P-04-177

Forsmark site investigation

Drill hole KFM01A

Triaxial compression test (HUT)

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Helsinki University of Technology, Rock Engineering

June 2004

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ISSN 1651-4416
SKB P-04-177

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Key words: AP PF 400-04-04, Field note no Forsmark 96, Rock mechanics, Triaxial compression test, Poisson's ratio, E-modulus, Strain, Strength, Deformation, Post-peak behaviour.

Abstract

The complete stress-strain behaviour of rock samples from SKB's investigation site at Forsmark was studied with a total of five triaxial compression tests. The 51 mm diameter samples were taken from the borehole KFM01A at levels between 495-502 m. Moreover, the rock type was Medium-grained metagranite (-granodiorite). The specimens were photographed before and after the mechanical test.

The test specimens were prepared at the Swedish National Testing and Research Institute (SP). The tests were carried out at the Laboratory of Rock Engineering, Helsinki University of Technology, Espoo, on May 12-13, 2004. The water-saturated density of the specimens was determined before tests and the specimens were tested fully saturated.

The measured density for the water stored specimens were in the range 2657-2680 kg/m^3, which yields a mean value of 2662 kg/m^3 and the obtained values for the compressive strength were 247.4 and 262.8 MPa (confining stress 2 MPa), 348.2 and 353.4 MPa (confining stress 7 MPa), and 384.7 MPa (confining stress 10 MPa).

Contents

1 Introduction

This document reports the data collected by triaxial compression testing, which is one of the activities performed as part of the site investigation at Forsmark, see map in Figure 1-1. The work was carried out in accordance with activity plan AP PF 400-04-04 (SKB internal controlling document).

Triaxial compression testing is used to describe the complete stress-strain curve for cylindrical intact rock core samples at different surrounding pressures. Furthermore, it provides the compression strength and deformation properties of the rock, as well as a description of post-peak behaviour.

The tests were carried out at the Laboratory of Rock Engineering, Helsinki University of Technology in Espoo, Finland. The prepared specimens were received on February 16, 2004. The physical properties of the specimens were determined on April 29, 2004. Before testing, the specimens were water-saturated during one week and their water-saturated density was determined. The specimens were tested on May 12-13, 2004. The specimens were photographed before and after tests.

