International
Progress Report

IPR-03-16

Äspö Hard Rock Laboratory

Äspö Pillar Stability Experiment

3D overcoring rock stress measurements in borehole KA3376B01 at Äspö HRL

Jonny Sjöberg

SwedPower AB

December 2002

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

Äspö Hard Rock
Laboratory

Report no.	No.
IPR-03-16	F86K
Author	Date
Jonny Sjöberg	Dec. 2002
Checked by	Date
Christer Andrsson Rolf Christiansson	2004-01-19
Approved	Date
Christer Svemar	2004-02-04

Äspö Hard Rock Laboratory

Äspö Pillar Stability Experiment

3D overcoring rock stress measurements in borehole KA3376B01 at Äspö HRL

Jonny Sjöberg

SwedPower AB

December 2002

Keywords: Äspö HRL, stress, state, three – dimensional overcoring, stress measurements, borre probe

Abstract

Three-dimensional overcoring stress measurements using the *Borre* probe were conducted in borehole KA3376B01 at the Äspö Hard Rock Laboratory. The borehole was drilled 0.9° downward and with a bearing of 45.54° in the local Äspö coordinate system.

A total of seven measurements were attempted between 45.54 and 57.77 meters hole depth (as measured from the tunnel wall). Four of these could be interpreted, whereas the other three tests failed. Biaxial testing was successfully conducted for five overcore samples. Biaxial test data indicated very high Young's modulus for all samples. The test results indicated non-linear response in some cases, but fair isotropy of the rock.

The resulting stresses are, in general, higher than expected when comparing them with results from previous measurements in the area, with the exception of test no. 3. Major principal stress magnitudes are almost twice as high, whereas the minor principal stress is lower than that of earlier measurements. Furthermore, the vertical stress is significantly higher than the expected stress due to overburden. On the other hand, the measured stress orientations are consistent for test nos. 3, 5 and 7, and in agreement with that of past measurements as well as the general stress orientation for southern and central Fennoscandia.

Taken together, the measurement results do not provide a clear representation of the *in situ* stress field at the site. Only test no. 3 give stress magnitudes that are close to previously measured stresses in the area. However, stress orientations are similar to the earlier measurement results and in agreement with the current knowledge of the stress state at Äspö and its surroundings.

Sammanfattning

I borrhål KA3376B01 beläget i Äspölaboratoriet har tredimensionella bergspännningsmätningar utförts genom överborrning av *Borre* sonden. Borrhålet hade en inklination på 0,9^{o} nedåt och bäringen var 45,54^{o} ost mätt i Äspös lokala koordinatsystem Äspö96.

Mellan håldjupen 45,54 och 57,77 meter genomfördes totalt sju stycken överborrningar. Av dessa kunde resultat från fyra användas och de övriga tre mätningarna misslyckades. Fem av de överborrade kärnorna biaxialtestades med lyckade resultat. Biaxialtesterna indikerade höga elasticitetsmoduler för alla provkroppar, i vissa erhölls något oelastiska töjningar men generellt sett uppvisade kärnorna en rimlig isotropi.

Med undantag för test nr. 3 gav de erhållna resultaten från bergspänningsmätningarna högre magnituder än vad som kunde förväntas baserat på resultat från tidigare mätningar i närområdet. Uppmätta magnituder för den största huvudspänningen är nästan dubbelt så höga medan magnituderna för den minsta huvudspänningen var lägre än vad som tidigare uppmätts. Vidare är den uppmätta vertikala spänningen högre än vad som kan förväntas med hänsyn till befintlig överlast. De uppmätta spänningsorienteringarna visar en liten spridning mellan testerna nr. 3, 5 och 7 och stämmer väl överens med tidigare mätningar vid Äspö samt för den generella spänningsriktningen i de södra och centrala delarna av Fennoskanderna.

Utifrån mätningarna är det svårt att dra slutsatser på magnituderna av in situ spänningsfältet. Endast test nr. 3 gav resultat som stämmer rimligt väl överens med mätningar som tidigare gjorts i området. Uppmätta riktningarna på spänningsfälten stämmer dock väl överens med befintlig kunskap om spänningsriktningarna vid Äspölaboratoriet och omkringliggande områden.

Contents

1 Introduction

This report presents, in brief, the results from overcoring stress measurements in borehole KA3376B01 at the Äspö Hard Rock Laboratory (HRL). Field measurements were conducted during the period November 18-25, 2002.

These measurements are part of a larger project concerning a study on rock mass strength at Äspö HRL. Thus, the objective of these measurements was to provide data on the *in situ* stress state in the proposed test area for a subsequent full-scale pillar test.

All measurements were conducted using the three-dimensional *Borre* probe for overcoring. As the method is well-known within SKB, the measurement procedure is not presented in this report. The report only presents measurement results and a brief discussion of these, as per the directives of SKB.

2 Field work

Measurements were taken in borehole KA3376B01 at the Äspö HRL (Figure 2-1). The borehole was drilled 0.89° downward and with a bearing of 45.54°, relative to the Äspö local coordinate system. The borehole collar is at local coordinates X = 7285.155, Y = 2085.740 and Z = -445.510. Drilling was carried out using conventional core drilling equipment with 76 mm hole diameter.

A total of seven (7) tests were attempted between 45.54 and 57.77 meters hole depth (as measured from the tunnel wall). Test nos. 1 and 3 were done with the new logger of the *Borre* probe (termed *Borre III*). These were only partly successful; hence, the old logger was used for all other tests. A test with wireline pilot hole drilling was also conducted, but due to time constraints, that hole was not used for installation of the probe. All measurement installations of the probe were thus made in pilot holes drilled using the conventional pilot hole drilling equipment.

Consistent strain gauge response was obtained for test nos. 2, 5 and 7. Test 3 could be partly interpreted, whereas test nos. 1, 4 and 6 failed. Rock conditions proved to be variable, ranging from fine-grained to coarse-grained diorite/granite. Furthermore, a section of pegmatite-like rock (almost exclusively feldspar) was encountered for test no. 2. This test also experienced core disking at the end of the overcore sample (behind the strain gauges).

