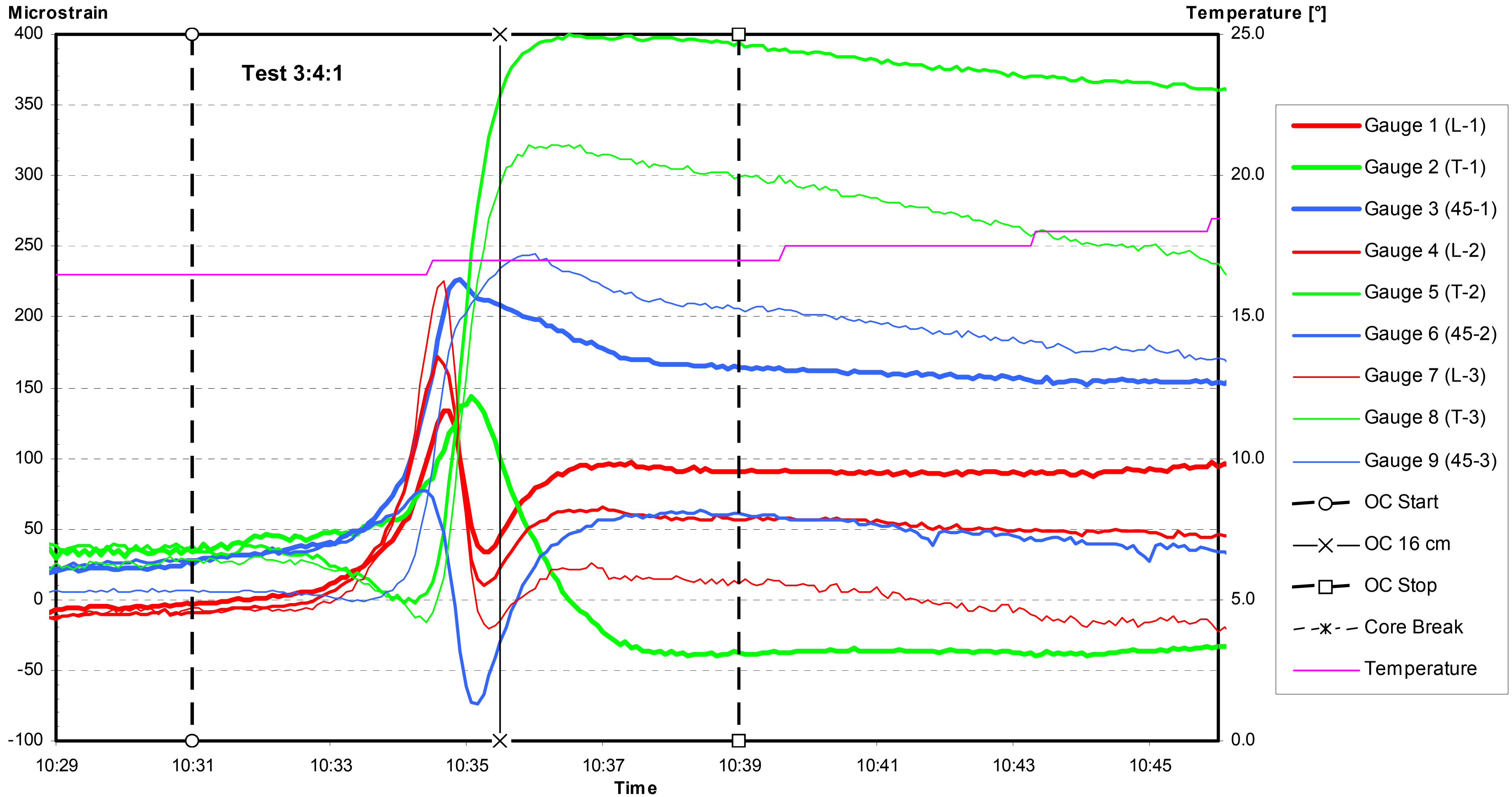


Figure B28. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 3:4:1, 645.92 m borehole length. Strain values reset to zero at 10:00.*

Appendix C

Biaxial test data

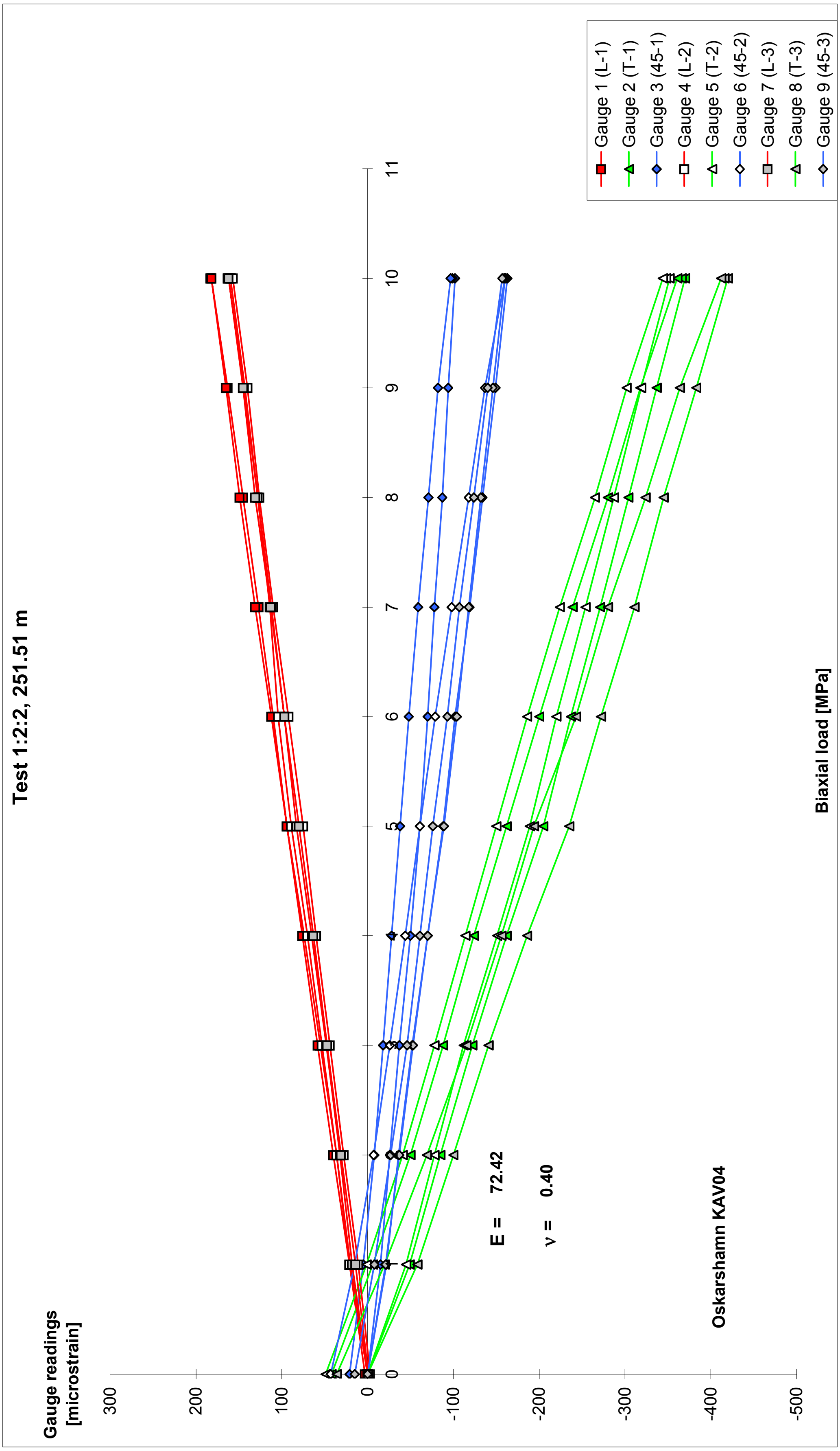


Figure C1. *Results from biaxial testing of test no. 1:2:2, 251.51 m borehole length.*

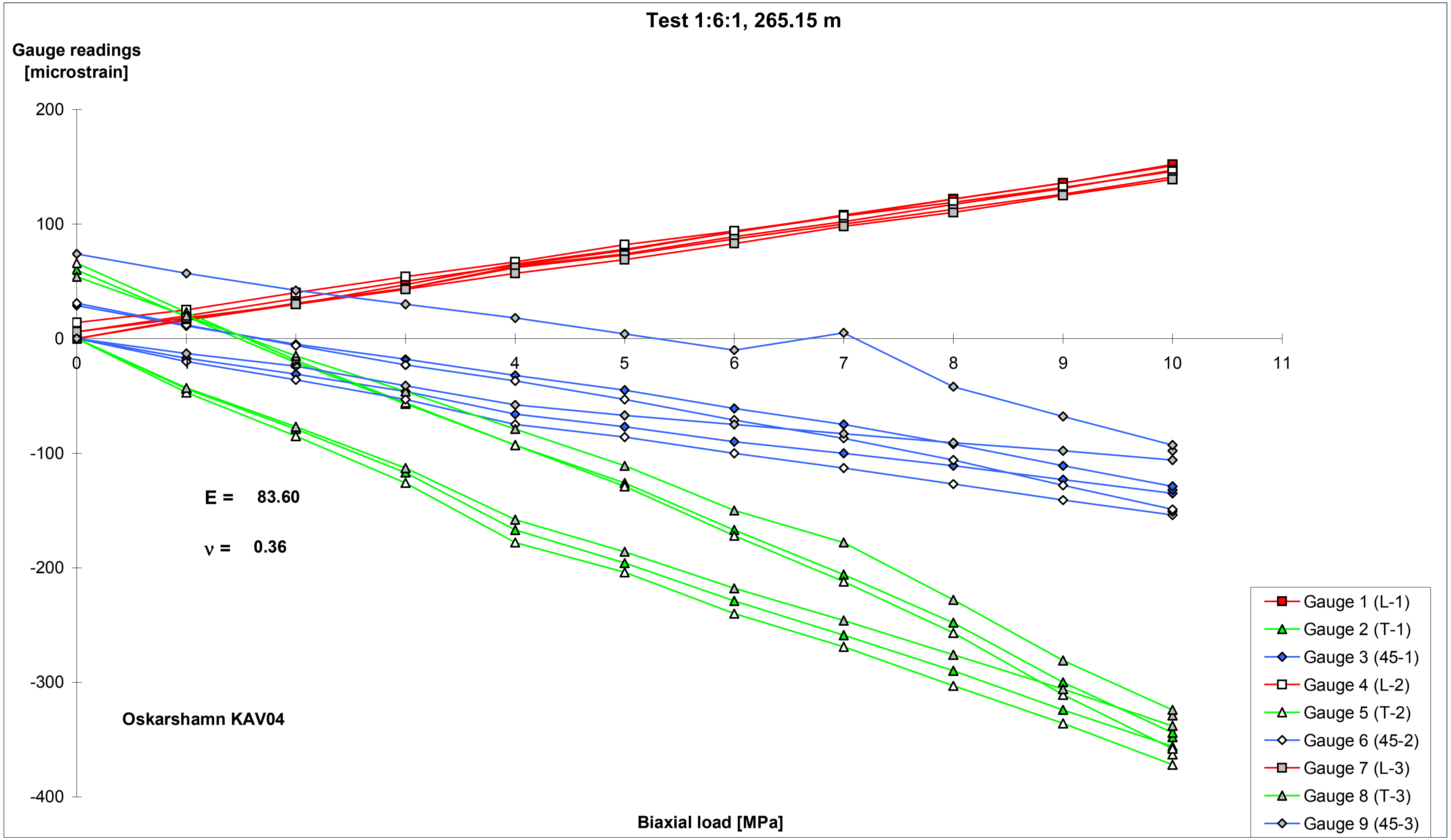


Figure C2. *Results from biaxial testing of test no. 1:6:1, 265.15 m borehole length.*

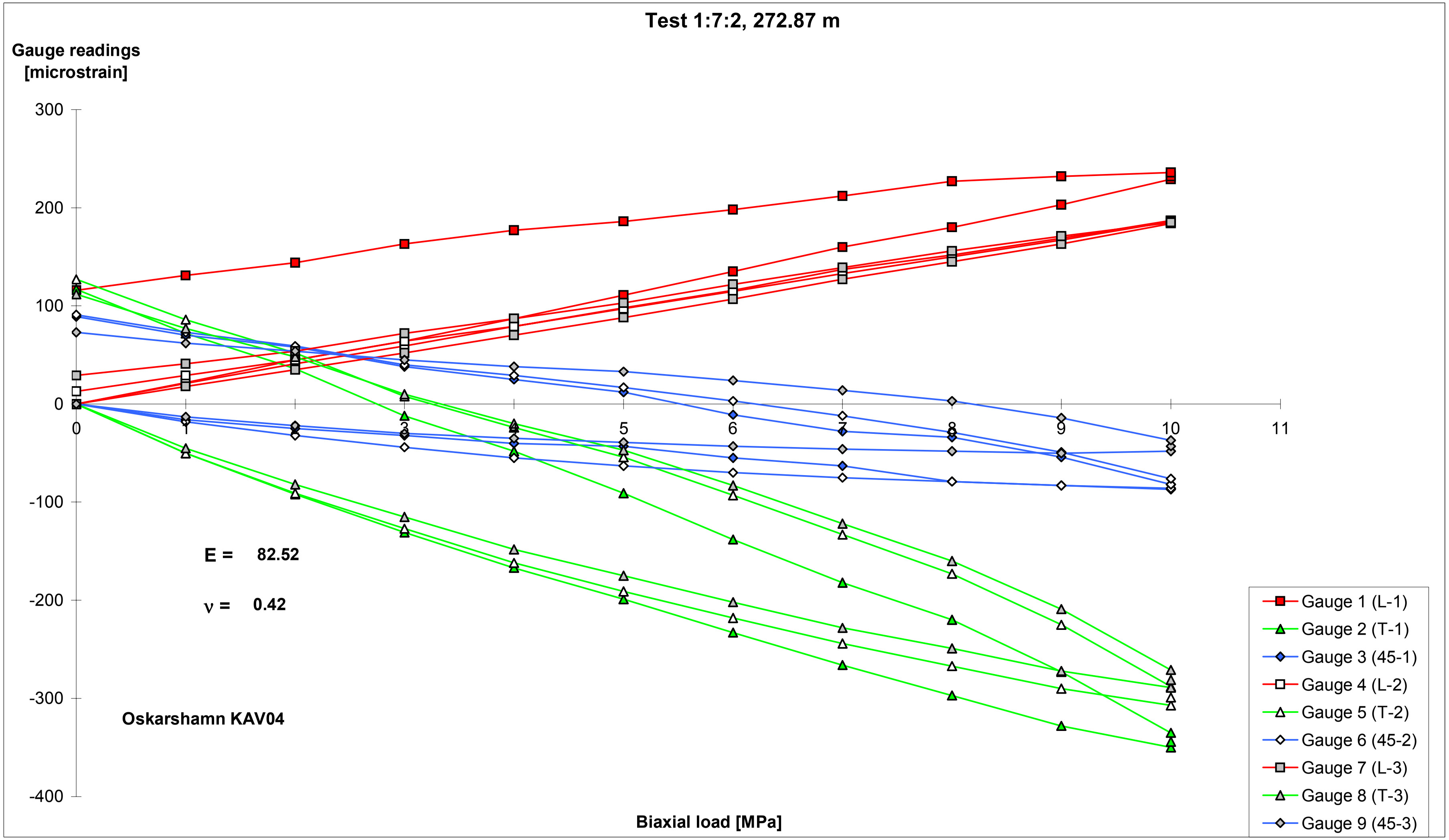


Figure C3. *Results from biaxial testing of test no. 1:7:2, 272.87 m borehole length.*