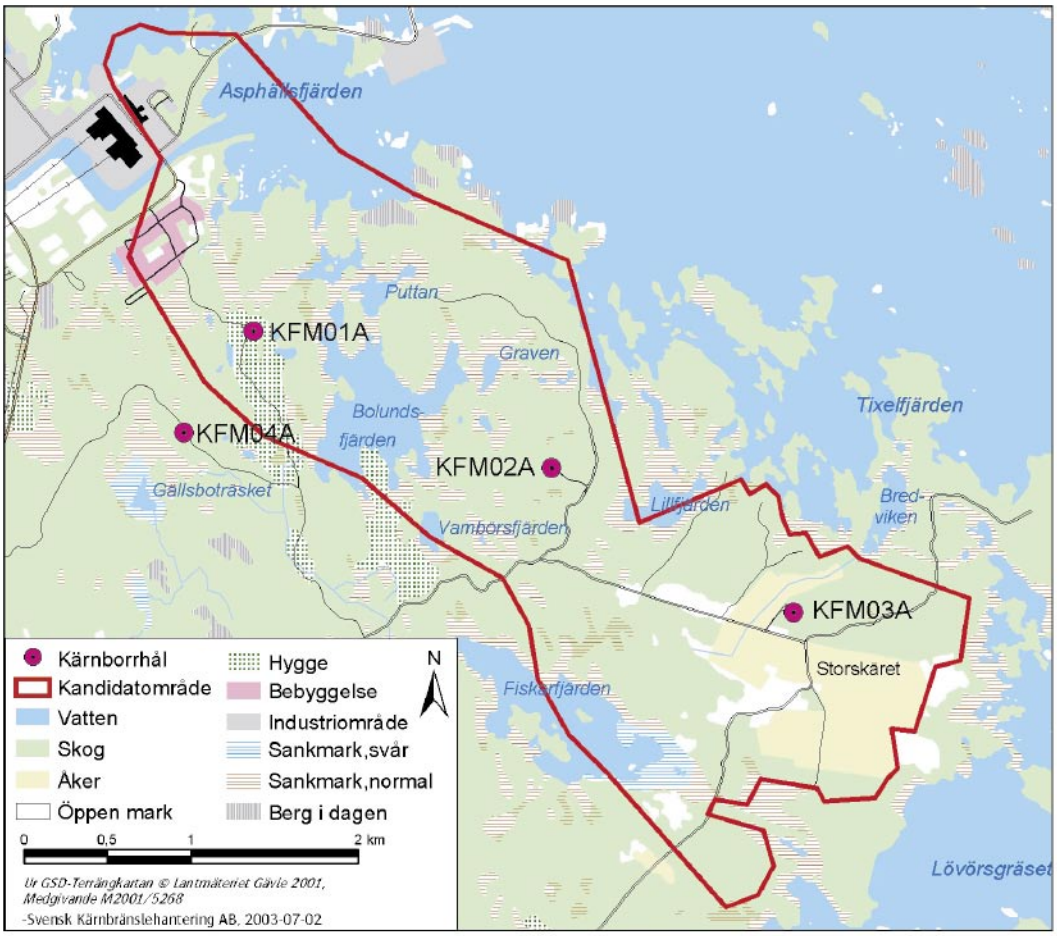


Figure 1-1. *Location of the borehole KFM01A at the Forsmark site.*

2 Objective and scope

The main objective of this experimental work is to compare the indirect tensile test results with results of similar tests performed at the main laboratory, the SP laboratory in Borås, Sweden.

The results from the tests are going to be used in the site descriptive rock mechanics model, which will be established for the candidate area selected for site investigations at Forsmark.

3 Equipment

The testing system was the MTS 815 Rock Mechanics Testing System (MTS 815), a computer controlled, servo hydraulic compression machine (Figure 3-1). It consists of a triaxial pressure vessel, a 2500 kN in-vessel load cell, a confining pressure intensifier, a load frame, hydraulic power supply, test controller, test processor and PC. The MTS 815 has three independent channels: axial pressure, confining pressure and pore pressure, which can be servo controlled by 16 readouts. The most common controls are actuator displacement, axial force, confining pressure, axial strain of a specimen and circumferential displacement of a specimen.

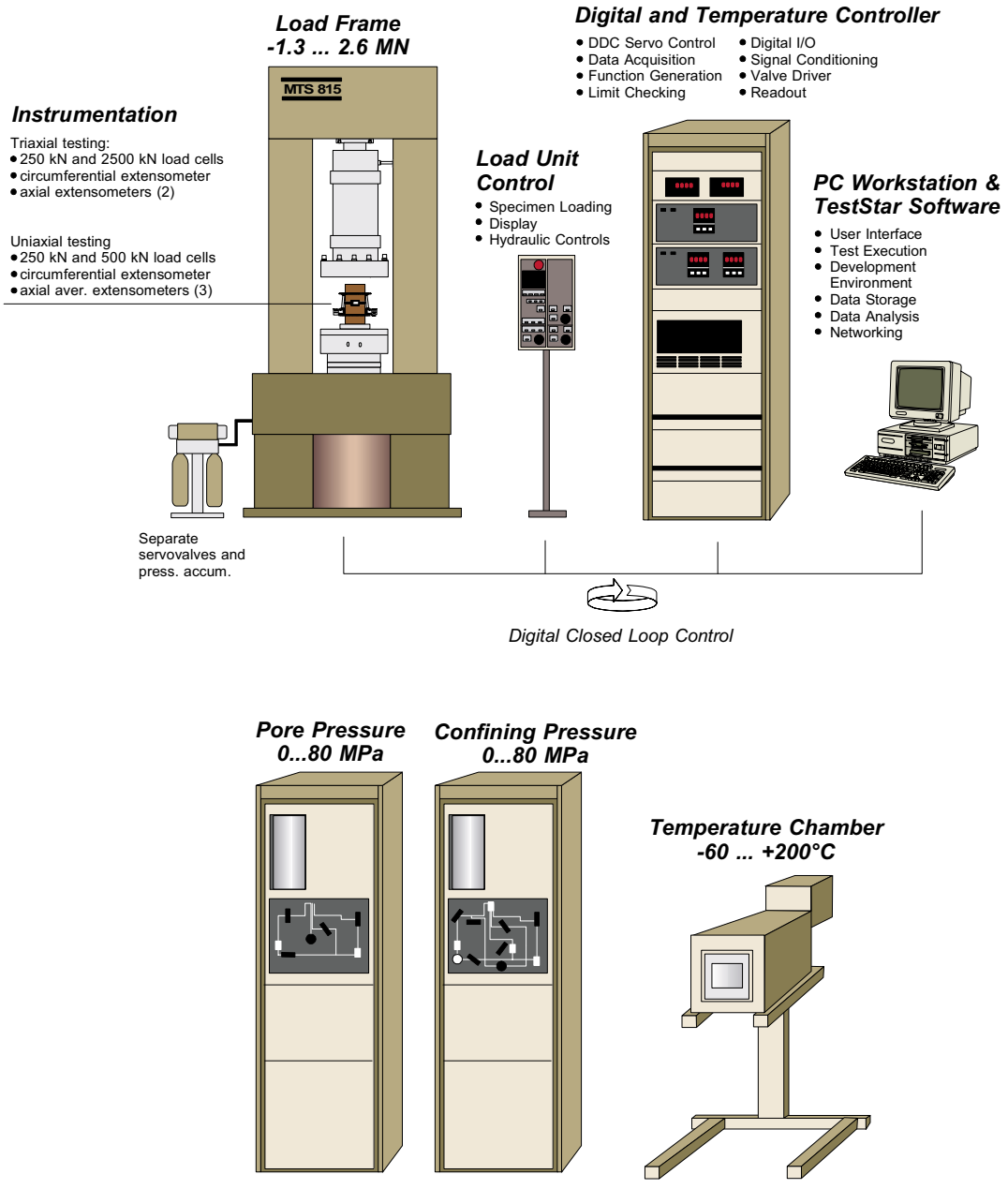


Figure 3-1. *MTS 815 Rock Mechanics Testing System.*

The axial and radial deformation of the specimen is measured with axial and radial strain extensometers (Figure 3-2).