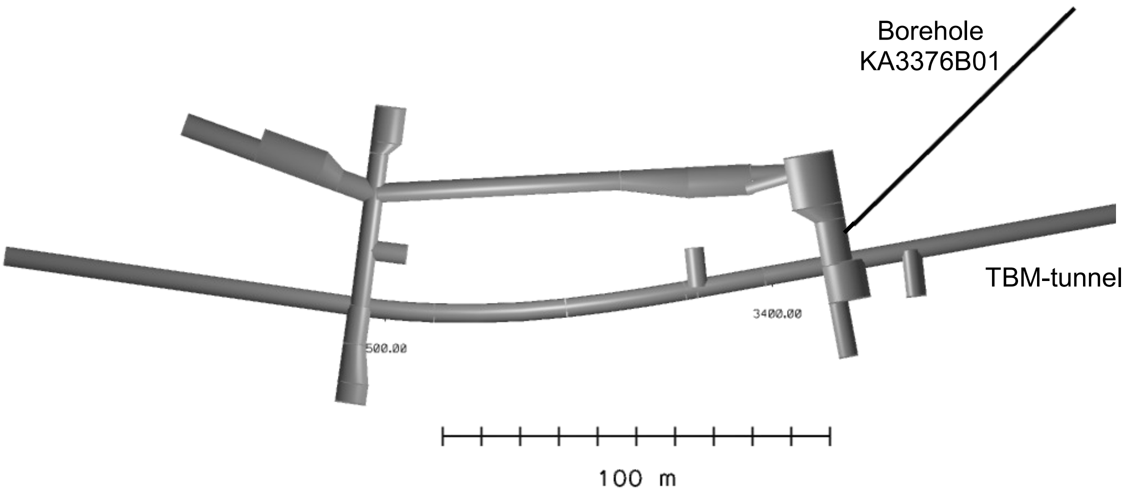


Figure 2-1 *Location of borehole KA3376B01 at the Äspö HRL, 450 meter level.*

3 Results

3.1 Overcoring Test Data

Test data are summarized in Table 3-1. The strain gauge response curves registered during the overcoring process are presented in Appendix A for test nos. 2, 3, 5 and 7. The most distinct strain response was that of tests 2 and 5. Test no. 3 showed large variations prior to and after overcoring, whereas test no. 7 displayed fairly large gauge drift after completed overcoring. Nevertheless, both of these were possible to use in subsequent stress determination, see Section 3.3.

Table 3-1. Test data from measurements in borehole KA3376B01.

Test no.	Hole depth [m]	Comment	Included in evaluation
1	45.68	Failed	No
2	46.47	Test OK, possible core disking	Yes
3	50.16	Partly unstable, overcoring OK	Yes
4	50.88	Unstable, debonding	No
5	52.56	Test OK	Yes
6	55.34	Unstable	No
7	57.77	Test OK, unstable after overcoring	Yes

Note: Hole depth calculated from the tunnel wall.

3.2 Biaxial Testing

Biaxial testing could be carried out for test nos. 3, 4, 5, 6 and 7. For tests 1 and 2, the overcore sample was too short to enable biaxial tests, due to fracturing during overcoring and core disking. The gauge response curves from the tests conducted are given in Appendix B. The obtained values on Young's modulus and Poisson's ratio are presented in Table 3-2. These were determined as secant values from the unloading part of the biaxial testing curves.

For test no. 4, debonding was evident for rosette # 3 and the results from this rosette were thus discarded from evaluation. For test nos. 5 and 7, rosette 1 did not function during biaxial testing and these results were also discarded in the analysis of the biaxial testing results. Moreover, for test 7, rosette 3 showed very non-linear response and was rejected.

The biaxial test response curves (Appendix B) indicated fairly linear and isotropic rock behavior for test nos. 3 and 6, with more non-linear response for tests 5 and 7. Anisotropy is, however, not particularly evident as similar results are obtained for the different strain gauge rosettes (at different orientations).

Table 3-2. Results from biaxial tests on overcore rock samples from borehole KA3376B01.

Test no.	Hole depth [m]	Young's modulus, *E* [GPa]	Poisson's ratio, ν
3	50.16	123.2	0.51 **)
4 *)	50.88	137.2	0.24
5	52.56	104.8	0.26
6 *)	55.34	85.6	0.22
7	57.77	131.2	0.39 **)
Average		116.4	0.32
Average excluding test nos. 3 and 7		109.2	0.24

Note: Hole depth calculated from the tunnel wall.
*) Test data not used in stress calculation, as overcoring measurements failed.
**) Unrealistically high values (Myrvang, 1997)

Overall, the obtained values on the elastic constants are high, compared to previous tests at Äspö HRL, see e.g., Nordlund et al., (1999). Only results from test no. 6 indicated a Young's modulus less than 100 GPa, whereas values obtained by Nordlund et al., (from laboratory testing) were in the range of 70-75 GPa. Moreover, values on Poisson's ratio are unrealistically high for test nos. 3 and 7. Values for igneous rocks seldom exceed 0.35 (Myrvang, 1997) and higher values may be an indication of microcracking. Consequently, two average values were calculated and presented in Table 3-2 — one with all tests included, and one with test nos. 3 and 7 excluded.

3.3 *In situ* Stress State

Stresses were 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. Note that for test no. 3, very large strain variations were observed prior to overcoring, see Appendix A. However, by choosing the start time wisely (and under the assumption that the strain response should be small prior to overcoring), it is possible to calculate strain differences, as the response during and after overcoring is distinct.

Biaxial test data were not available for test no. 2. However, to enable a rough estimate of measured stresses, estimated values were used in the stress calculations. Two sets of values were used: (1) mean values for Äspö diorite according to Nordlund et al. (1999), i.e., E = 73 GPa, ν = 0.28, and (2) mean values from test nos. 4, 5 and 6 (Table 3-2), i.e., E = 109.2 GPa, ν = 0.24. Neither of these values may be applicable to the pegmatite encountered in test no. 2, but were used in lieu of other available test data. Test no. 2 also displayed core disking — the implications thereof are discussed in Section 4.

Alternative results were also calculated for test nos. 3 and 7, for which very high

Poisson's ratio was found from the biaxial testing. A second set of stresses were calculated using the average values on *E* and *ν* from Table 3-2. The resulting stresses are shown in Table 3-3, Table 3-4, and **Table 3-5**. All orientations are given relative to north in the local Äspö coordinate system. Orientations of the principal stresses are also shown in Figure 3-1.

The differences between the values obtained using the two sets of elastic constants is considerable. However, it is difficult to state which of these values are more reliable or representative of the actual stress state at the site. The relatively large variation among the different tests makes it difficult to justify calculation of average values; hence, this was not performed. A brief discussion on the measured stresses is given in Section 4 of this report.

Table 3-3. Magnitudes of principal stress as determined by overcoring in borehole KA3376B01.

Test no.	Hole depth [m]	σ_1 [MPa]	σ_2 [MPa]	σ_3 [MPa]
2:1 [1)]	46.47	46.5	29.2	19.6
2:2 [2)]		67.9	41.9	25.1
3:1 [3)]	50.16	31.3	13.2	11.5
3:2 [2)]		23.1	10.0	-1.0
5	52.56	57.0	29.0	4.3
7:1 [3)]	57.77	68.5	16.5	6.0
7:2 [2)]		52.3	9.1	-0.6

Note: Hole depth calculated from the tunnel wall.
1) Estimated elastic constants from Nordlund, et al. (1999).
2) Average values from all biaxial testing used in calculations, cf. Table 3-2.
3) Results from biaxial testing used directly in calculations, cf. Table 3-2.

Table 3-4. Orientations of principal stress as determined by overcoring in borehole KA3376B01.

Test no.	Hole depth [m]	σ_1 Trend/Plunge [°]	σ_2 Trend/Plunge [°]	σ_3 Trend/Plunge [°]
2:1 [1)]	46.47	312/78	102/10	193/06
2:2 [2)]		312/78	108/11	199/05
3:1 [3)]	50.16	138/16	244/43	033/42
3:2 [2)]		138/16	297/73	046/06
5	52.56	123/48	343/34	239/21
7:1 [3)]	57.77	129/24	232/26	002/53
7:2 [2)]		129/24	261/55	028/23

Note: Hole depth calculated from the tunnel wall. Trend is counted clockwise from local Äspö North and plunge is defined positive downward from the horizontal plane.
1) Estimated elastic constants from Nordlund, et al. (1999).
2) Average values from all biaxial testing used in calculations, cf. Table 3-2.
3) Results from biaxial testing used directly in calculations, cf. Table 3-2.