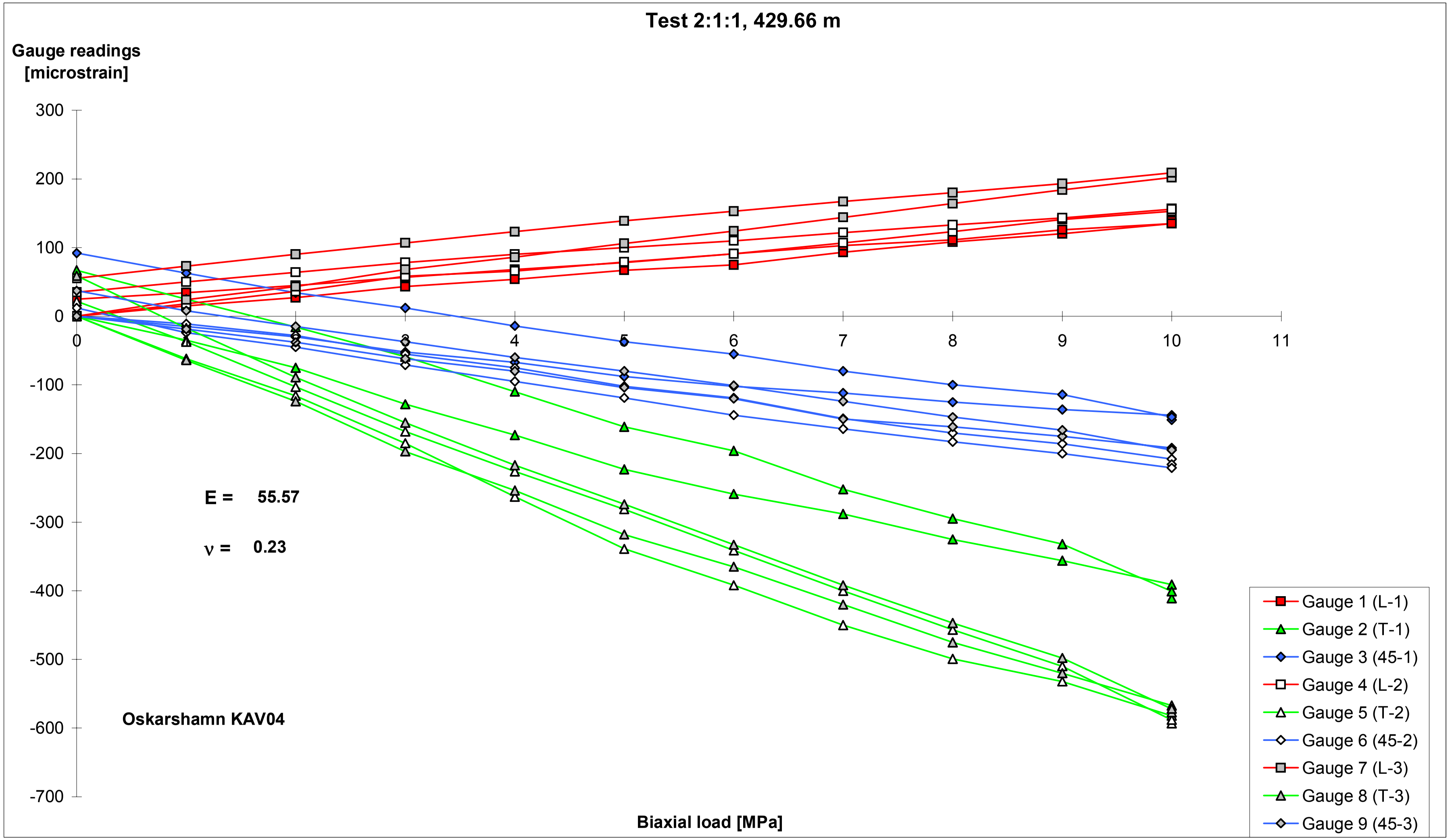


Figure C4. *Results from biaxial testing of test no. 2:1:1, 429.66 m borehole length.*

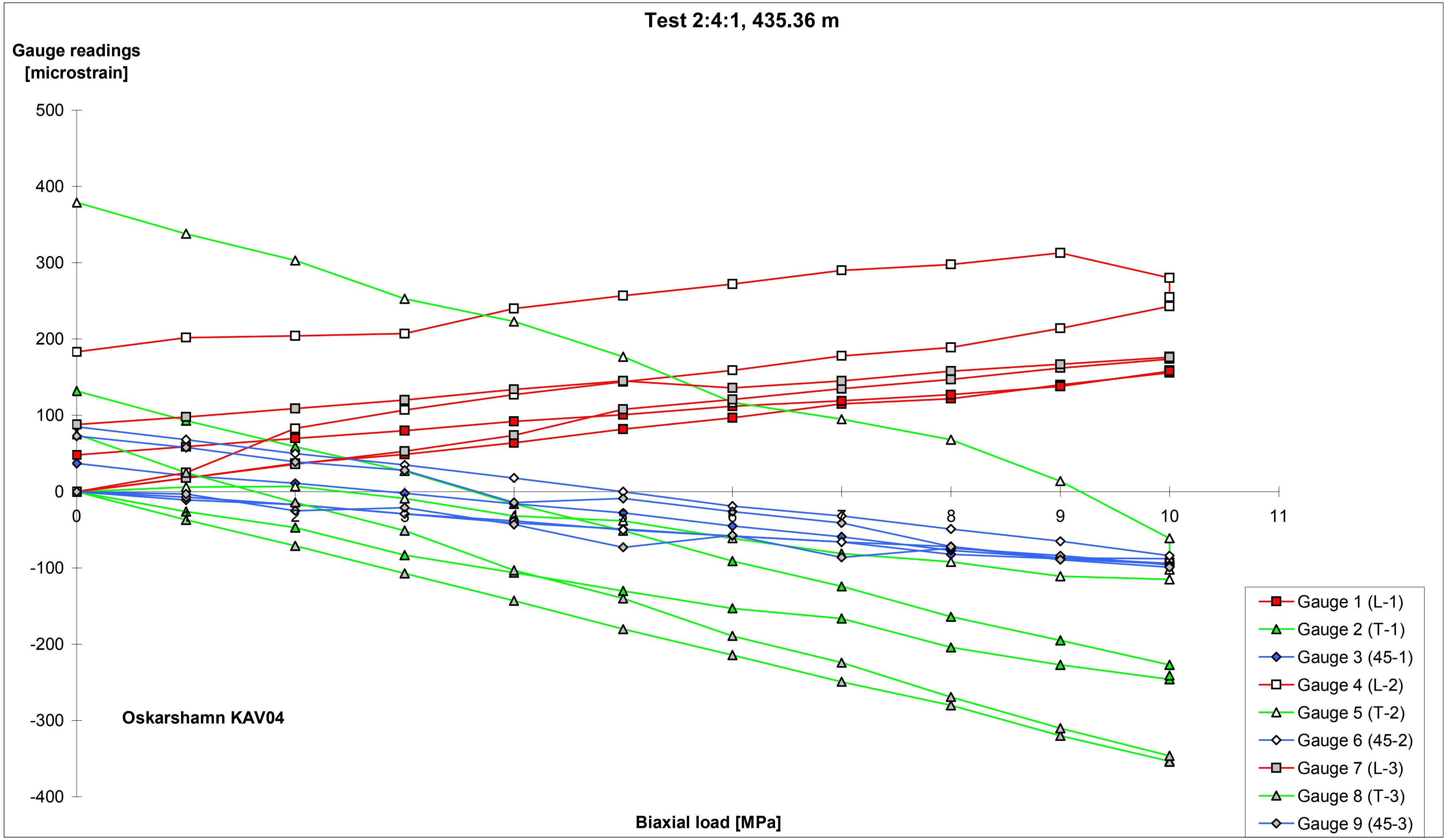


Figure C5. Results from biaxial testing of test no. 2:4:1, 435.36 m borehole length.

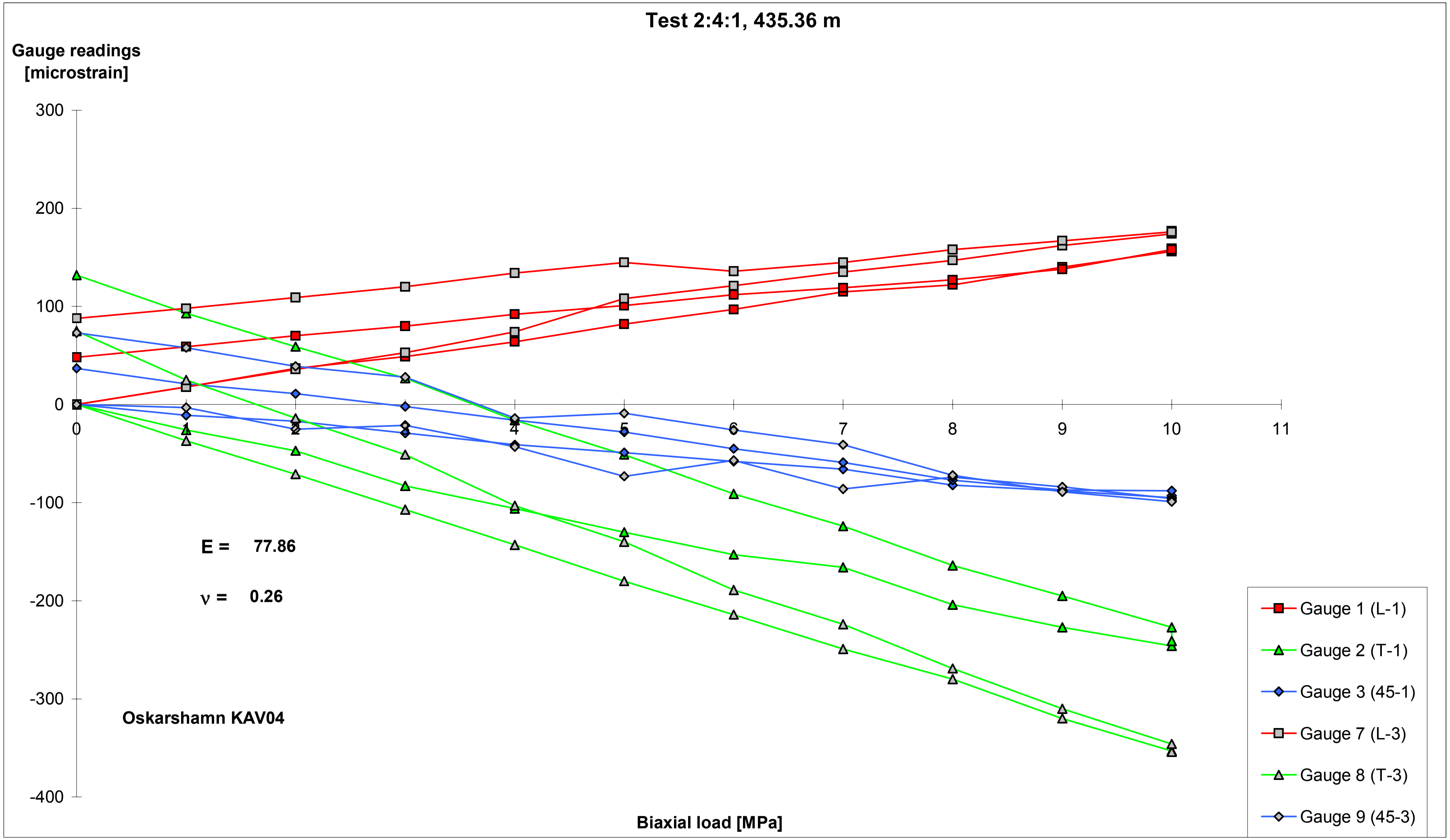


Figure C6. *Results from biaxial testing of test no. 2:4:1, 435.36 m borehole length, excluding rosette no. 2.*

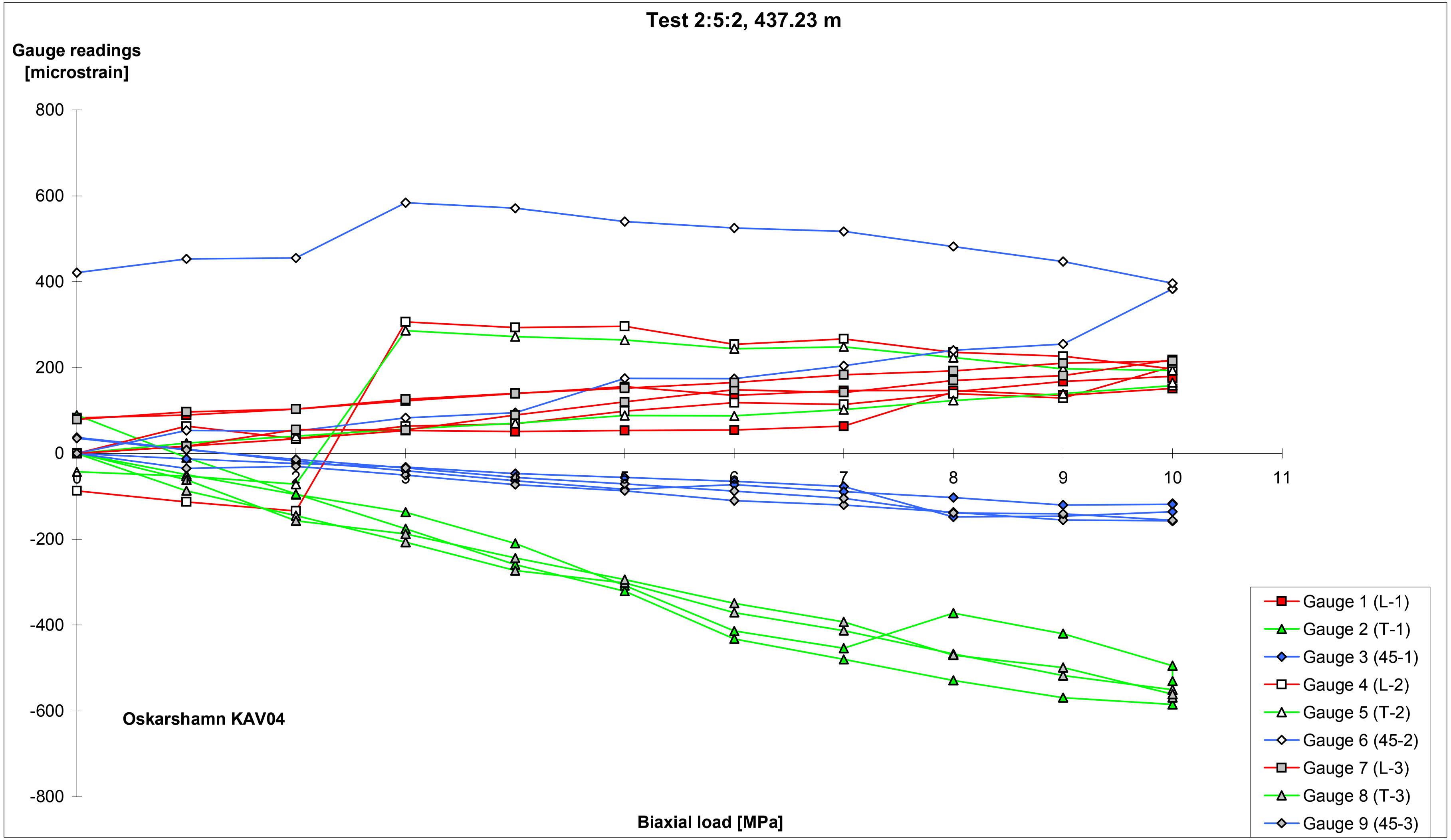


Figure C7. *Results from biaxial testing of test no. 2:5:2, 437.23 m borehole length.*

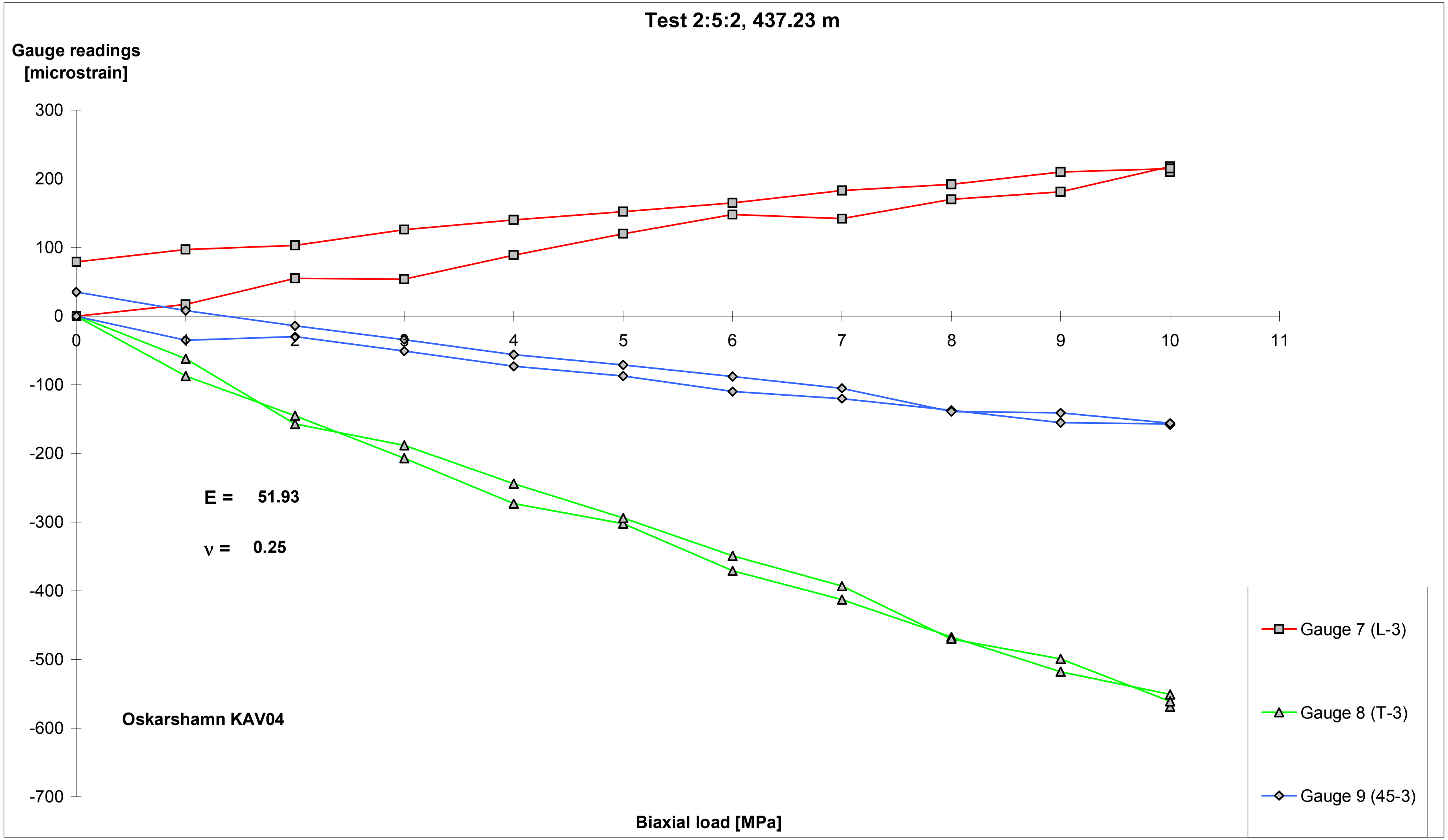


Figure C8. *Results from biaxial testing of test no. 2:5:2, 437.23 m borehole length, excluding rosette nos. 1 and 2.*