In the triaxial tests the specimen and the deformation measuring equipment are placed inside the pressure vessel. The confining pressure is produced by confining oil. To prevent the confining oil from penetrating into the specimen, it is sealed with an EPDM rubber jacket. The deformations are measured on the jacket. The axial deformation is measured with two separately read direct contact axial extensometers from a 50 mm gage length. The radial strain is measured with one circumferential extensometer connected to a roller chain assembly wrapped around the jacketed specimen. All extensometers are held around the specimen by a contact force produced by mounting springs (Figure 3-2). The actuator displacement is also recorded. At the specimen ends non-lubricated steel end caps are used. The axial load is applied through one spherical seat in order to ensure uniform load distribution.

The water-saturation equipment included four sample containers with an air-tight lid, a balance, an immersion bath and a purpose-built wire basket suspended from the balance by a fine wire.

Figure 3-2. *Triaxial compression test extensometers on a jacketed specimen (Photo by Pekka Eloranta).*

4 Execution

The tests were executed according to the method description SKB MD 190.003e, version 1.9. The test methodology follows the International Society of Rock Mechanics (ISRM) suggested method /ISRM , 1983; 1999/.

The test specimens were water-saturated according to the method description SKB MD 160.002e, version 1.0. The test methodology follows mainly the standard /SFS-EN 13755/.

4.1 Description of the samples

The samples are from the hole KFM01A at the Forsmark investigation site. The test specimens were labeled at the Swedish National Testing and Research Institute (SP) (Table 4-1).

Table 4-1. Triaxial compression test samples from the hole KFM01A, Forsmark.

Seclow (m)	Specimen ID	Rock type	Cell pressure (MPa)
501.32	F01A-115-6	Meta granodiorite-granite	2
498.99	F01A-115-8	Meta granodiorite-granite	7
499.28	F01A-115-10	Meta granodiorite-granite	2
499.71	S01A-115-12	Meta granodiorite-granite	7
495.29	S01A-115-14	Meta granodiorite-granite	10

4.2 Testing

The specimens were prepared at the Swedish National Testing and Research Institute (SP) and they were received on February 16, 2004, at the Helsinki University of Technology.

The physical properties of the laboratory-air-dry specimens were determined on April 29, 2004. The length of each specimen was determined by taking the average of three measurements. The diameter of the specimen was measured by averaging two diameters measured at right angles to each other close to the top, the mid-height and the bottom of the specimen. The length-to-diameter ratio was calculated, and the straightness of the specimen, the parallelism, perpendicularity and flatness of the end surfaces were verified to be within the tolerances presented in the ASTM D 4543-01. In addition, the laboratory-air-dry mass of the specimen was recorded.

The specimens were photographed prior to water-saturation on April 29, 2004, using a digital camera.

Before testing, the specimens were water-saturated according to the standard /SFS-EN 13755/ with the following departure from the specified procedure. The specimens were not weighed during saturation. The specimens were saturated for at least one week (7 days).

The specimens were divided into four sample containers, one or two specimens each. Water-saturation began on May 4 – May 6, 2004.

After water-saturation, the water-saturated density of the specimens was determined in accordance with the ISRM suggested method /ISRM, 1979/. The specimens were transferred in the sample container in to an immersion bath. Each specimen was transferred under water from the container to a wire basket and weighed. The specimen was then removed from the immersion bath and surface-dried with a moist cloth removing only surface water. The saturated-surface-dry specimen was then weighed. The water-saturated density is calculated from the volume of the sample (Archimedes' principle) and its water-saturated weight.

The saturated-surface-dry specimens waiting to be tested were stored in a wet sample container with an air-tight lid to keep them water-saturated.

The water-saturation was finished and the specimens were tested on May 12-13, 2004.

The tests were conducted under radial strain rate control corresponding to an elastic axial loading rate of about 0.75 MPa/s (Table 4-2). First the specimen is driven to contact under programmed control. The pressure vessel cannot be filled by computer control. Therefore the programmed test control was set to the hold mode for this period. To settle the jacket and the extensometers on the jacket, a confining ramp to the test confining pressure was executed. After the confining ramp, the pressure was again increased to the test pressure. One loading ramp in the elastic region is done to ensure a well-settled specimen before actual loading ramp to failure. In both of these loading steps, axial load control is used, first to overcome the radial extensometer hysteresis, and after that the control is changed to radial strain rate to ensure a controlled test in the post-peak region.