Table 3-5. Horizontal and vertical stress components calculated from measured principal stresses in borehole KA3376B01.

Test no.	Hole depth [m]	σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
2:1 [1]	46.47	29.7	19.8	45.6	105
2:2 [2]		42.8	25.4	66.7	111
3:1 [3]	50.16	29.9	12.4	13.9	137
3:2 [2]		22.1	-0.9	10.9	137
5	52.56	39.8	8.9	41.6	140
7:1 [3]	57.77	58.2	14.1	18.8	127
7:2 [2]		44.7	1.1	15.0	127

Note: Hole depth calculated from the tunnel wall. Trend is counted clockwise from local Äspö North.

1) Estimated elastic constants from Nordlund, et al. (1999).

2) Average values from all biaxial testing used in calculations, cf. Table 3-2.

3) Results from biaxial testing used directly in calculations, cf. Table 3-2.

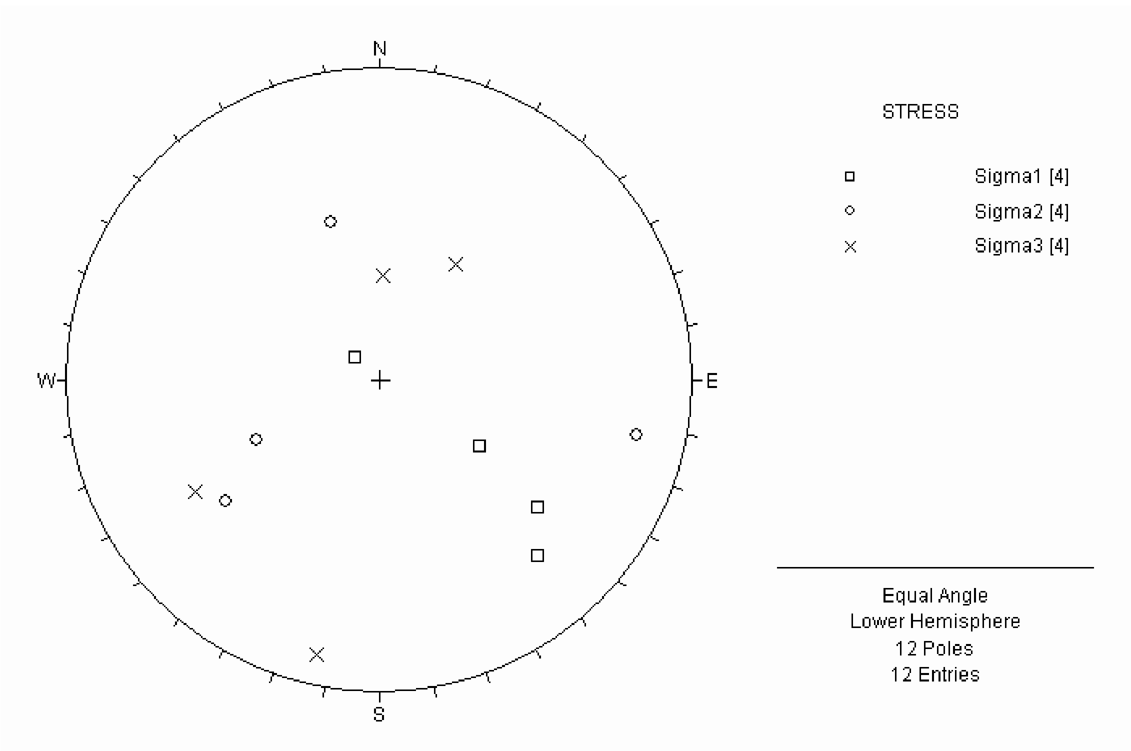


Figure 3-1 *Orientations of measured principal stresses in borehole KA3376B01, shown in a lower hemisphere projection. Orientations shown for cases 2:1, 3:1, 5 and 7:1, cf. Table 3-2.*

4 Discussion and conclusions

The results from the measurements conducted are supposed to represent the virgin stress state at a depth of around 450 meter at the Äspö HRL. However, measured stresses are, in general, higher than expected when comparing them with results from previous measurements in the area. Klasson and Andersson (2001), obtained average magnitudes for the principal stresses of 30, 15 and 9 MPa, for σ_1, σ_2, and σ_3 , respectively. Comparing these values with the current measurement results, it is found that the present results all show significantly higher major principal stress magnitudes, with the exception of test no. 3. Moreover, very low values on the minor principal stress were found for test nos. 5 and 7 (or even tensile stresses, depending on the choice of elastic constants).

The vertical stress due to overburden would be around 12 MPa at a depth of 450 meters. Test no. 3 indicate a vertical stress close to this value, whereas test no. 7 indicate a vertical stress that is around 50% higher. However, both test nos. 2 and 5 give vertical stresses that are several times higher than the expected overburden stress. Test no. 2 is judged unreliable as core disking was noted at the end of the overcore sample. Although this was behind the location of the strain gauges, it is an indication of large axial strains and microcracking in the overcore cylinder. The resulting stresses with the major principal stress oriented almost vertically is also an indication of unreliable measurement. Apart from test no. 2, it is difficult to reject the other measurements based on the strain response and available test data.

Studying the obtained stress orientations, it is found that these are remarkably consistent for test nos. 3, 5 and 7. The orientations of the major principal stress and the maximum horizontal stress are both in the NW-SE direction. This is similar to previous measurement results at Äspö and in accordance with the general stress orientation for southern and central Fennoscandia, see e.g., Hakami et al. 2002.

The biaxial test results are of varying quality. Non-linear response was observed in some of the tests, whereas some test exhibited very good linearity. Values on Young's modulus are, nevertheless, generally much higher than found previously for tests from the Äspö HRL (cf. Nordlund et al., 1999). Some of the strain gauge rosettes did not function during biaxial testing. However, for cases when all rosettes functioned, similar values on the elastic constants was found for all rosettes, thus indicating fair isotropy of the rock.

One may argue that the high stress magnitudes for most of the tests is due to the high values on Young's modulus used in the stress determination. Reducing these to more "normal" values for Äspö rock would give lower major principal stress magnitudes (linear relation with the value of E). However, this would also lead to lower values on the intermediate and minor principal stress. The latter is already very low, or even tensile for some cases, cf. Table 3-3. An even lower minor principal stress appears unlikely.

Taken together, the measurement results do not provide a clear representation of the *in situ* stress field at the site. Only test no. 3 give stress magnitudes that are close to previously measured stresses in the area. However, stress orientations are similar to the previous measurement results and in agreement with the current knowledge of the stress state at Äspö and its surroundings.

5 References

Hakami, E, Hakami, H and Cosgrove, J. (2002) Strategy for a rock mechanics site descriptive model. Development and testing of an approach to modelling the state of stress. SKB Report R-02-03.