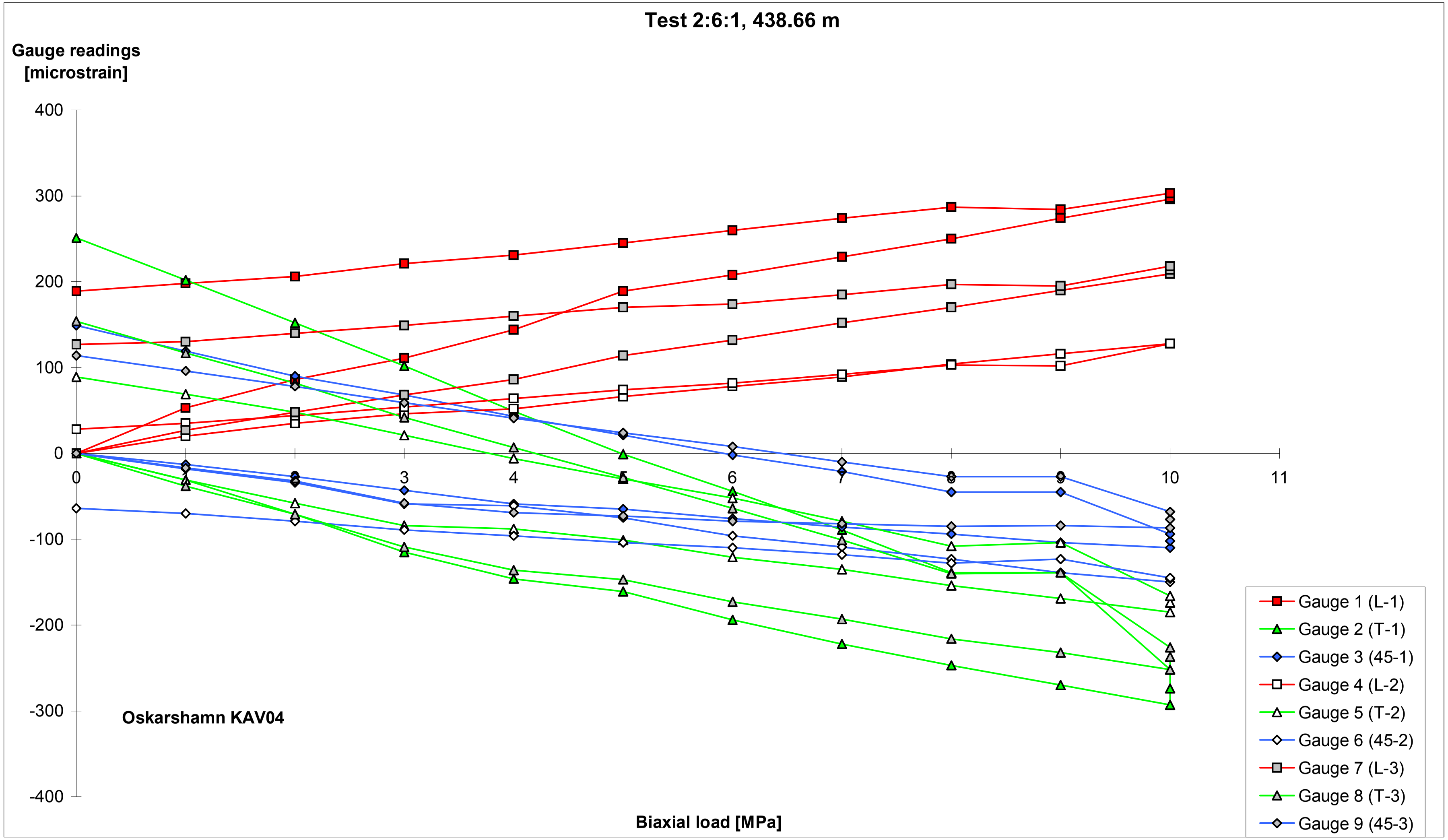


Figure C9. *Results from biaxial testing of test no. 2:6:1, 438.66 m borehole length.*

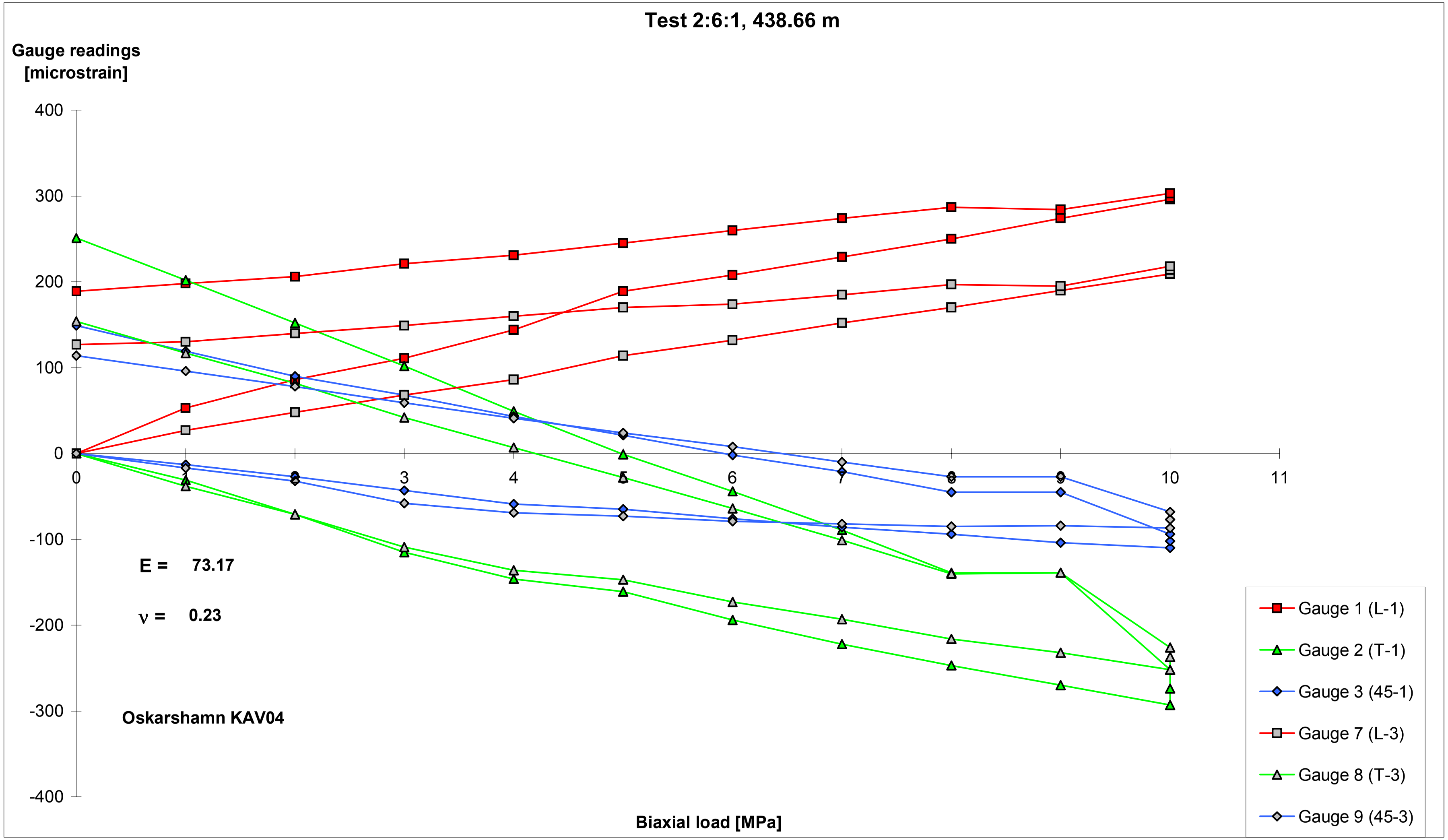


Figure C10. *Results from biaxial testing of test no. 2:6:1, 438.66 m borehole length, excluding rosette no. 2.*

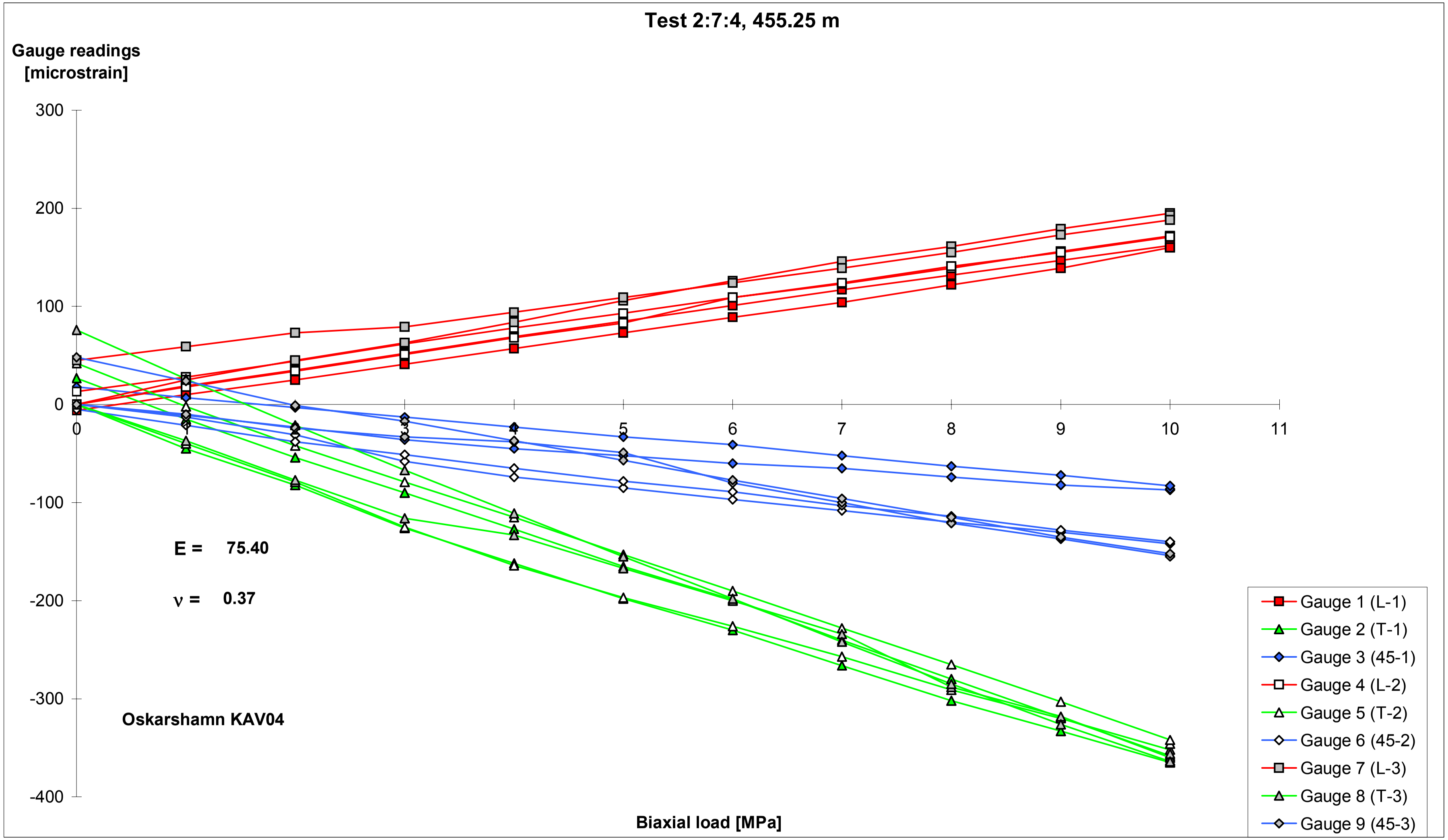


Figure C11. *Results from biaxial testing of test no. 2:7:4, 455.25 m borehole length.*

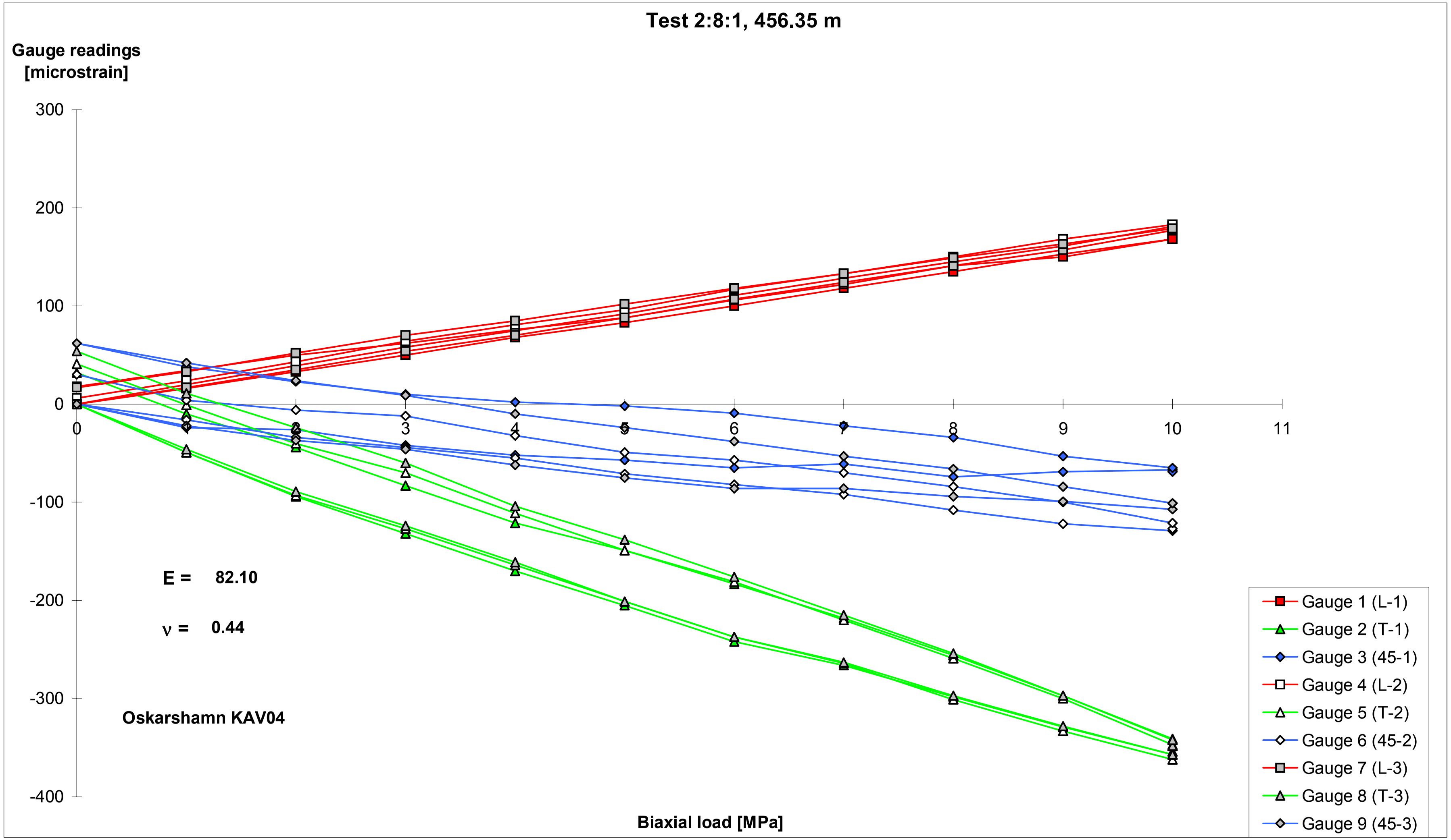


Figure C12. *Results from biaxial testing of test no. 2:8:1, 456.35 m borehole length.*