All measured data were recorded at a frequency of 1 Hz.

Tangent Young's modulus and Poisson's ratio were determined at an axial stress level equal to 50% of the compressive strength of the specimen. The slopes of the stress-strain curves were determined between 40-60% of the peak strength using linear fit.

The specimens were photographed after testing on May 12-14, 2004.

The axial and radial extensometers were calibrated on May 6, 1998. Their condition was monitored before each test series using a reference non-jacketed aluminum specimen at a confining pressure of 20 MPa. Young's modulus and Poisson's ratio were used as monitoring values. Both values were determined as a secant from the range of 0.05% of radial strain to 150 MPa.

Table 4-2. Triaxial compression test procedure.

1	**Drive specimen manually near to contact**
	- No axial force is allowed
2	**Reset readings**
	- Reset readings of axial and radial extensometers, actuator displacement, axial force and confining pressure
3	**Start programmed test control**
4	**Drive specimen to force contact**
	- Move actuator up 0.2 mm/min until axial force is 1.0 kN
5	**Hold axial load while filling the pressure vessel with confining oil**
	- Program holds load for 60 seconds, during this period the test control is set manually to the hold state, which holds the axial load
	- Fill pressure vessel with confining oil
	- Release the manual hold to resume the programmed control
6	**Confining ramp to settle jacket and extensometers on jacket**
	- Increase confining pressure 0.05 MPa/s to <test> MPa
	- Decrease confining pressure 0.05 MPa/s to 0.5 MPa
7	**Set confining pressure to test value**
	- Increase confining pressure 0.05 MPa/s to <test> MPa
8	**Axial load ramp to settle the specimen**
	- Increase axial load so that loading rate is 0.75 MPa/s until radial strain is -0.01% or axial stress is 75 MPa
	- Decrease axial load so that loading rate is 0.75 MPa/s until axial force is 1 kN
9	**Axial load ramp to failure**
	- Increase axial load so that loading rate is 0.75 MPa/s until radial strain is –0.01% or axial stress is 75 MPa
	- Change to radial strain rate control
	- Increase radial strain, the radial strain rate corresponding initially to the elastic loading rate of 0.75 MP/s, until the end of the radial extensometer range is reached or the test is stopped manually
10	**Unloading**
	- Remove remaining force by programmed control
	- Decrease confining pressure 0.05 MPa/s to 0.2 MPa

5 Results

The results of the individual specimens are presented in Section 5.1 and a summary of the results is given in Section 5.2. The original results and data obtained from the testing were reported to the SICADA database under field note no Forsmark 96.

5.1 Description and presentation of the specimen

The photographs of the specimens before and after testing are presented in the following pages (Figures 5-1 – 5-5). The results are presented in Appendices 2-6.

(a) Before testing (2004-04-29) *(b) After testing (2004-05-12)*

Figure 5-1. *Photographs of the specimen F01A-115-6.*

(a) Before testing (2004-04-29) *(b) After testing (2004-05-12)*

Figure 5-2. *Photographs of the specimen F01A-115-8.*

(a) Before testing (2004-04-29) *(b) After testing (2004-05-13)*

Figure 5-3. *Photographs of the specimen F01A-115-10.*

(a) Before testing (2004-04-29) *(b) After testing (2004-05-14)*

Figure 5-4. *Photographs of the specimen F01A-115-12.*

(a) Before testing (2004-04-29) *(b) After testing (2004-05-14)*

Figure 5-5. *Photographs of the specimen F01A-115-14.*

5.2 Results for the entire test series

A summary of the results is presented in Table 5-1.

Table 5-1. Summary of the results.

Specimen ID	Confining pressure (MPa)	Length (mm)	Diameter (mm)	Density (kg/m^3)	Compressive strength (MPa)	Young's modulus (GPa)	Poisson's ratio
F01A-115-6	2	126.4	50.8	2680	247.4	75.3	0.31
F01A-115-8	7	126.4	50.8	2657	353.4	78.3	0.28
F01A-115-10	2	126.4	50.8	2659	262.8	76.3	0.29
F01A-115-12	7	126.4	50.8	2660	348.2	76.2	0.29
F01A-115-14	10	126.4	50.9	2655	384.7	79.6	0.29

5.3 Nonconformities

Before testing, the specimens were water-saturated according to the standard /SFS-EN 13755/, except for that the specimens were not weighed during saturation.

5.4 Discussion

The test equipment functioned without problems.

References

ASTM D 4543-01. Standard practice for preparing rock core specimens and determining dimensional and shape tolerance. ASTM vol. 04.08

ISRM, 1979. Suggested method for determining water content, porosity, density, absorption and related properties and swelling and slake-durability index properties.

ISRM, 1983. ISRM Suggested Method for determining the strength of rock material in triaxial compression: Revised Version.