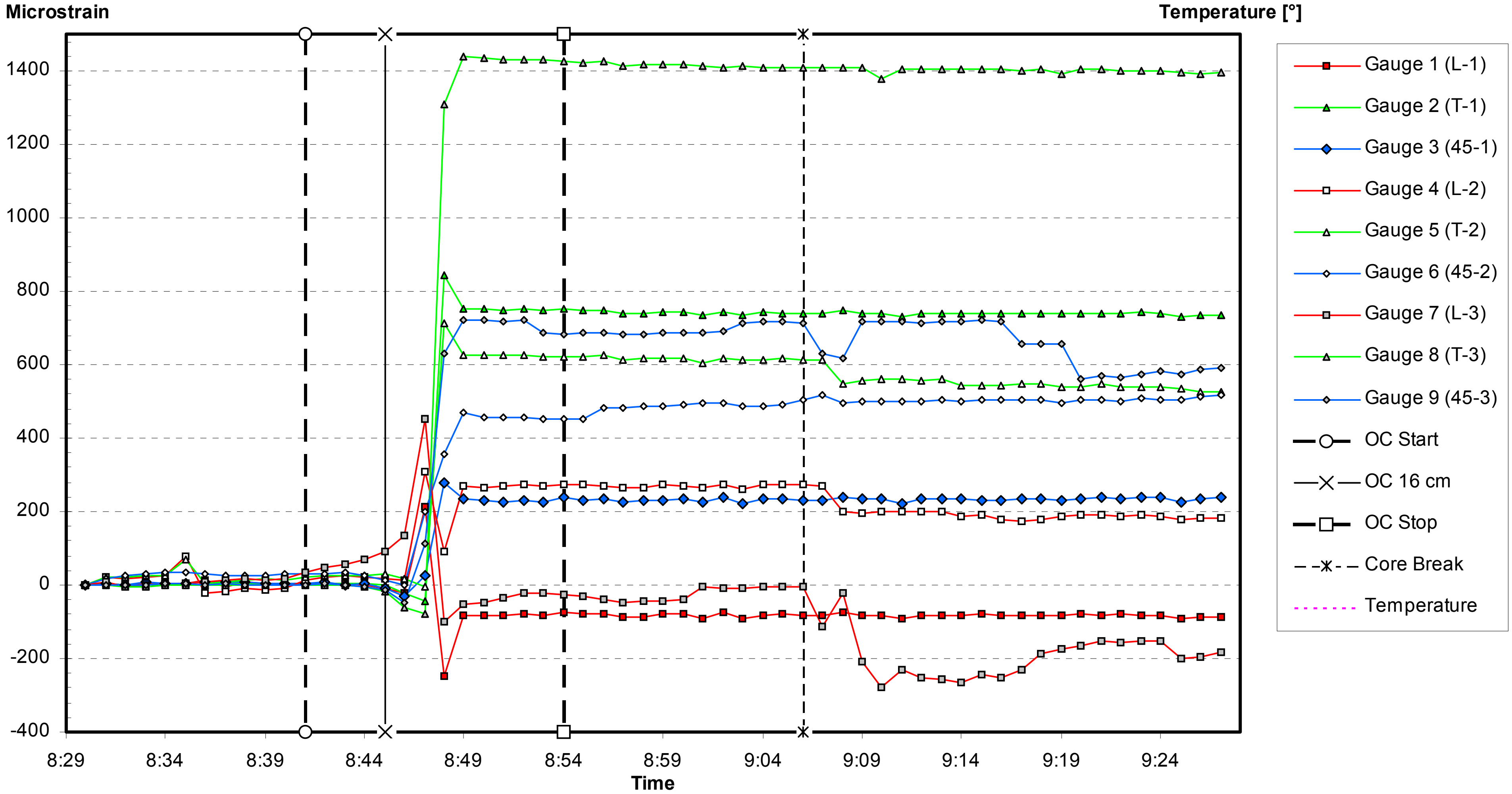
Klasson, H and Andersson, S. (2001) PM on 3D overcoring rock stress measurements in borehole KF0093A01 at the Äspö HRL. June, 2001. PM to SKB.

Myrvang, A (1997). Evaluation of in-situ rock stress measurements at the ZEDEX test area. 1997. SKB Äspö Hard Rock Laboratory Progress Report HRL-97-22.

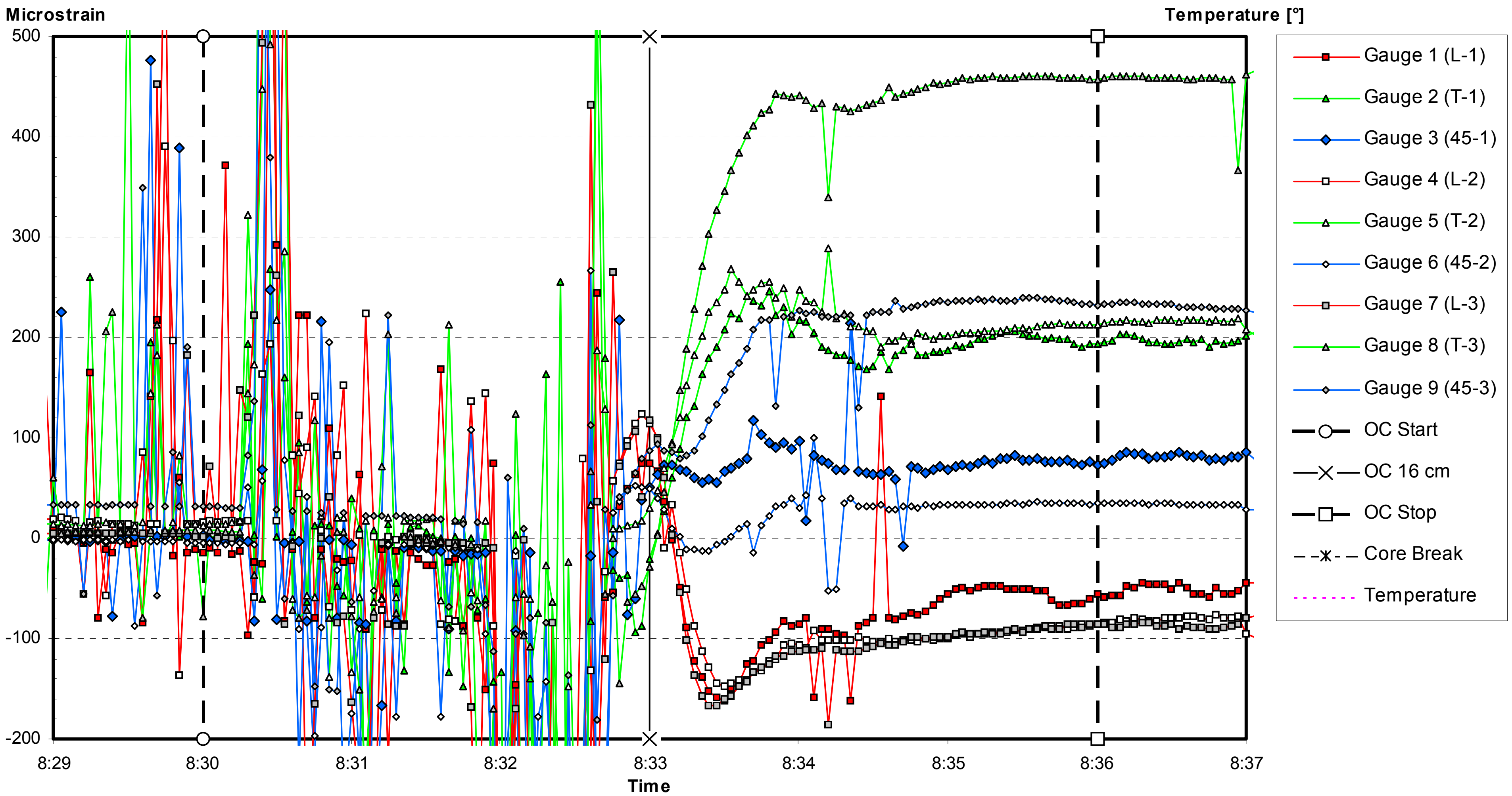
Nordlund, E., Li C. and Carlsson, B. (1999) Mechanical properties of the diorite in the prototype repository at Äspö HRL. Laboratory tests. Äspö Hard Rock Laboratory Repository. Progress Report IPSR-99-25. Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden.