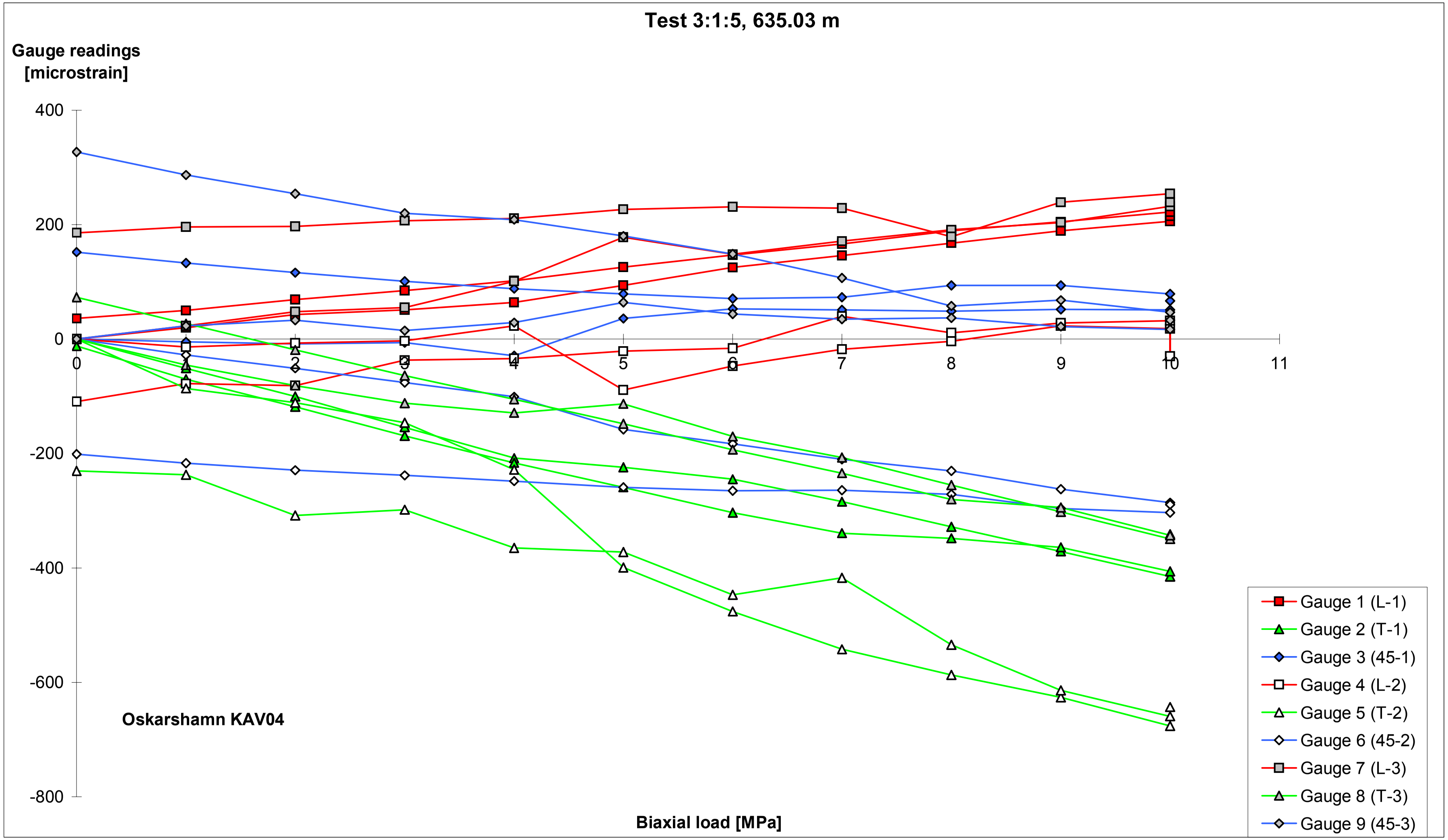


Figure C13. *Results from biaxial testing of test no. 3:1:5, 635.03 m borehole length.*

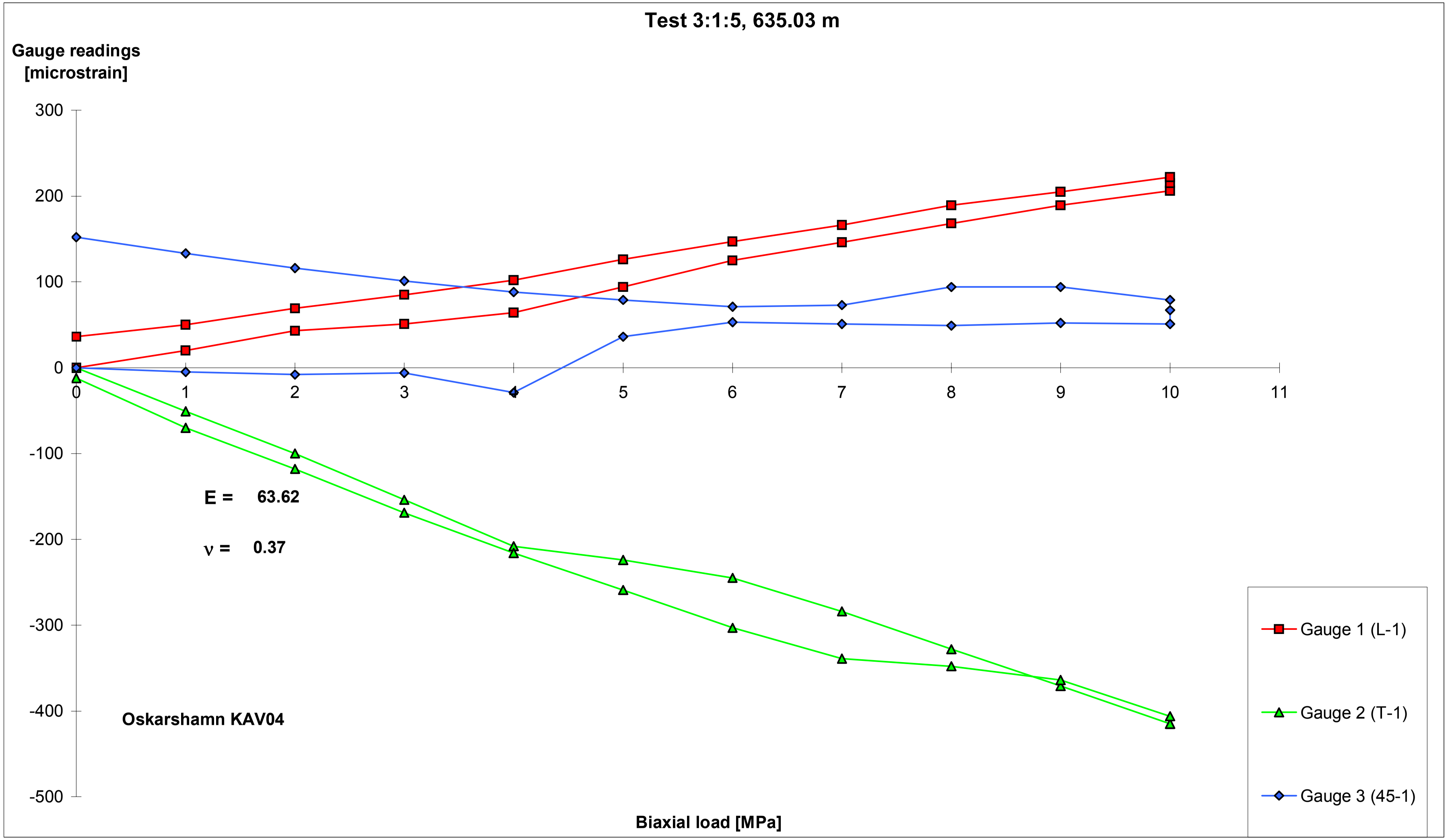


Figure C14. *Results from biaxial testing of test no. 3:1:5, 635.03 m borehole length, excluding rosette nos. 2 and 3.*

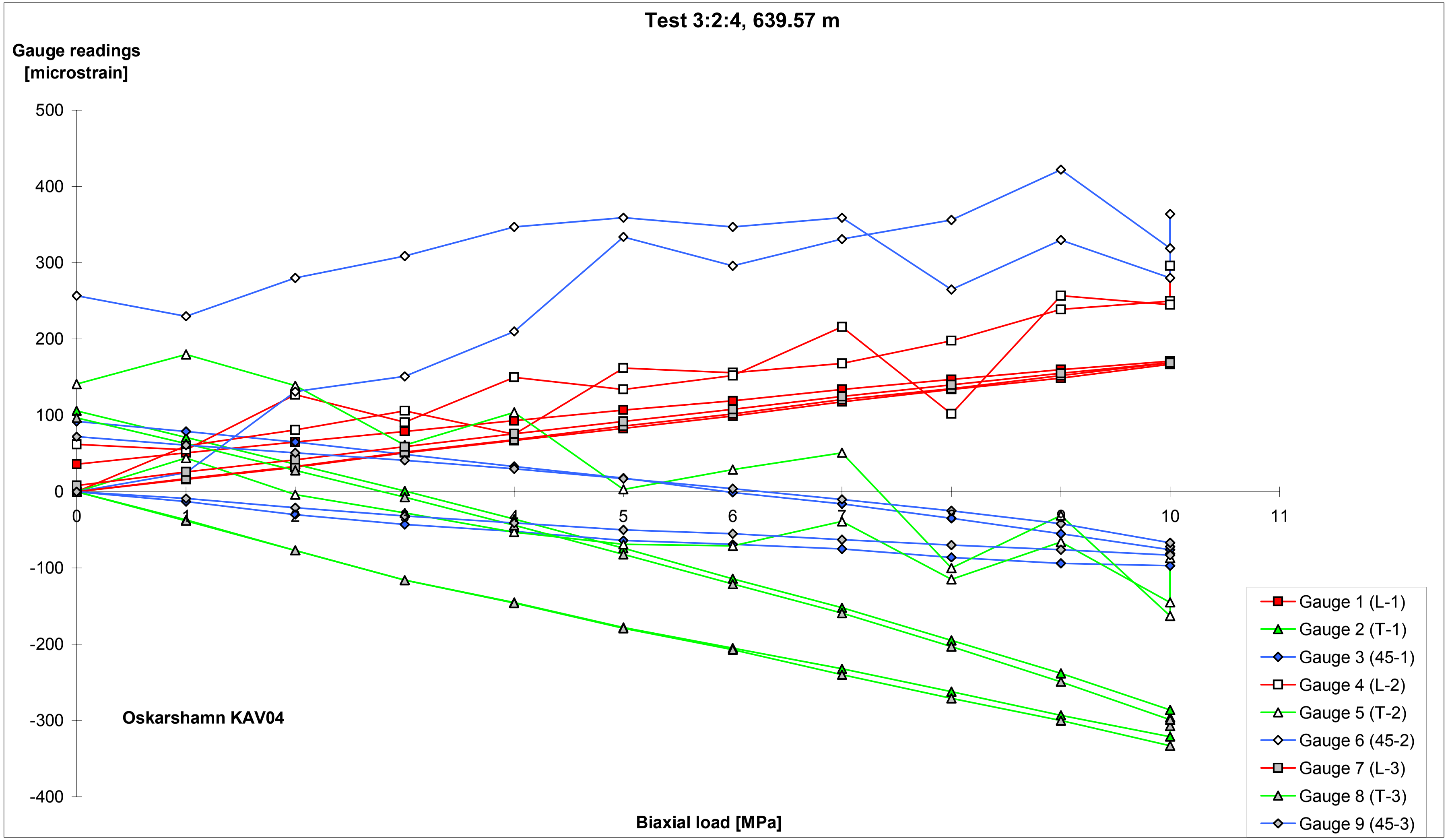


Figure C15. *Results from biaxial testing of test no. 3:2:4, 639.57 m borehole length.*

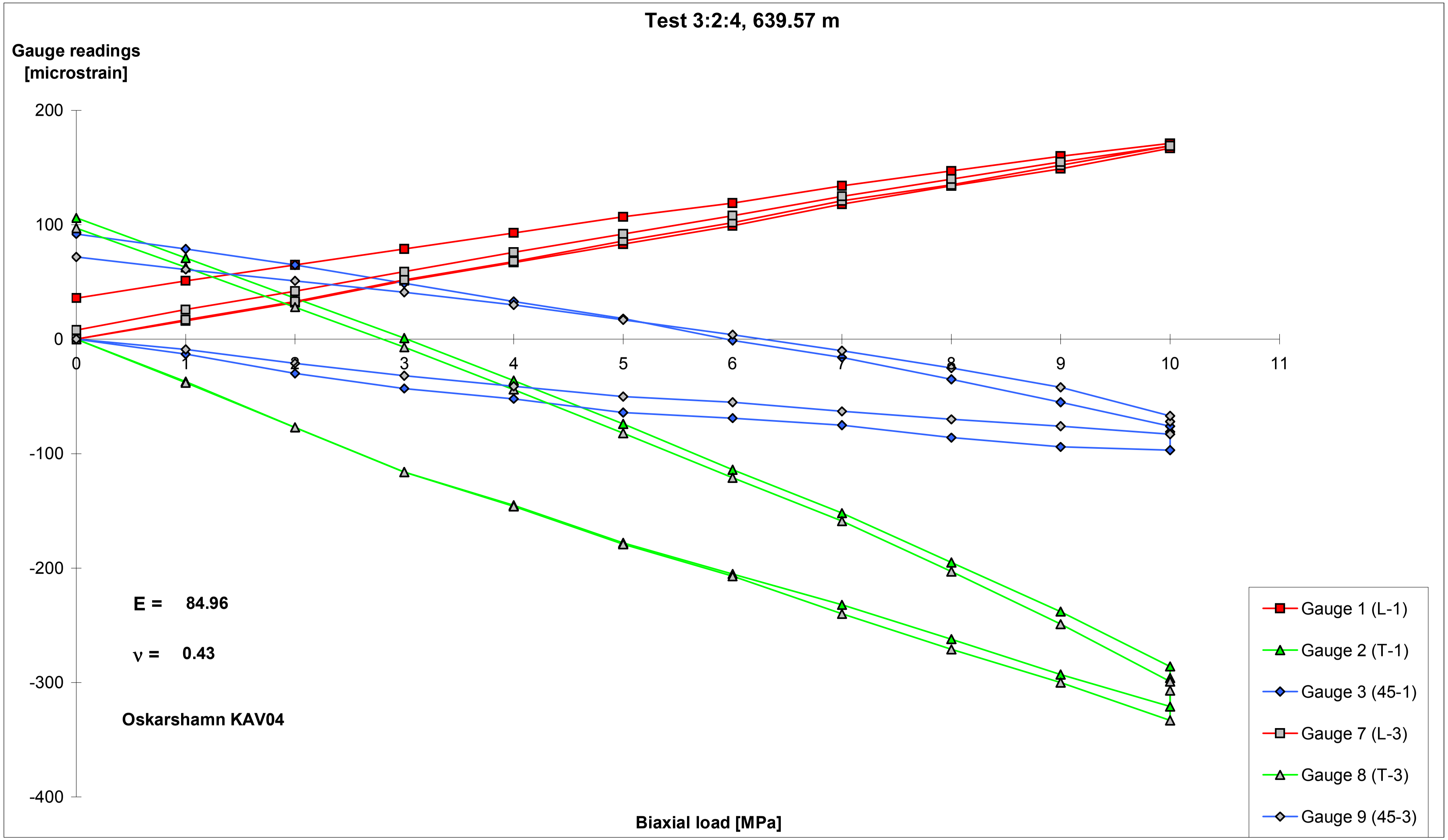


Figure C16. *Results from biaxial testing of test no. 3:2:4, 639.57 m borehole length, excluding rosette no. 2.*

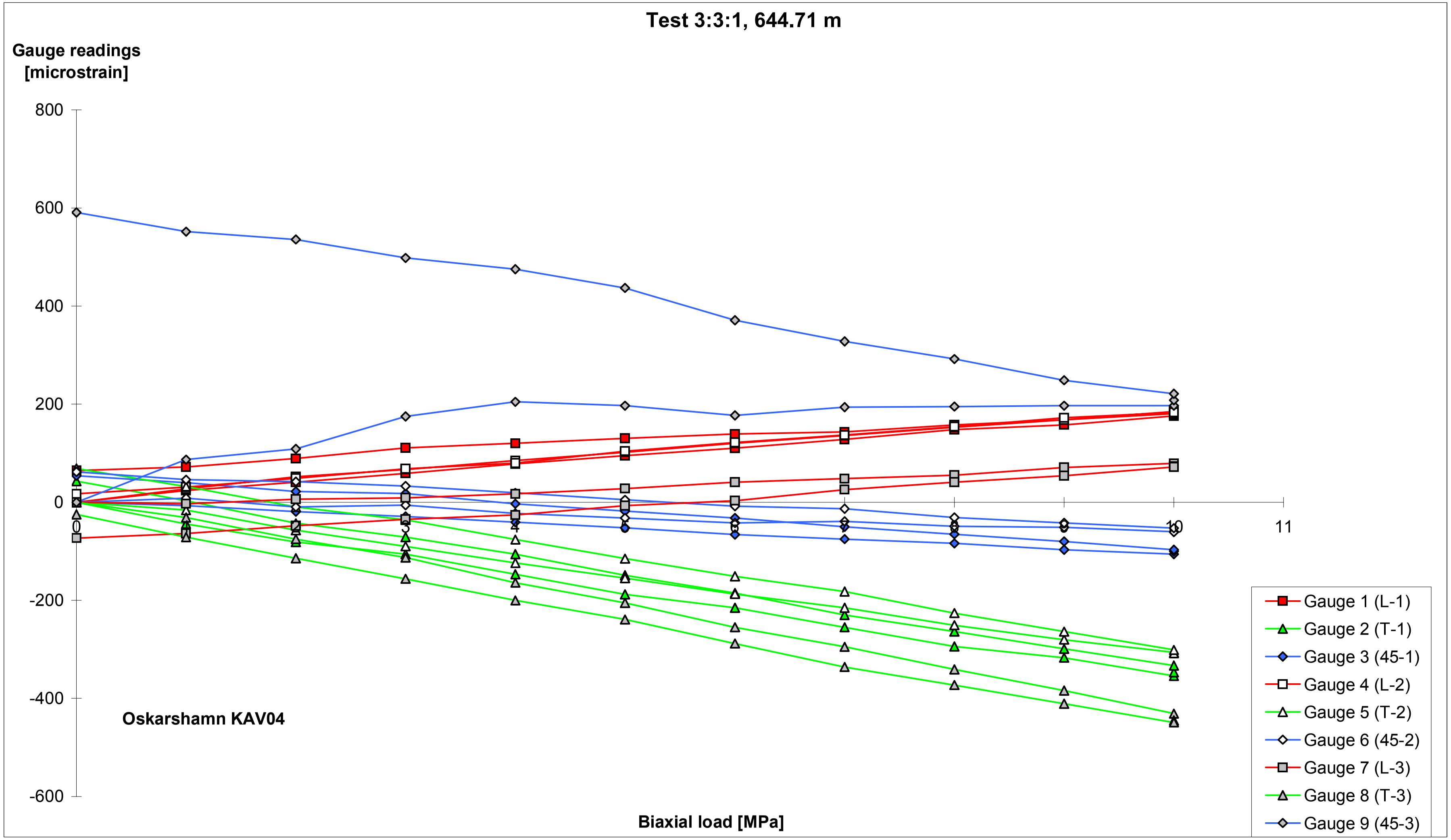


Figure C17. *Results from biaxial testing of test no. 3:3:1, 644.71 m borehole length.*