ISRM, 1999. Draft ISRM suggested method for the complete stress – strain curve for intact rock in uniaxial compression. International Journal of Rock Mechanics and Mining Sciences, 36, 3, p. 279–289.

SFS-EN 13755. Natural stone test methods – Determination of water absorption at atmospheric pressure.

Appendix 1

Test information sheet for triaxial compression test

Title: **Test information sheet for triaxial compression test of intact rock** Page 1 (2)
Date: 2004-04-28 *Order:* _____
Author: Pekka Eloranta
Reference: SKB MD 190.003e Appendix 5 *Specimen ID:* _____

1. Reception and arrival at the laboratory *Date:* _____ *By:* _____

Remarks: _____

2. Geological description of the specimen *Date:* _____ *By:* _____
(According to the SKB Boremap mapping)

Remarks: _____

3. Preparation of the specimen

Cutting: *Remarks:* _____ *Date:* _____ *By:* _____

Grinding: *Remarks:* _____ *Date:* _____ *By:* _____

4. Physical properties of the specimen *Date:* _____ *By:* _____
(According to the ASTM D 4543)

Height (mm): 1 _____ 2 _____ 3 _____ *Average height (mm):* _____

Diameter (mm): 1 _____ 2 _____ 3 _____ *Average diameter (mm):* _____

4 _____ 5 _____ 6 _____ *Height/Diameter ratio:* _____

Mass (g): _____ *(laboratory air-dry)* *Straightness of the sides (mm):* _____

Perpendicularity (mm): _____ *Parallellism and flatness of the end surfaces (mm):* _____

Remarks: _____

5. Photographing the specimen before testing *Date:* _____ *By:* _____

Equipment: _____

Filenames: _____

Remarks: _____

6. Water-saturation of the specimen *Date:* _____ *By:* _____

Start (t_0): date _____ time _____ *End:* date _____ time _____

Equipment: [ ] *Mettler PM4000, serial number N95274*
[ ] *Mettler PJ3600, serial number M88692*
[ ] _____

Saturated-submerged mass (g): _____

Saturated-surface-dry mass (g): _____

Remarks: _____

7. Testing the specimen

Date: _____
By: _____

Moisture condition of the specimen at time of test:

[ ] *as received* [ ] *saturated* [ ] *laboratory air-dry* [ ] *oven dry*

Equipment: *MTS 815 Rock Mechanics Test System*

Test setup

[ ] *Triaxial*

Force transducer (serial number and range)

[ ] *none* [ ] *0124980 (250 kN)* [ ] *0124981 (2500 kN)*

Circumferential strain extensometer (serial number)

[ ] *none* [ ] *138* [ ] _____

Axial strain extensometer (serial number)

[ ] *none* [ ] *121* [ ] _____

Rubber: _____ *Diameter on rubber (mm):* _____

L_i *(mm):* _____ *(Initial chord length between the center of the two end rollers of the circumferential extensometer.)*

Run: _____

Raw data: _____

Start: _____ *time* *Confining pressure (MPa):* _____

Stop: _____ *time* *Peak load (kN):* _____

Failure:

Remarks: _____

8. Photographing the specimen after testing

Date: _____
By: _____

Equipment: _____

Filenames: _____

Remarks: _____

9. Handling, processing and storage of the measured data

Date: _____
By: _____

Remarks: _____

10. Storing the specimen after testing

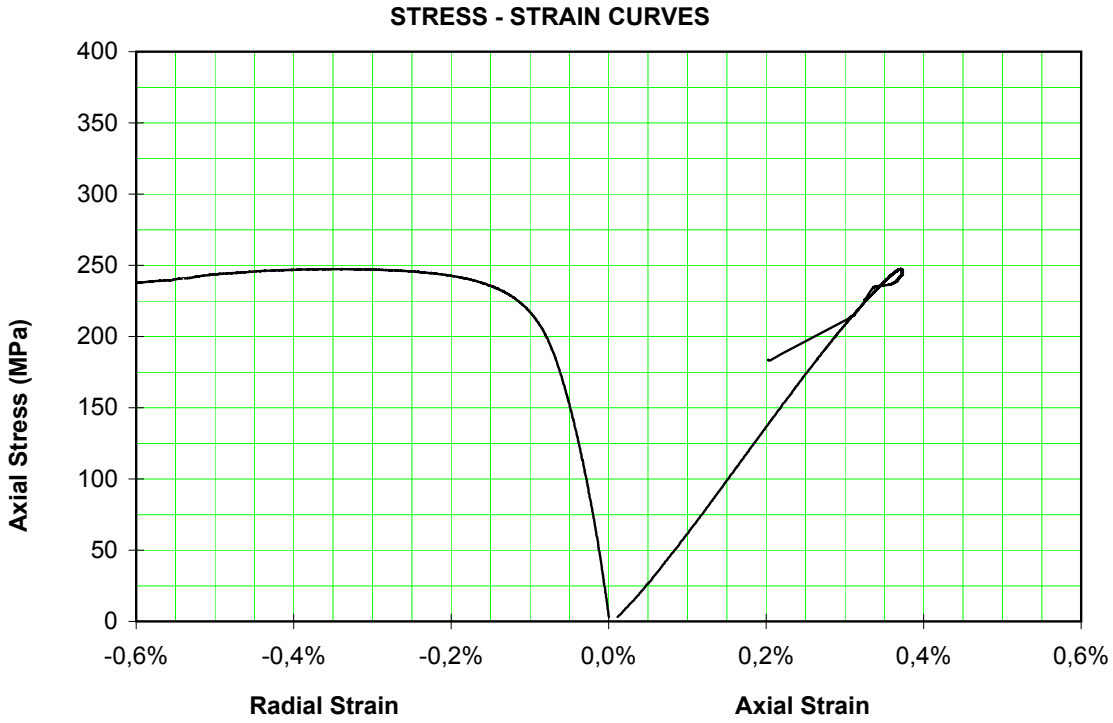
Date: _____
By: _____

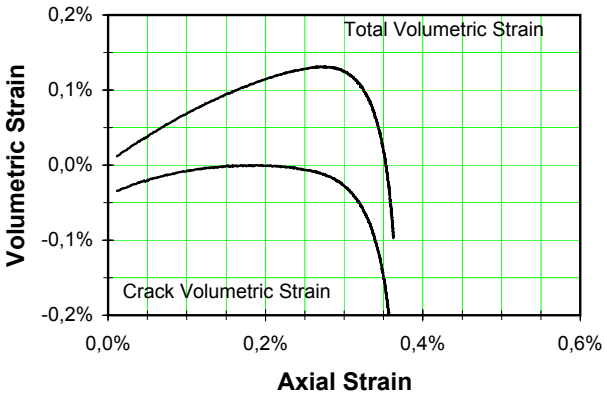
Place: _____

Remarks: _____

Appendix 2

Test results of the specimen F01A-115-6





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Triaxial	*Confining Pressure:*	2 MPa
Equipment:	MTS 815		
Specimen Data	**F01A-115-6**		
Site:	Forsmark	*Length:*	126,4 mm
Hole:	KFM01A	*Diameter:*	50,8 mm
Depth:	501,32 m	*Saturated Density:*	2680 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	247,4 MPa	*Test Date:*	2002-05-12
Young's Modulus:	75,3 GPa	*Test Duration:*	01:06 (h:min)
Poisson's Ratio:	0,31	*Failure Mode:*	Axial splitting
Remarks:	The axial extensometers were probably slipping at the post-peak range		

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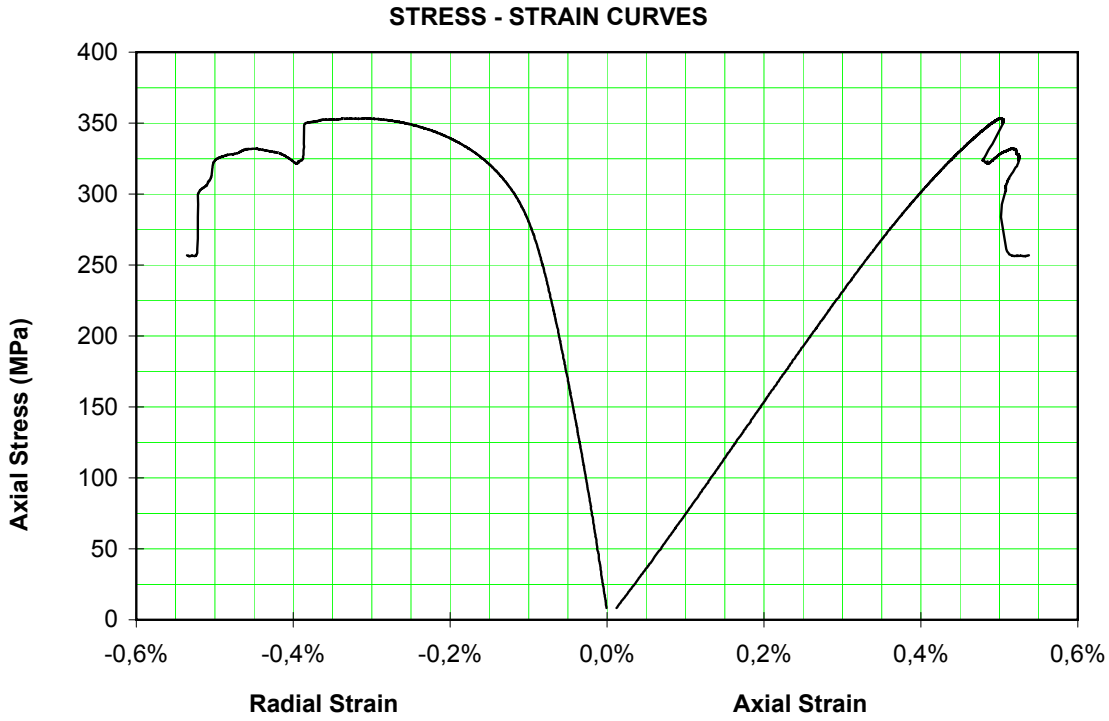
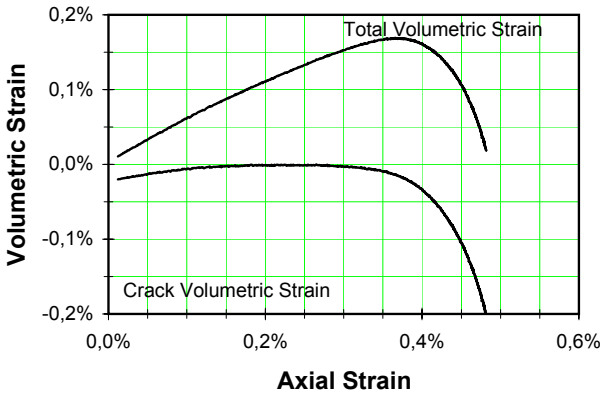
e-mail: rocklab@hut.fi