Appendix A: Registered strains during overcoring Borehole KA3376B01, Äspö HRL

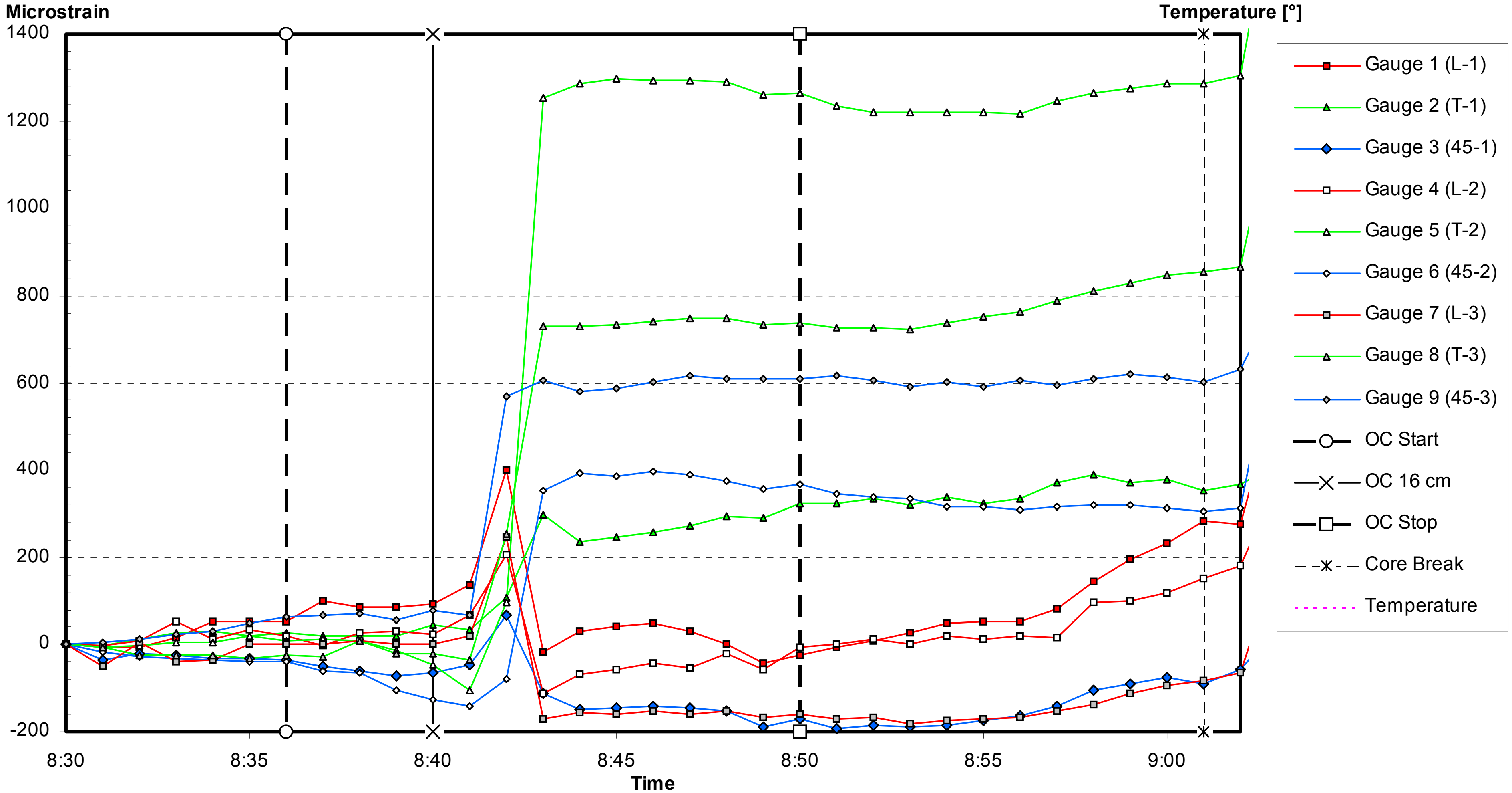
(4 pp)



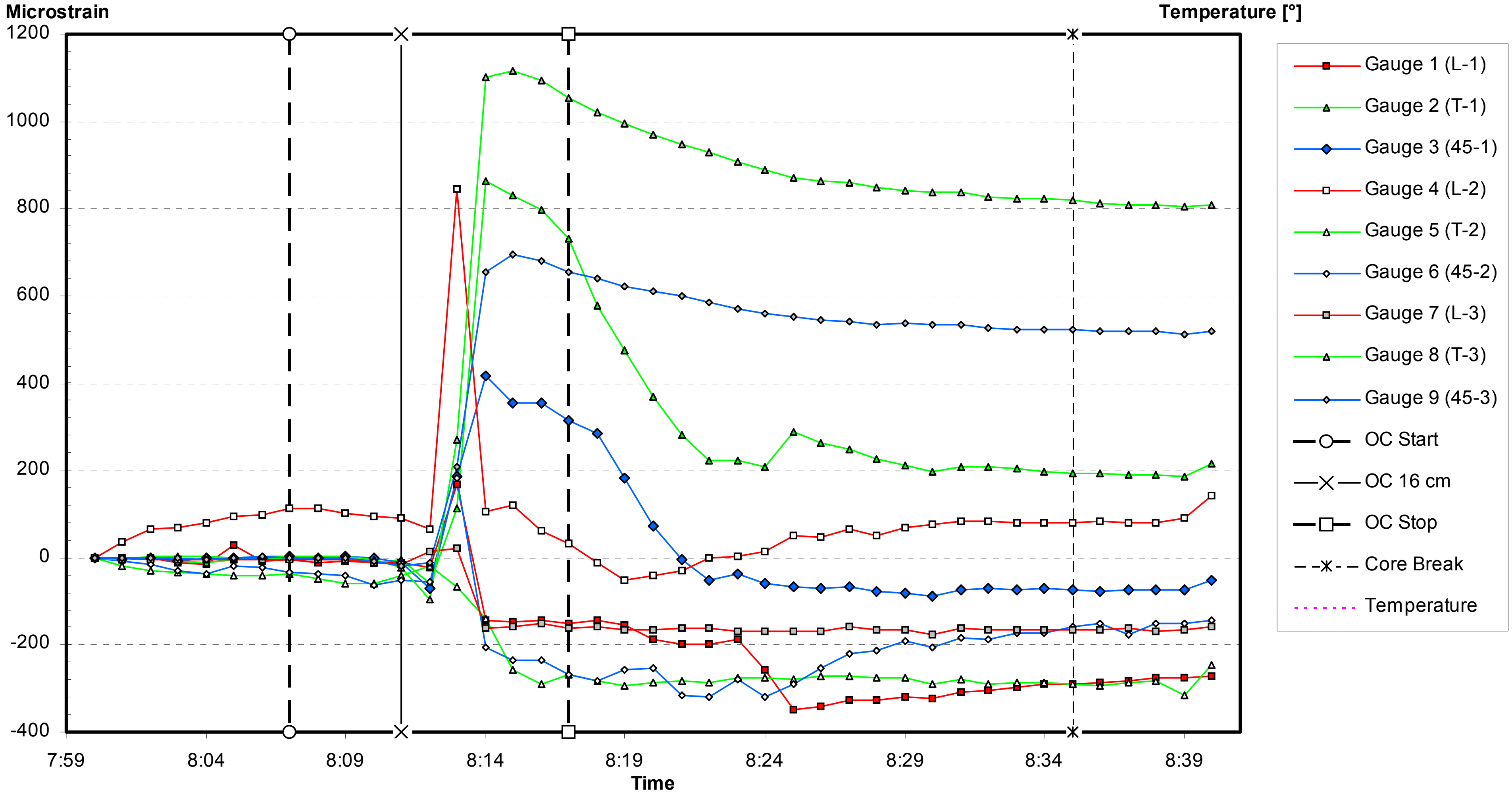
Test 2, 46.47 m depth, borehole KA3376B01, Äspö HRL