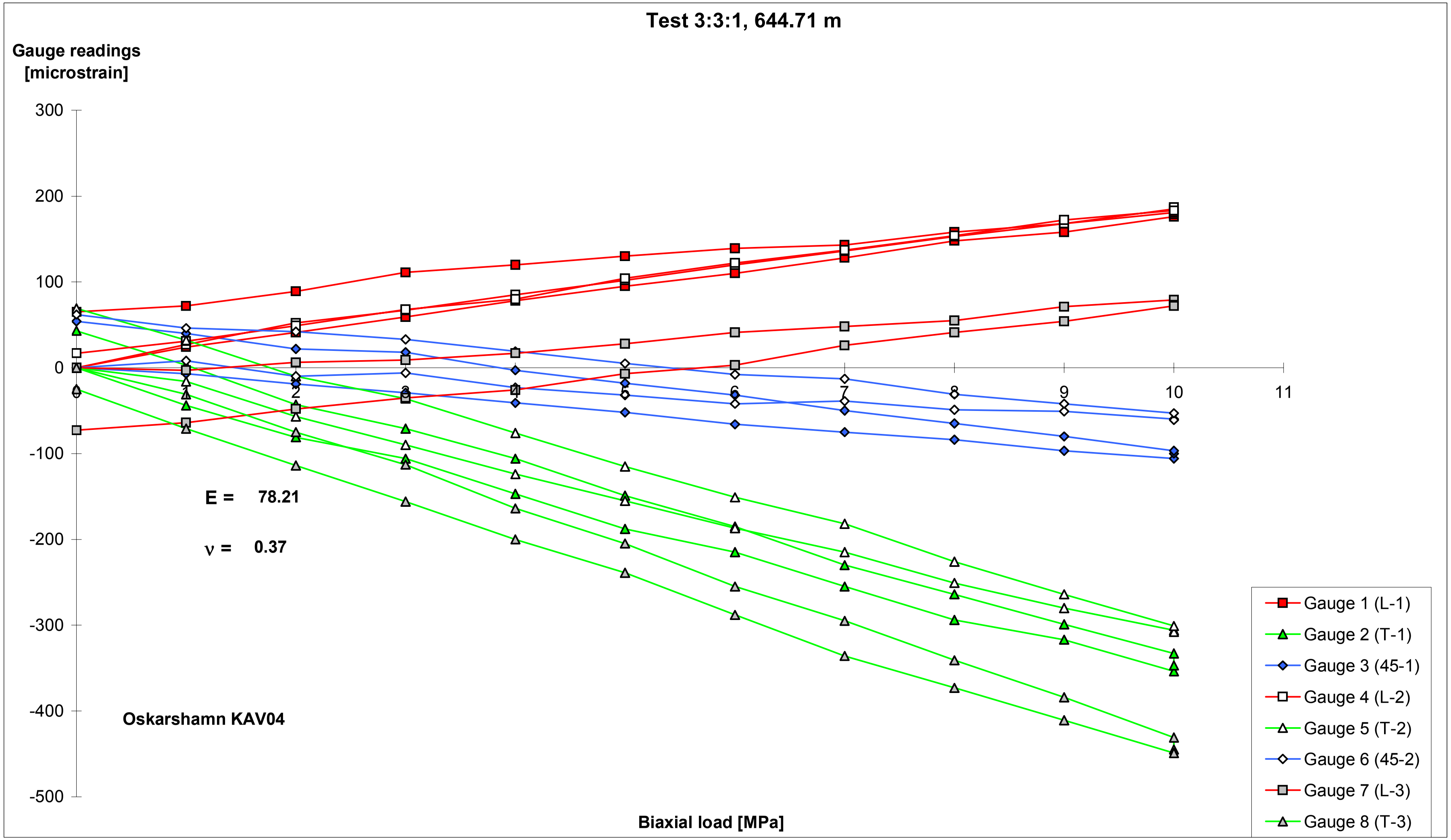


Figure C18. *Results from biaxial testing of test no. 3:3:1, 644.71 m borehole length, excluding gauge no. 9.*

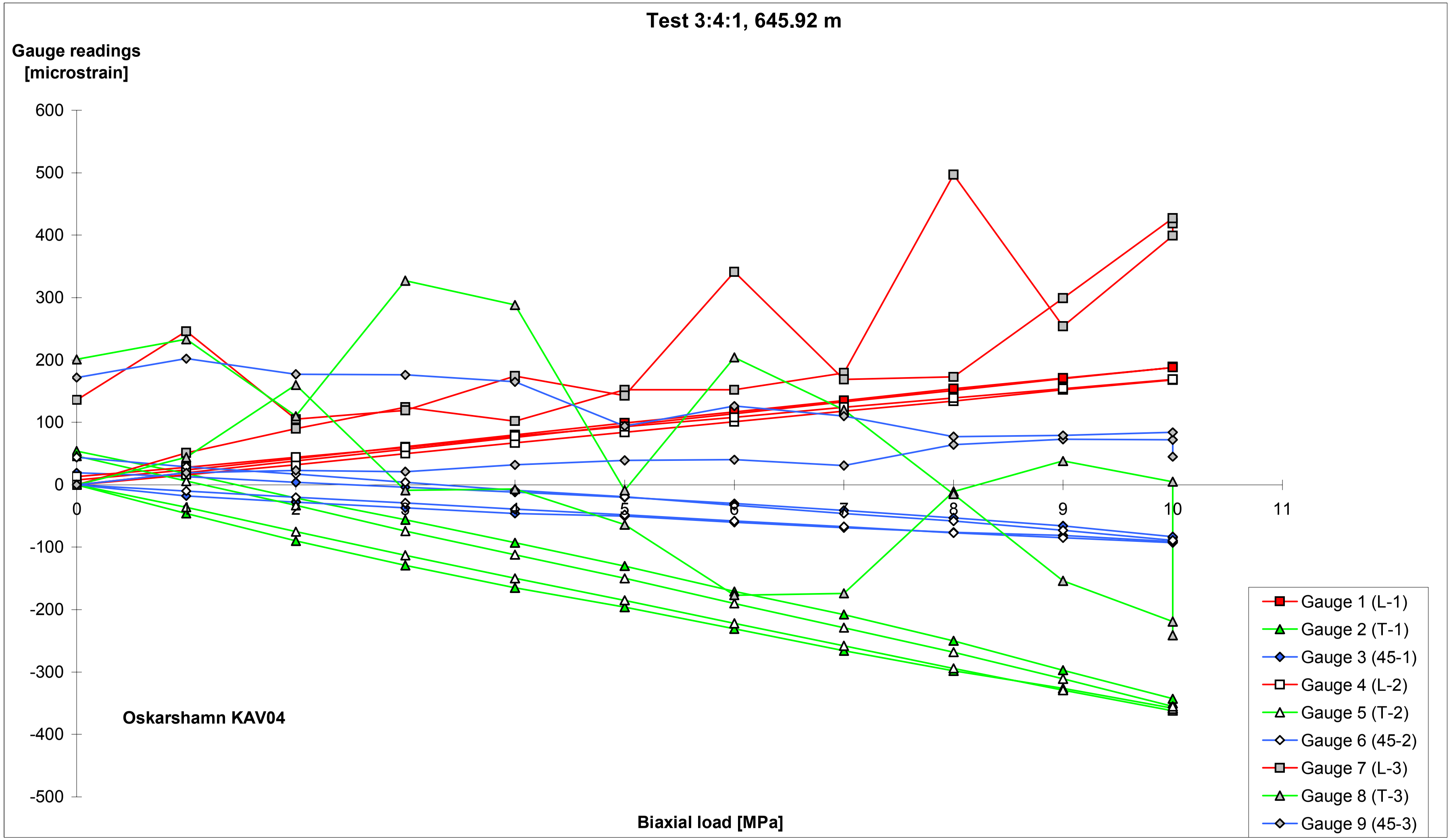


Figure C19. *Results from biaxial testing of test no. 3:4:1, 645.92 m borehole length.*

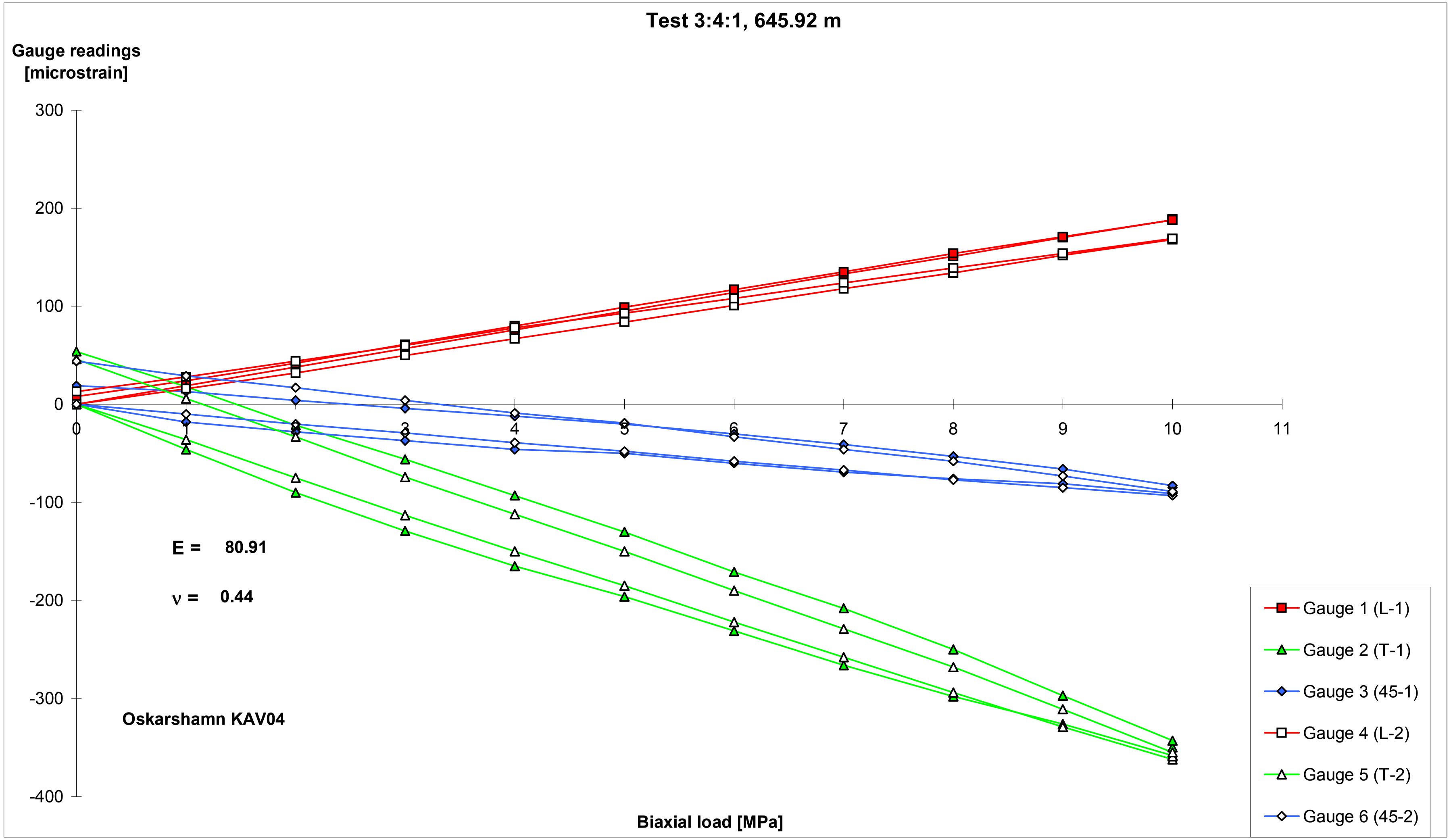


Figure C20. *Results from biaxial testing of test no. 3:4:1, 645.92 m borehole length, excluding rosette no.3 .*

Appendix D

Stress calculation input data and results

Table D1. Measured and average in situ stresses for borehole KAV04, Level 1, test nos. 1:2:2, 1:6:1, and 1:7:2.

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description : Oskarshamn KAV04
Measurement Level : 1
Date : 2004-03-30

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

Input Data

Depth [m]	Hole dip [º]	Hole bearing [º]	Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	Needle bearing [º]	Overcoring Time [hh:mm:ss]	Overcoring Time [hh:mm:ss]
251.51	85.5	74.6	271	72.4	0.40	346	Start=11:08:00	Stop=11:29:45
265.15	85.5	75	343	83.6	0.36	58	Start=10:15:30	Stop=10:28:00
272.87	85.4	76.1	174	82.5	0.42	250	Start=10:00:40	Stop=10:13:20

Strains

Depth [m]	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]
251.51	7	104	91	14	-26	-25	32	75	37
265.15	-13	29	16	-22	141	71	-19	3	-31
272.87	13	226	43	13	64	111	13	44	71

Calculated Principal Stresses

Depth [m]	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]
251.51	4.5	26.6	143.8	3.0	62.4	307.1	0.7	6.8	50.4
265.15	4.5	0.2	113.4	0.9	43.2	203.6	-0.3	46.8	23.1
272.87	10.7	37.1	254.6	5.0	51.4	56.5	3.2	8.9	157.8
Average	*5.2*	*27.6*	*275.4*	*3.6*	*47.3*	*150.9*	*2.0*	*29.7*	*22.7*

Calculated Horizontal and Vertical Stresses

Depth [m]	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?
251.51	4.2	141.6	0.7	51.6	3.3	332.7	No
265.15	4.5	113.3	0.3	23.3	0.3	44.7	No
272.87	8.6	72.4	3.3	162.4	7.0	329.4	Yes
Average	*4.8*	*103.7*	*2.4*	*13.7*	*3.5*		

Table D2. Measured and average in situ stresses for borehole KAV04, Level 2:A, test nos. 2:1:1 and 2:4:1.

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description : Oskarshamn KAV04
Measurement Level : 2:A
Date : 2004-03-31

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

Input Data

Depth [m]	Hole dip [º]	Hole bearing [º]	Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	Needle bearing [º]	Overcoring Time [hh:mm:ss]	Overcoring Time [hh:mm:ss]
429.66	84.8	85.7	55	55.6	0.23	141	Start=10:18:00	Stop=10:39:40
435.36	84.9	85.4	84	77.9	0.26	169	Start=10:57:30	Stop=11:05:00

Strains

Depth [m]	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]
429.66	100	446	323	94	470	316	40	157	6
435.36	58	468	373	-30	115	41	-52	282	-40

Calculated Principal Stresses

Depth [m]	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]
429.66	14.0	2.9	352.1	11.2	57.4	257.5	6.1	32.4	84.0
435.36	18.3	24.9	333.3	7.8	18.5	234.4	2.3	58.2	111.7
Average	*15.8*	*21.7*	*337.9*	*9.4*	*35.0*	*231.7*	*4.6*	*47.0*	*93.1*

Calculated Horizontal and Vertical Stresses

Depth [m]	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?
429.66	13.9	173.2	7.6	83.2	9.8	2200.1	No
435.36	15.6	158.4	7.1	68.4	5.7	7256.5	No
Average	*14.7*	*164.7*	*7.5*	*74.7*	*7.7*		

Table D3. Measured and average in situ stresses for borehole KAV04, Level 2:B, test nos. 2:5:2 and 2:6:1.