Appendix 3

Test results of the specimen F01A-115-8





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Triaxial	*Confining Pressure:*	7 MPa
Equipment:	MTS 815		
Specimen Data	**F01A-115-8**		
Site:	Forsmark	*Length:*	126,4 mm
Hole:	KFM01A	*Diameter:*	50,8 mm
Depth:	498,99 m	*Saturated Density:*	2657 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	353,4 MPa	*Test Date:*	2002-05-12
Young's Modulus:	78,3 GPa	*Test Duration:*	01:00 (h:min)
Poisson's Ratio:	0,28	*Failure Mode:*	Axial splitting
Remarks:	None		

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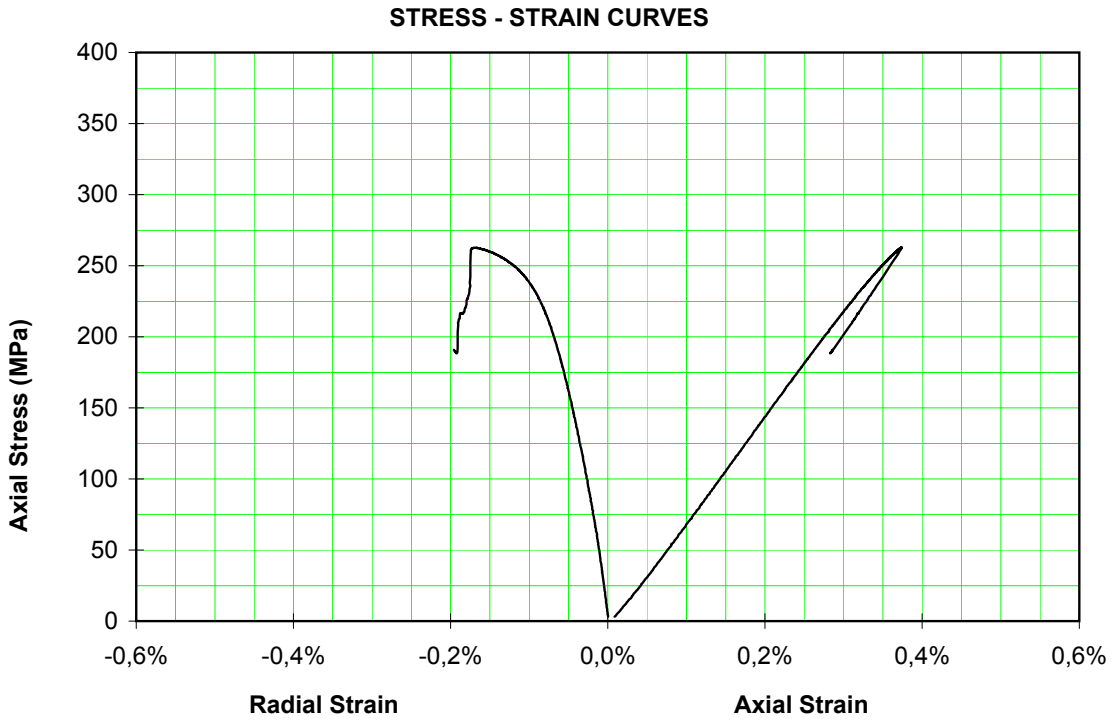
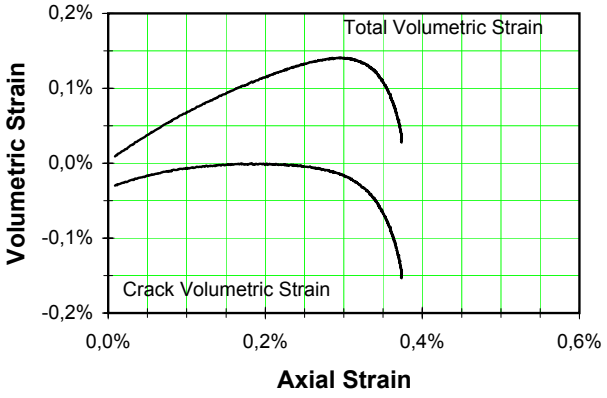
Appendix 4