Test 3, 50.16 m depth, borehole KA3376B01, Äspö HRL



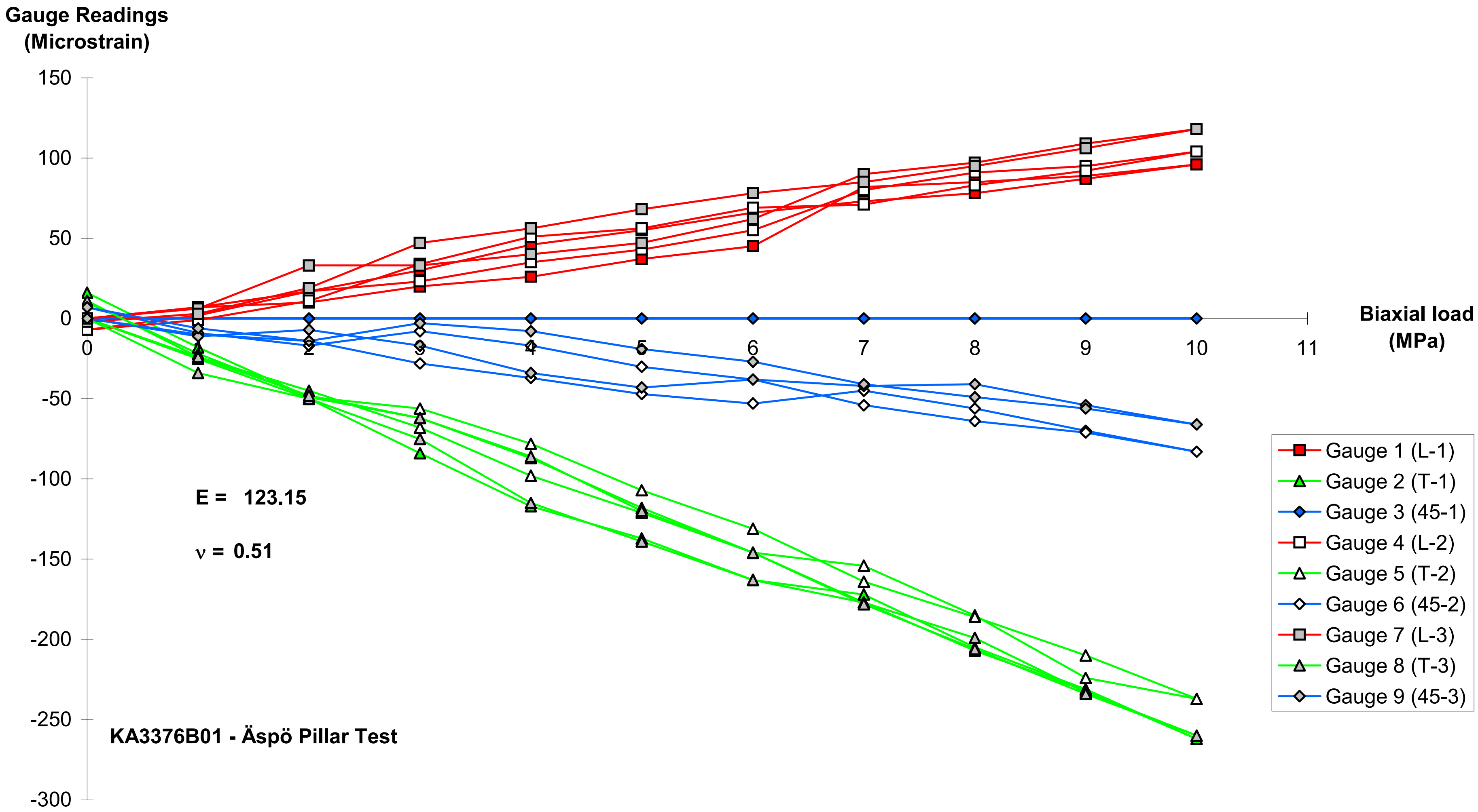
Test 5, 52.56 m depth, borehole KA3376B01, Äspö HRL