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description : Oskarshamn KAV04
Measurement Level : 2:B
Date : 2004-03-31

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

Input Data

Depth [m]	Hole dip [º]	Hole bearing [º]	Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	Needle bearing [º]	Overcoring Time [hh:mm:ss]	[hh:mm:ss]
437.23	84.9	85.8	57	51.9	0.25	143	Start=10:18:55	Stop=10:39:15
438.66	84.9	85.8	133	73.2	0.23	219	Start=10:23:10	Stop=10:31:00

Strains

Depth [m]	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]
437.23	144	342	460	146	17	-9	148	527	150
438.66	127	299	433	48	279	36	163	140	164

Calculated Principal Stresses

Depth [m]	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]
437.23	17.1	46.1	294.4	8.6	35.5	72.2	3.9	22.3	179.2
438.66	20.1	43.0	69.8	8.9	3.0	162.6	6.7	46.8	255.8
Average	*14.5*	*52.8*	*57.9*	*11.9*	*26.6*	*286.7*	*6.2*	*24.0*	*183.8*

Calculated Horizontal and Vertical Stresses

Depth [m]	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?
437.23	12.3	101.8	4.9	11.8	12.3	834.9	Yes
438.66	13.9	68.6	8.9	158.6	12.9	9370.7	No
Average	*12.6*	*88.8*	*7.4*	*178.8*	*12.6*		

Table D4. Measured and average in situ stresses for borehole KAV04, Level 2:C, test nos. 2:7:4 and 2:8:1.

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description : Oskarshamn KAV04
Measurement Level : 2:C
Date : 2004-03-31

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

Input Data

Depth [m]	Hole dip [º]	Hole bearing [º]	Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	Needle bearing [º]	Overcoring Time [hh:mm:ss]	Overcoring Time [hh:mm:ss]
455.25	84.7	88.4	53	75.4	0.37	141	Start=09:37:25	Stop=09:47:30
456.35	84.7	88.4	28	82.1	0.44	116	Start=09:20:55	Stop=09:42:45

Strains

Depth [m]	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]
455.25	-28	119	13	-3	274	176	11	-21	1
456.35	30	121	22	0	217	177	30	166	62

Calculated Principal Stresses

Depth [m]	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]
455.25	9.4	12.8	184.7	3.6	63.0	68.3	1.5	23.4	280.3
456.35	11.6	37.7	178.1	8.3	34.8	55.6	7.0	33.2	298.6
Average	*10.3*	*22.1*	*183.0*	*6.1*	*54.6*	*58.2*	*4.3*	*26.2*	*284.5*

Calculated Horizontal and Vertical Stresses

Depth [m]	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?
455.25	9.1	6.0	1.8	96.0	3.5	824.2	No
456.35	10.2	6.8	7.6	96.8	9.1	698.0	No
Average	*9.6*	*6.2*	*4.7*	*96.2*	*6.3*		

Table D5. Measured and average in situ stresses for borehole KAV04, Level 3, test nos. 3:1:5, 3:3:1, and 3:4:1.

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description : Oskarshamn KAV04
Measurement Level : 3
Date : 2004-03-30

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

Input Data

Depth [m]	Hole dip [º]	Hole bearing [º]	Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	Needle bearing [º]	Overcoring Time [hh:mm:ss]	Overcoring Time [hh:mm:ss]
635.03	84.3	100.5	340	63.6	0.37	80	Start=10:42:00	Stop=10:55:00
644.71	84.4	100.5	257	78.2	0.37	357	Start=10:25:10	Stop=10:33:30
645.92	84.4	100.5	308	80.9	0.44	48	Start=10:31:00	Stop=10:39:00

Strains

Depth [m]	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]
635.03	186	200	-207	219	151	306	270	287	545
644.71	94	189	191	91	216	29	55	556	364
645.92	94	-74	137	65	359	33	18	271	199

Calculated Principal Stresses

Depth [m]	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]
635.03	28.1	54.6	67.3	10.6	6.2	166.1	5.2	34.6	260.4
644.71	21.8	30.4	288.9	18.0	54.0	145.1	9.4	17.5	29.5
645.92	20.1	41.4	304.5	12.6	44.3	155.2	2.7	15.9	49.1
Average	*18.1*	*81.7*	*67.8*	*15.7*	*4.5*	*305.3*	*9.0*	*7.0*	*214.8*

Calculated Horizontal and Vertical Stresses

Depth [m]	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?
635.03	13.2	50.7	10.2	140.7	20.5	3616.7	No
644.71	20.8	116.8	10.2	26.8	18.2	1002.5	No
645.92	16.6	134.6	3.6	44.6	15.1	2943.4	No
Average	*15.7*	*124.6*	*9.1*	*34.6*	*17.9*		

Appendix E

Transient strain analysis results

Table E1. Results from transient strain analysis of selected overcoring measurements in borehole KAV04.

Test no.	Hole length [m]		G1 ε_{L1}	G2 ε_{T1}	G3 ε_{45_1}	G4 ε_{L2}	G5 ε_{T2}	G6 ε_{45_2}	G7 ε_{L3}	G8 ε_{T3}	G9 ε_{45_3}	Unexplained strain [%]	Max tensile stress [MPa]	Comments
2:5:2	437.23	Max strain amplitude [μstrain]	226	389	485	331	137	140	192	586	164	11	12	Large deviation between calculated and measured strains for nearly all gauges, in particular rosette no. 2 (gauge nos. 4, 5, 6) and the axial gauges (nos. 1, 7).
		Max strain difference [%]	62	30	25	102	86	112	99	24	51			
3:1:5	635.03	Max strain amplitude [μstrain]	320	274	292	220	247	318	395	352	564	5	13	Calculated values for tangential and inclined gauges show fair to good agreement with measured strains. Large deviation for all axial gauges, in particular no. 4.
		Max strain difference [%]	35	14	21	155	41	32	54	12	17			
3:2:4	639.57	Max strain amplitude [μstrain]	155	205	241	237	278	290	181	112	168	31 *)	14	Poor agreement for gauge nos. 1 and 8. Relatively good agreement between calculated and measured strains for the inclined gauges (nos. 3, 6, 9) and gauge no. 5.
		Max strain difference [%]	101	43	26	40	18	21	46	127	24			
3:3:1	644.71	Max strain amplitude [μstrain]	276	272	199	242	297	70	218	631	375	11 **)	16	Poor agreement for gauge no. 6. Fair to good agreement for all other gauges, expecially all tangential gauges (nos. 2, 5, 8).
		Max strain difference [%]	45	11	41	20	12	180	21	9	13			
3:4:1	645.92	Max strain amplitude [μstrain]	199	114	221	192	423	56	112	310	197	9	22	Poor agreement for gauge no. 6 and 7. Fair to good agreement for all other gauges, in particular gauge nos. 3, 4, 5, and 8.
		Max strain difference [%]	38	60	19	12	15	159	118	12	70			

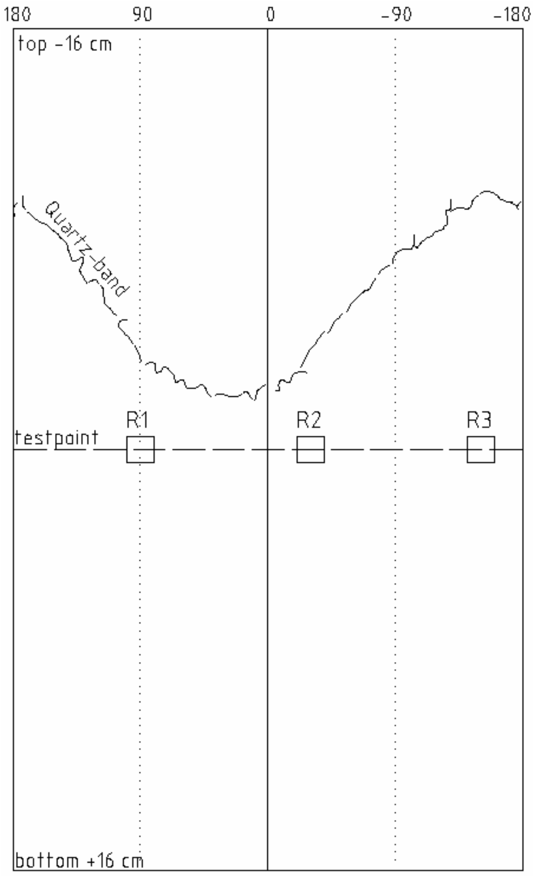
*) Value at +160 mm overcoring distance. Minimum value of 10 % reached between +40 and+75 mm overcoring distance (corresponding to times between 10:31:30 and 10:32:30, cf. Figure B22).

**) Value at +170 mm overcoring distance. Minimum value of 4 % reached at approximately +90 mm overcoring distance (corresponding to 10:33:30 for which strain differences were determined for classical analysis, cf. Figure B25).

Overcore logging sheets

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 1:2:2, 251.51 m depth



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

GEOLOGY

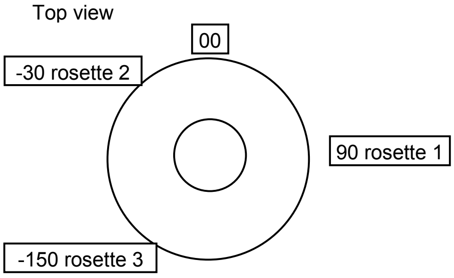
Granite, coarse-grained. Quartz-band in upper portion of sample.

STRUCTURES (JOINTS)

No joints observed. No new fractures after biaxial testing.

Mark any observed fractures

Top view

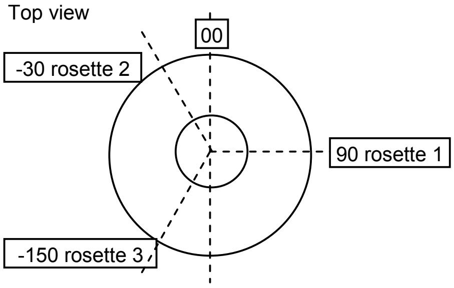


COMMENTS

Strain gauge orientation OK.

Control of strain gauge orientation

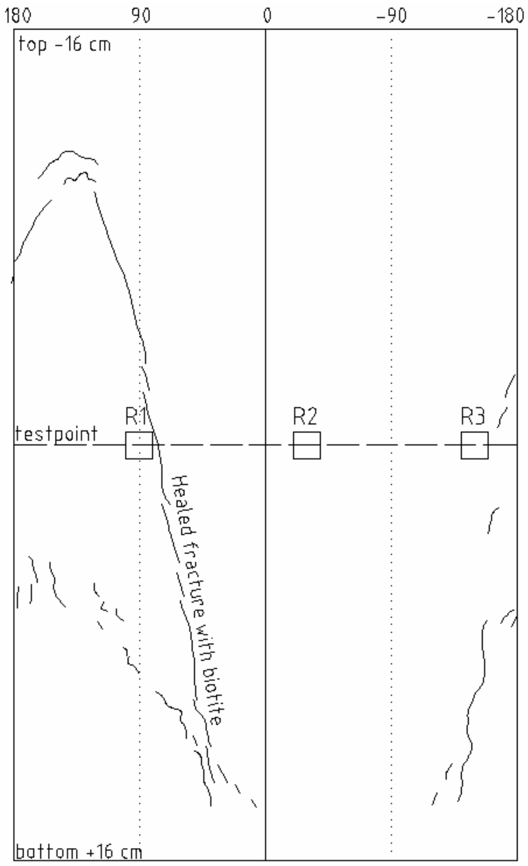
Top view



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 1:3:1, 252.57 m depth



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

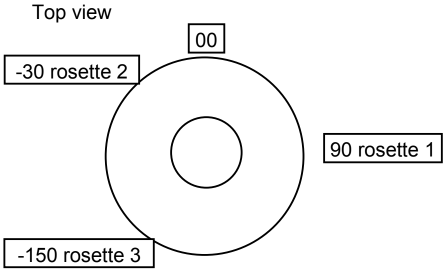
GEOLOGY

STRUCTURES (JOINTS)

Healed fracture at gauge position — not detected in the pilot core.

Mark any observed fractures

Top view

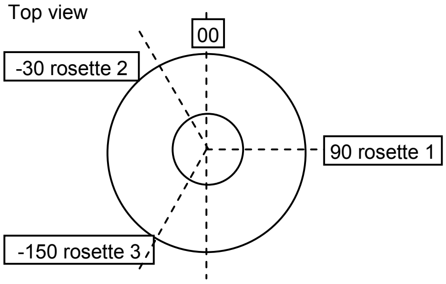


COMMENTS

Strain gauge orientation OK.

Control of strain gauge orientation

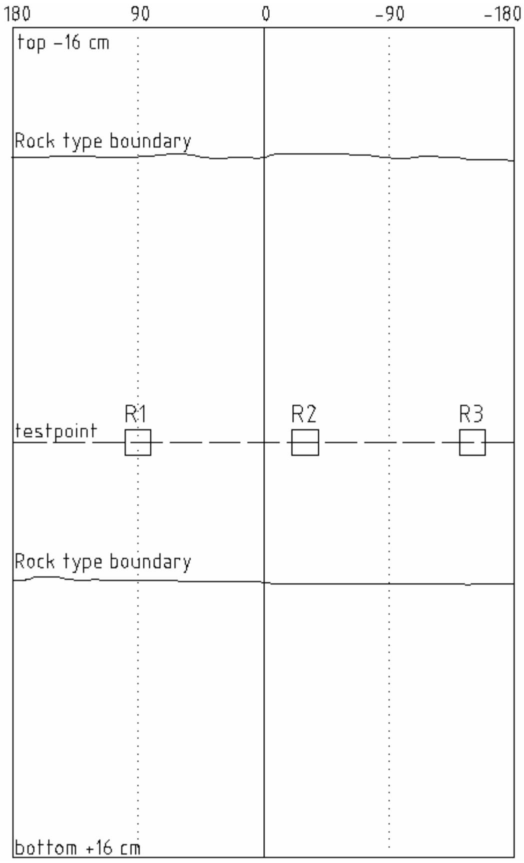
Top view



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KAV04, Test no. 1:6:1, 265.15 m depth**



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

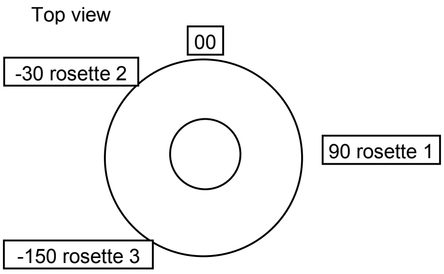
GEOLOGY

Changes in rock type in upper and lower portion of sample.

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

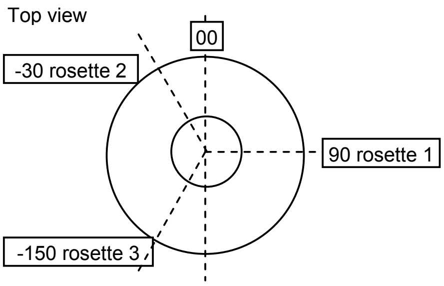
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

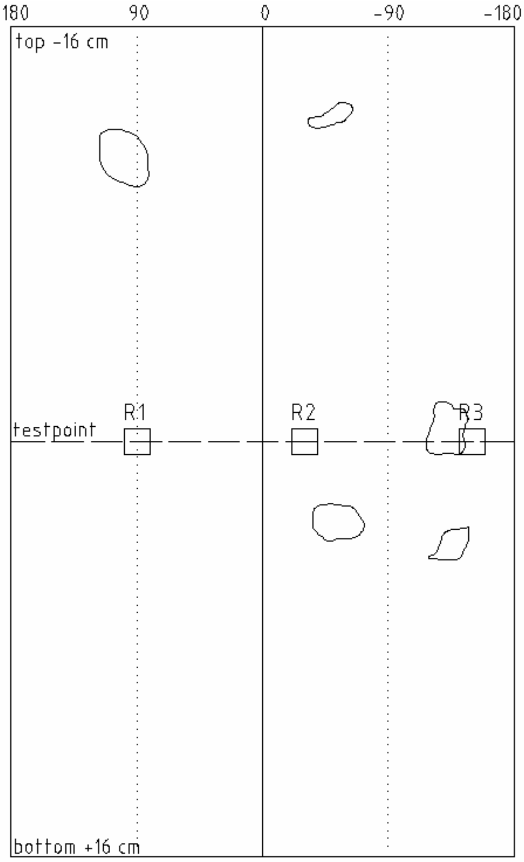
Control of strain gauge orientation



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 1:7:2, 272.87 m depth



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

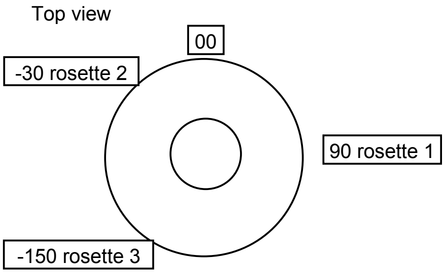
GEOLOGY

Quartz crystals observed in the sample.

STRUCTURES (JOINTS)

No joints observed before or after biaxial testing.