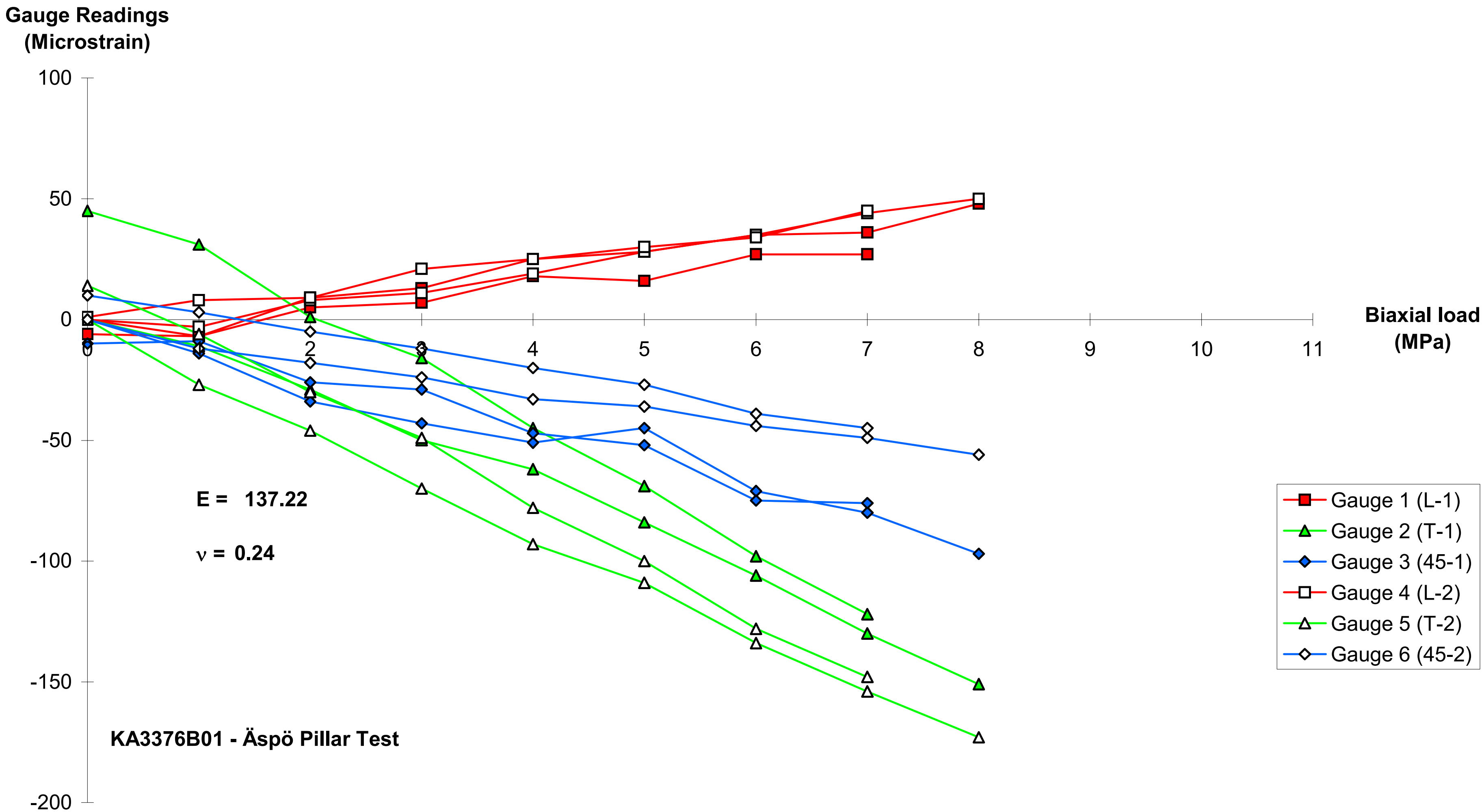
Test 7, 57.77 m depth, borehole KA3376B01, Äspö HRL

Appendix B: Biaxial tests
Borehole KA3376B01, Äspö HRL

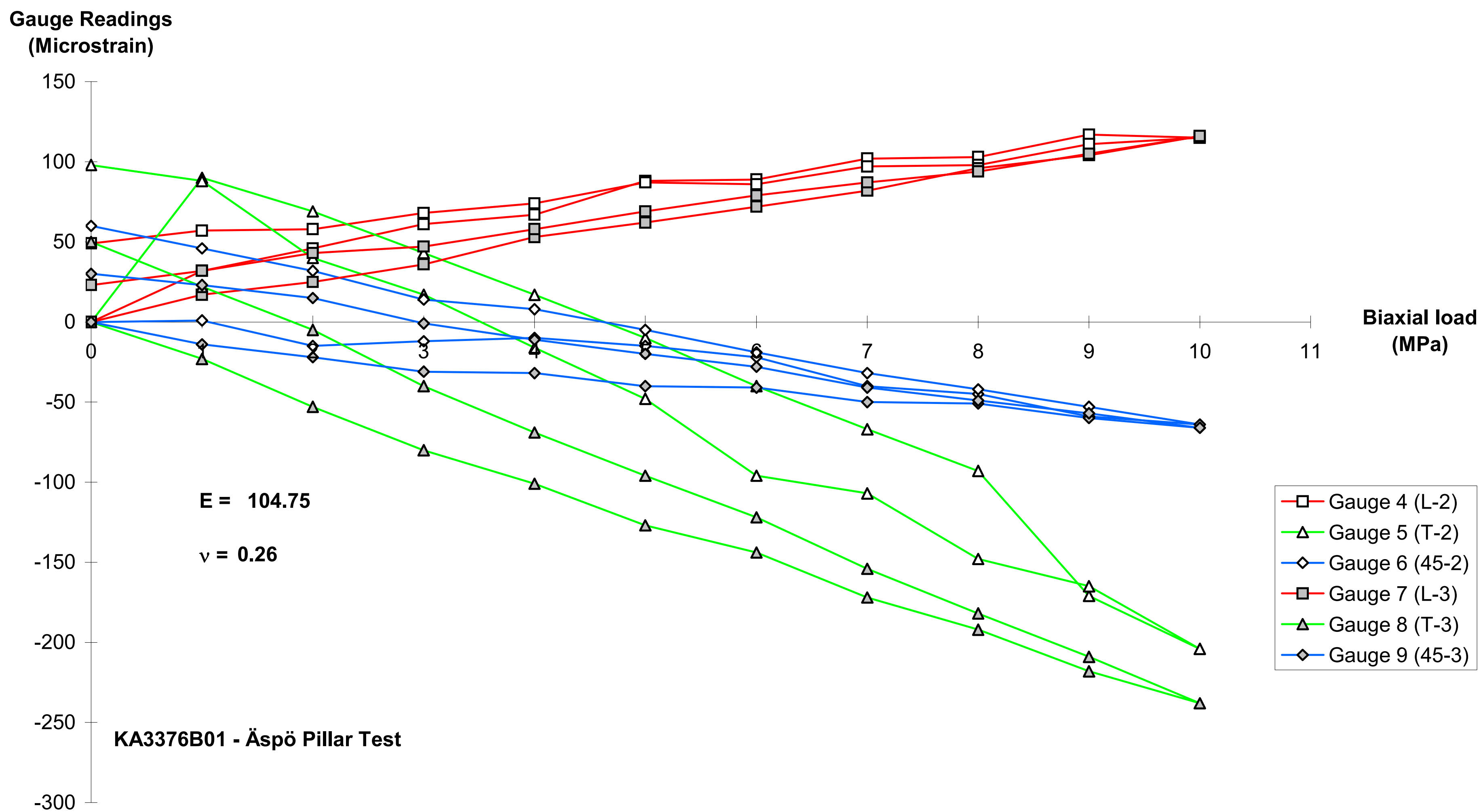
(5 pp)



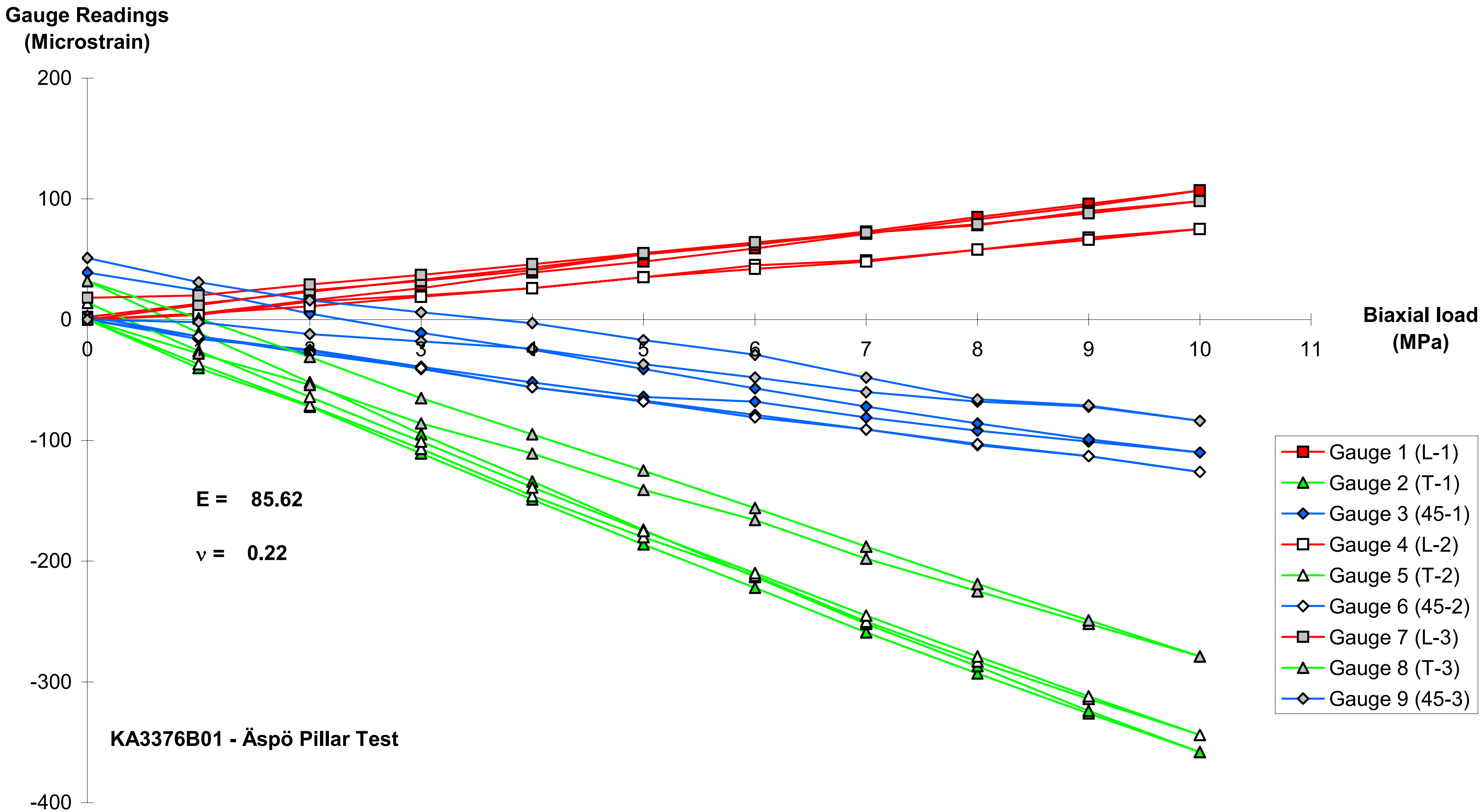
TEST 3, MEASUREMENT DEPTH: 50.16 m



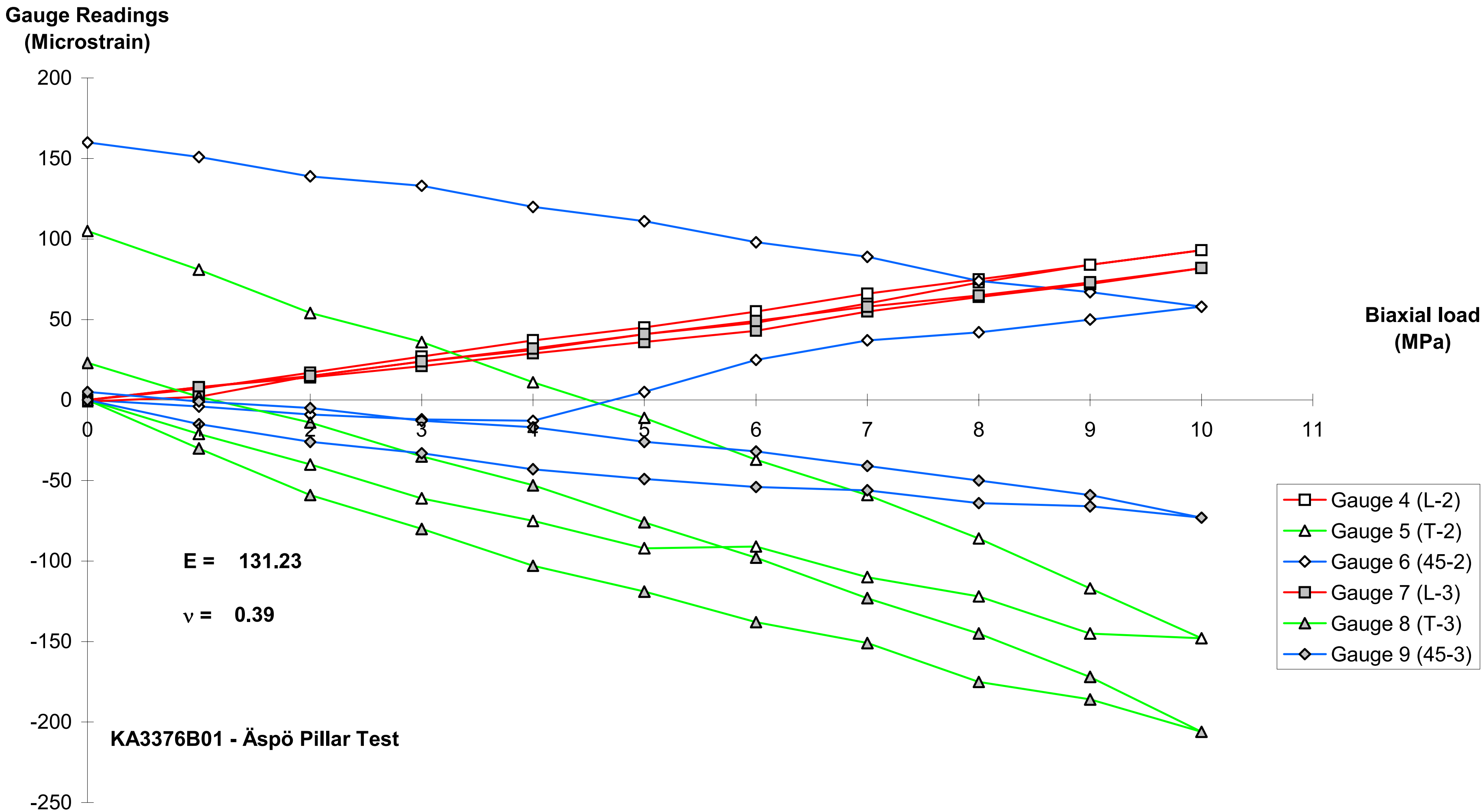
TEST 4, MEASUREMENT DEPTH: 50.88 m



TEST 5, MEASUREMENT DEPTH: 52.56 m



TEST 6, MEASUREMENT DEPTH: 55.34 M



TEST 7, MEASUREMENT DEPTH: 57.77 m