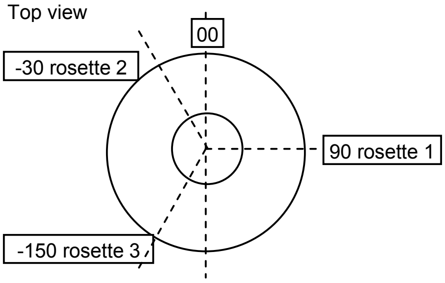
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

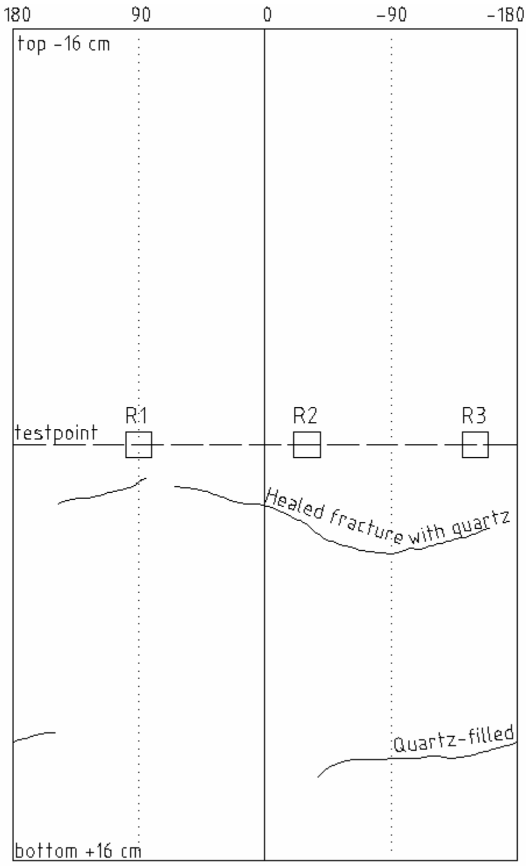
Control of strain gauge orientation



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 2:1:1, 429.66 m depth



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

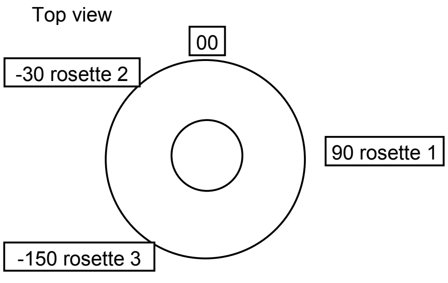
GEOLOGY

Granite, coarse-grained.

STRUCTURES (JOINTS)

Healed fracture, app. 0.5 mm width.
No fractures formed after biaxial testing.

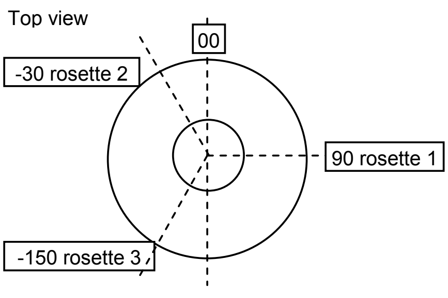
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

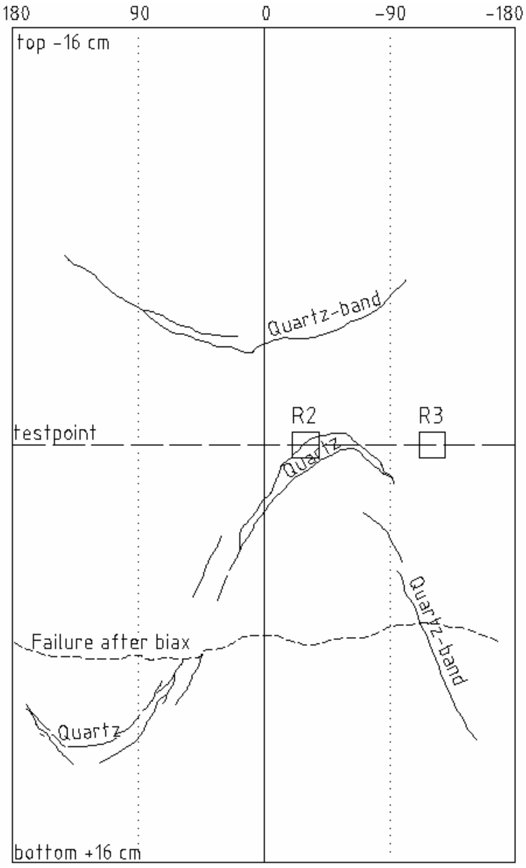
Control of strain gauge orientation



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KAV04, Test no. 2:2:2, 431.64 m depth**



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

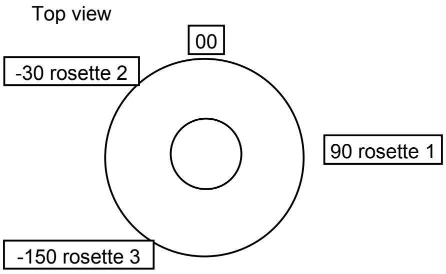
GEOLOGY

Granite, coarse-grained.

STRUCTURES (JOINTS)

Quartz-filled, healed fractures.
Failure perpendicular to core axis at app. 25 cm length during biaxial testing. Failure surface fresh, probably mostly through intact rock.
A similar fracture was, however, observed on the pilot core when the core was recovered from the drill tube and hence initially judged as a mechanical fracture.

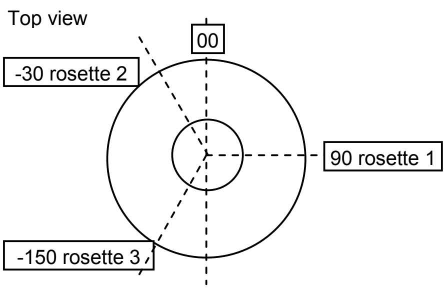
Mark any observed fractures



COMMENTS

Strain gauge tongues damaged and dislocated probably due to debris in the borehole. Coarse rock fragements found in bottom of pilot hole.

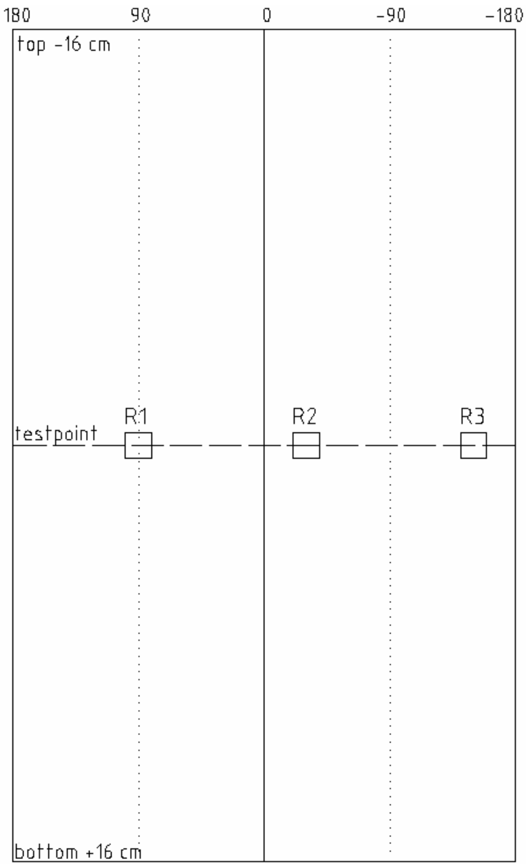
Control of strain gauge orientation



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 2:4:1, 435.36 m depth



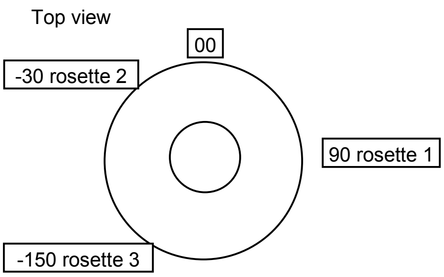
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

STRUCTURES (JOINTS)

No fractures.
No fractures after biaxial testing.

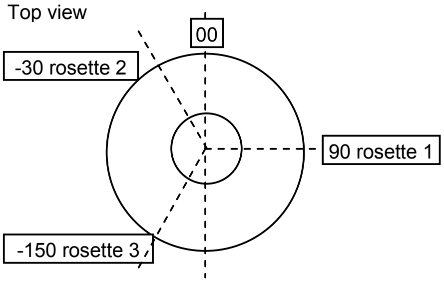
Mark any observed fractures



COMMENTS

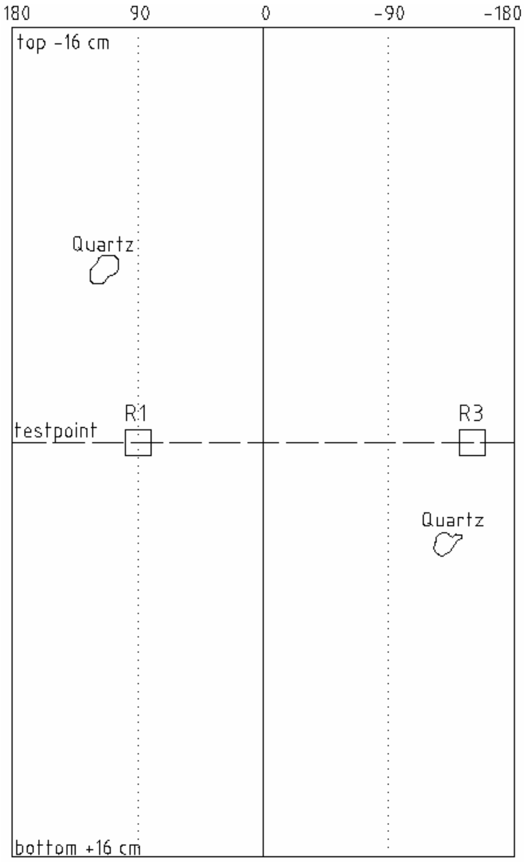
Strain gauge orientation OK.

Control of strain gauge orientation



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

OVERCORE SAMPLE LOG
Borehole no., test no., depth : **KAV04, Test no. 2:5:2, 437.23 m depth**



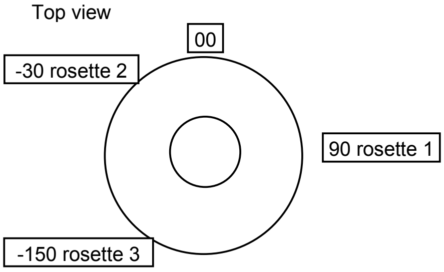
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

STRUCTURES (JOINTS)

No fractures.
No fractures after biaxial testing.

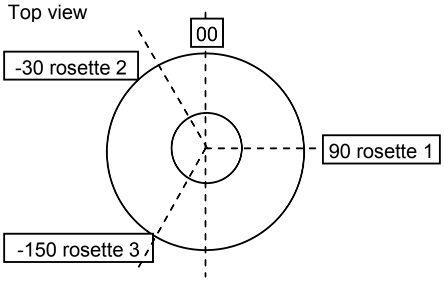
Mark any observed fractures



COMMENTS

Strain gauge orientation OK. Rosette 2 showed signs of debonding. Coarse rock fragments found on pilot hole wall and at the bottom of the pilot hole.

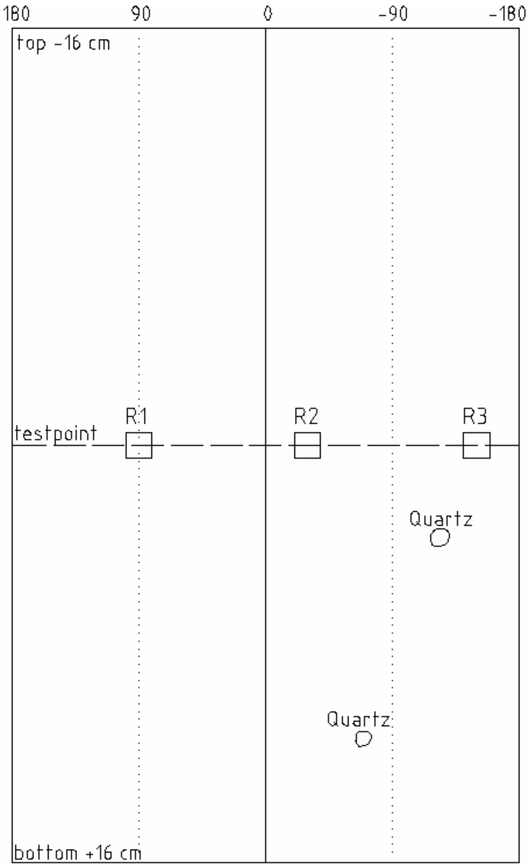
Control of strain gauge orientation



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 2:6:1, 438.66 m depth



Mark any observed fractures

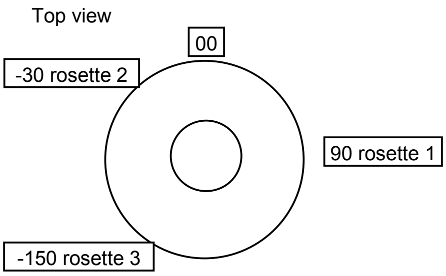
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

Granite

STRUCTURES (JOINTS)

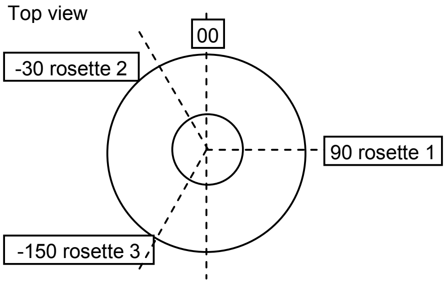
No fractures.
No fractures after biaxial testing.



COMMENTS

Strain gauge orientation OK.

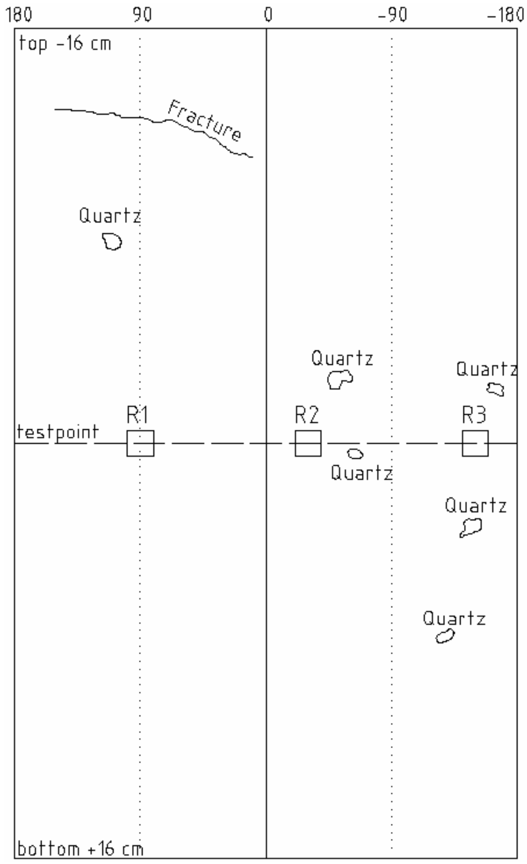
Control of strain gauge orientation



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 2:7:4, 455.25 m depth



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

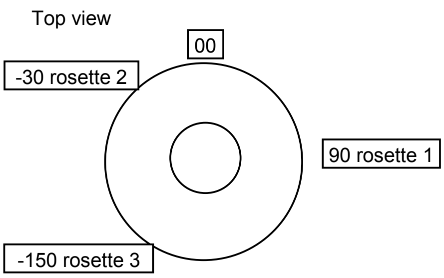
GEOLOGY

Granite. Quartz grains occurring sporadically.

STRUCTURES (JOINTS)

No fractures.
No fractures after biaxial testing.

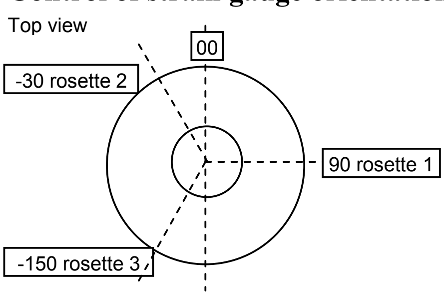
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

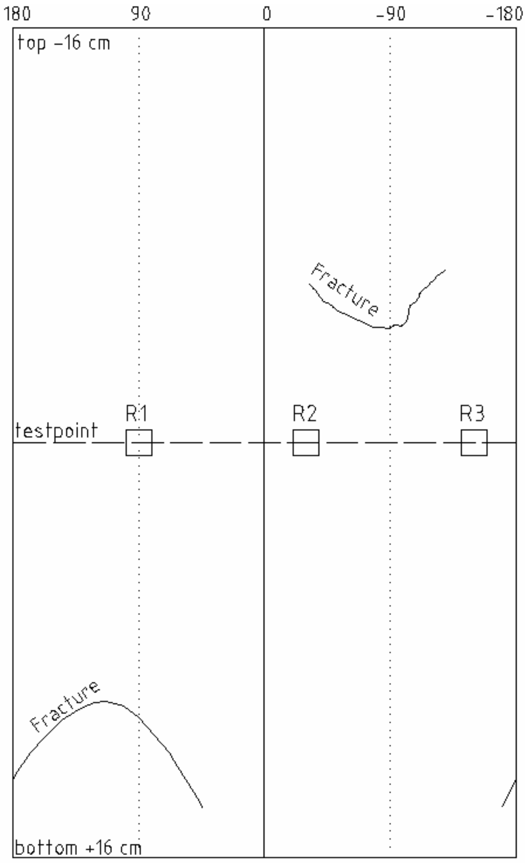
Control of strain gauge orientation



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 2:8:1, 456.35 m depth



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

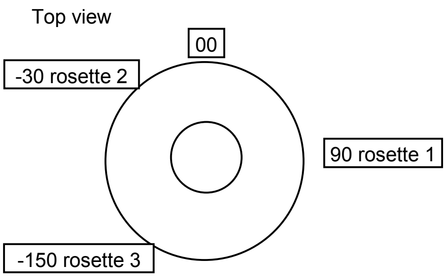
GEOLOGY

Granite.

STRUCTURES (JOINTS)

Healed fractures in top and bottom portion of sample. No fractures after biaxial testing.

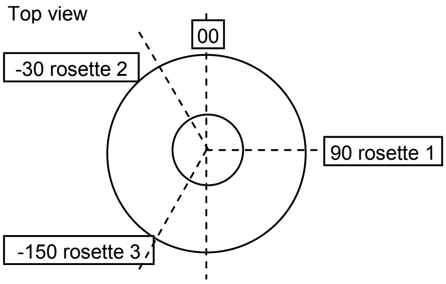
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

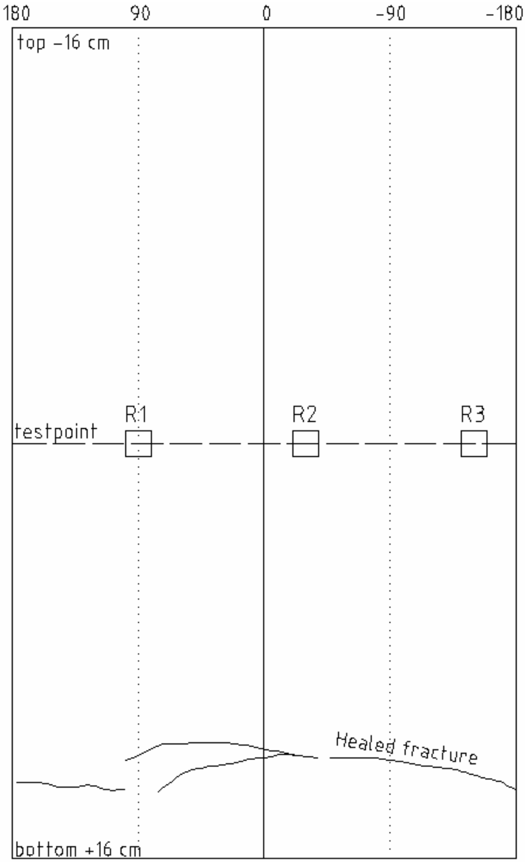
Control of strain gauge orientation



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 3:1:5, 635.03 m depth



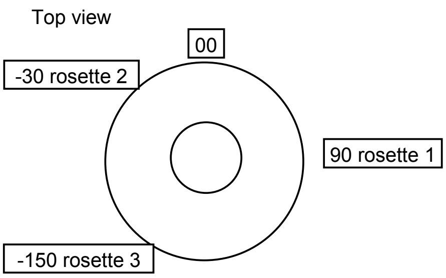
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

STRUCTURES (JOINTS)

Healed fracture near bottom of sample.
No fractures after biaxial testing.

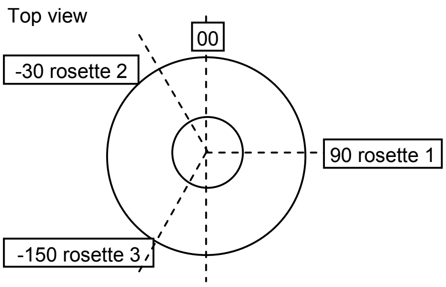
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

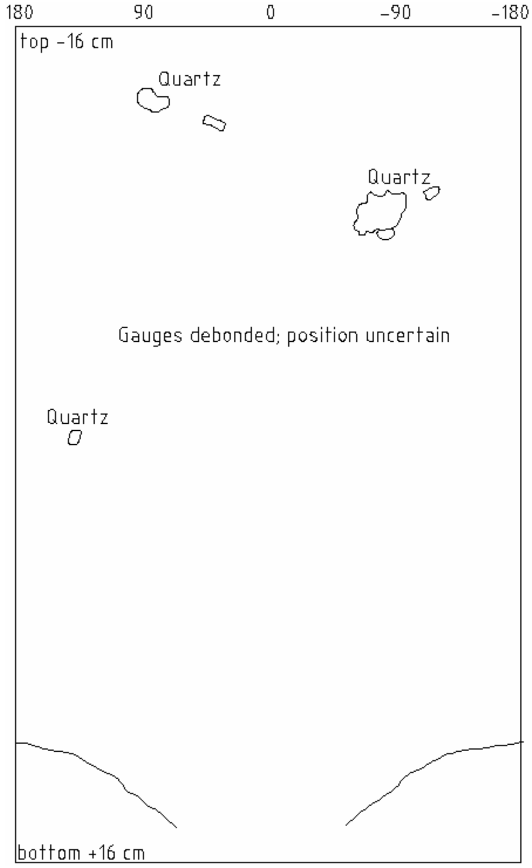
Control of strain gauge orientation



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 3:2:4, 639.57 m depth



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

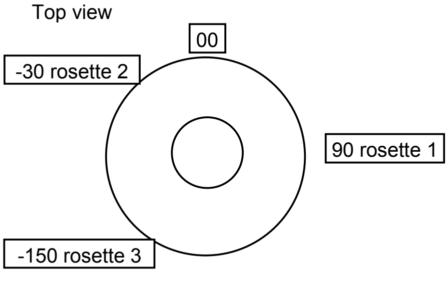
GEOLOGY

STRUCTURES (JOINTS)

Fracture/failure at bottom of sample.
No new fractures after biaxial testing.

Mark any observed fractures

Top view

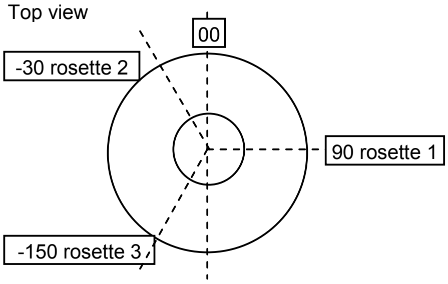


COMMENTS

Strain gauge orientation not known as gauges debonded.

Control of strain gauge orientation

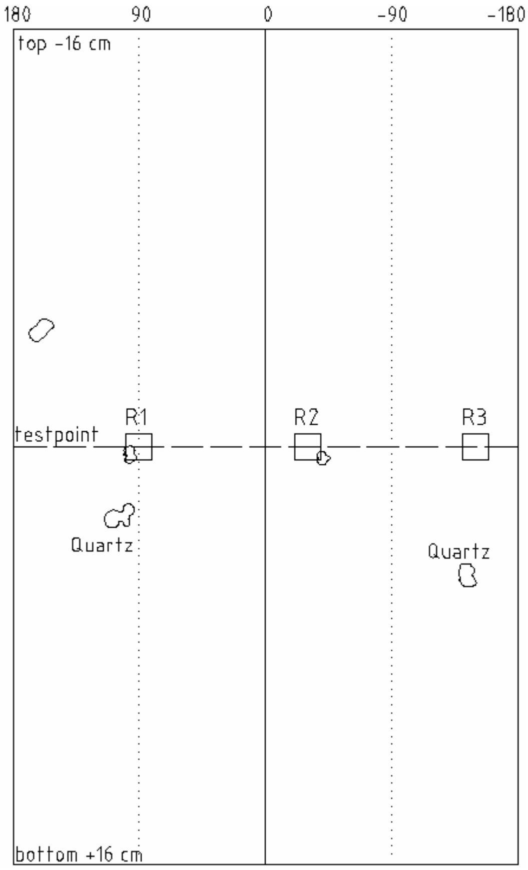
Top view



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KAV04, Test no. 3:3:1, 644.71 m depth



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

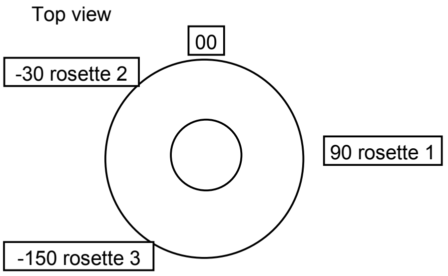
GEOLOGY

Sporadic occurrence of quartz grains.

STRUCTURES (JOINTS)

No fractures.
No fractures after biaxial testing.

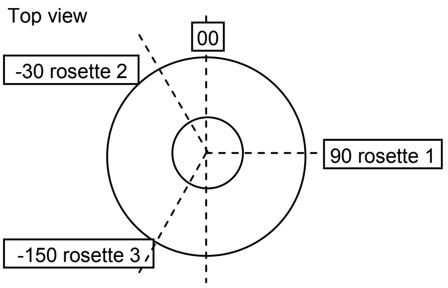
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

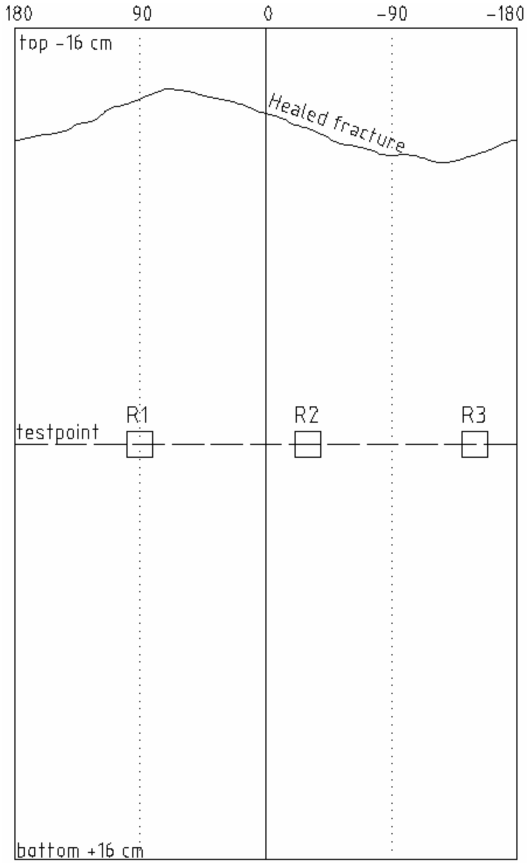
Control of strain gauge orientation



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

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KAV04, Test no. 3:4:1, 645.92 m depth**



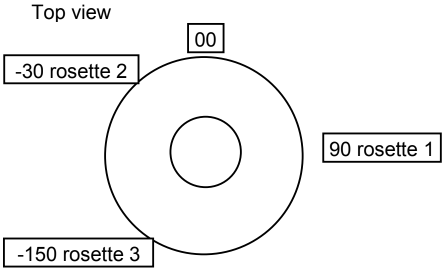
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

STRUCTURES (JOINTS)

Healed fracture in top portion of sample.
No new fractures after biaxial testing.

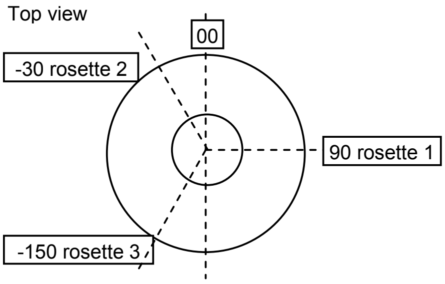
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

Control of strain gauge orientation



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

Appendix G

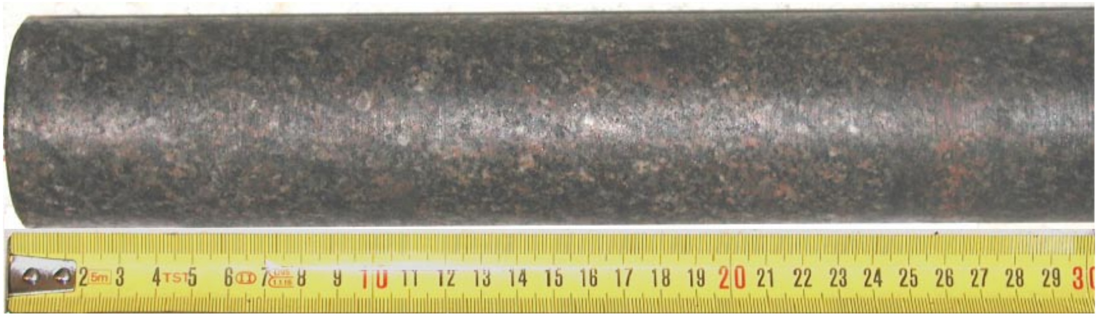
Photos of core samples

1:2:2, 251.51 m — pilot core

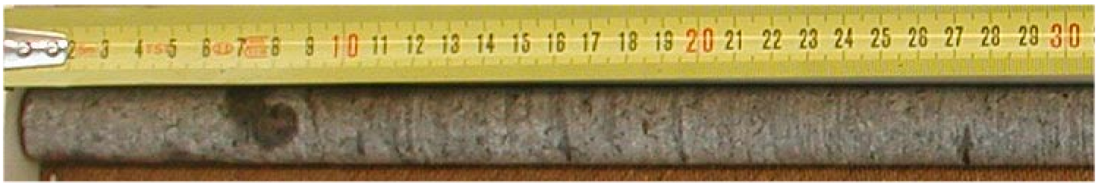
1:2:2, 251.51 m — overcore sample

1:6:1, 265.15 m — pilot core (30 cm)

1:6:1, 265.15 m — overcore sample



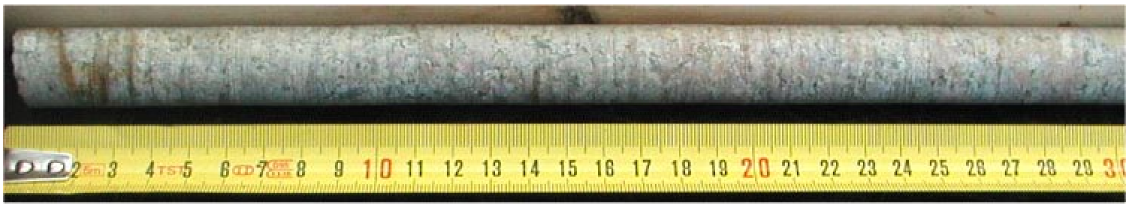
1:7:2, 272.87 m — pilot core



1:7:2, 272.87 m — overcore sample

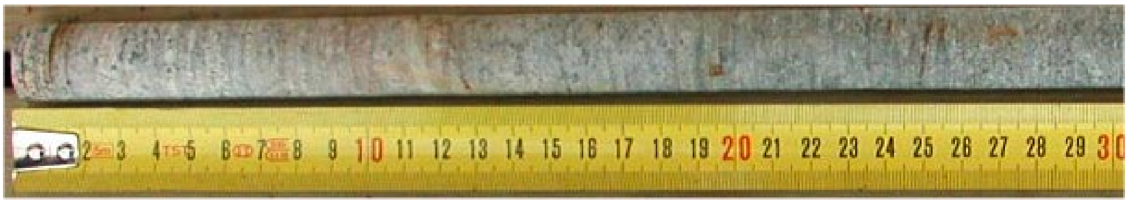
Figure G1. *Photos of pilot core and overcore sample for borehole KAV04, Level 1.*

2:1:1, 429.66 m — pilot core

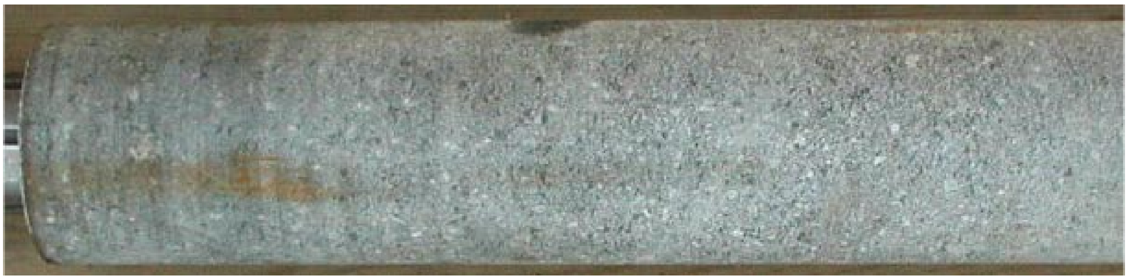


2:1:1, 429.66 m — overcore sample

2:4:1, 435.36 m — pilot core



2:4:1, 435.36 m — overcore sample (30 cm)



2:5:2, 437.23 m — pilot core

2:5:2, 437.23 m — overcore sample (30 cm)

Figure G2. *Photos of pilot core and overcore sample for borehole KAV04, Level 2.*

2:6:1, 438.66 m — pilot core

2:6:1, 438.66 m — overcore sample (30 cm)

2:7:4, 455.25 m — pilot core

2:7:4, 455.25 m — overcore sample

2:8:1, 456.35 m — pilot core

2:8:1, 456.35 m — overcore sample

Figure G2. (concluded.)

3:1:5, 635.03 m — pilot core (30 cm)

3:1:5, 635.03 m — overcore sample (30 cm)

3:2:4, 639.57 m — pilot core (failure during core handling)

3:2:4, 639.57 m — overcore sample (30 cm)

3:3:1, 644.71 m — pilot core

3:3:1, 644.71 m — overcore sample

Figure G3. *Photos of pilot core and overcore sample for borehole KAV04, Level 3.*

3:4:1, 645.92 m — pilot core

3:4:1, 645.92 m — overcore sample

Figure G3. (concluded.)