Test results of the specimen F01A-115-10





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Triaxial	*Confining Pressure:*	2 MPa
Equipment:	MTS 815		
Specimen Data	**F01A-115-10**		
Site:	Forsmark	*Length:*	126,4 mm
Hole:	KFM01A	*Diameter:*	50,8 mm
Depth:	499,28 m	*Saturated Density:*	2659 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	262,8 MPa	*Test Date:*	2002-05-13
Young's Modulus:	76,3 GPa	*Test Duration:*	00:32 (h:min)
Poisson's Ratio:	0,29	*Failure Mode:*	Axial splitting
Remarks:	None		

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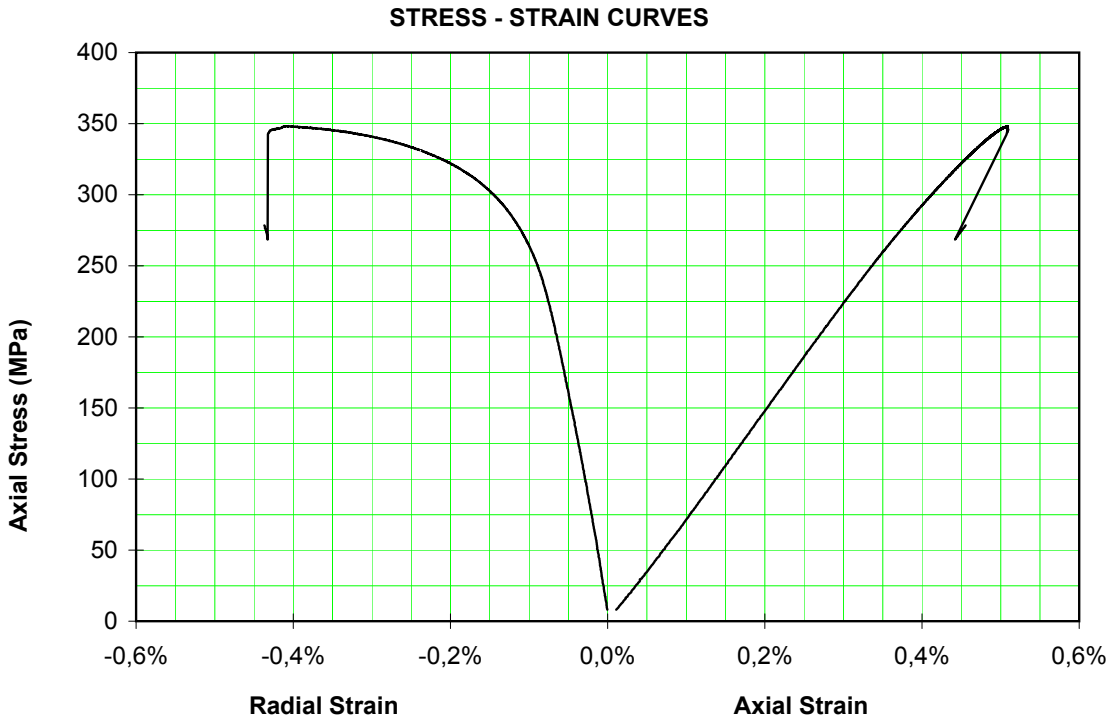
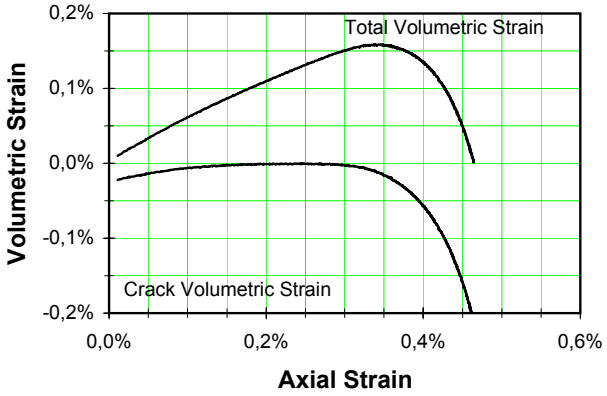
Appendix 5

Test results of the specimen F01A-115-12





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Triaxial	*Confining Pressure:*	7 MPa
Equipment:	MTS 815		
Specimen Data	**F01A-115-12**		
Site:	Forsmark	*Length:*	126,4 mm
Hole:	KFM01A	*Diameter:*	50,8 mm
Depth:	499,71 m	*Saturated Density:*	2660 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	348,2 MPa	*Test Date:*	2002-05-13
Young's Modulus:	76,2 GPa	*Test Duration:*	00:53 (h:min)
Poisson's Ratio:	0,29	*Failure Mode:*	Axial splitting
Remarks:	None		

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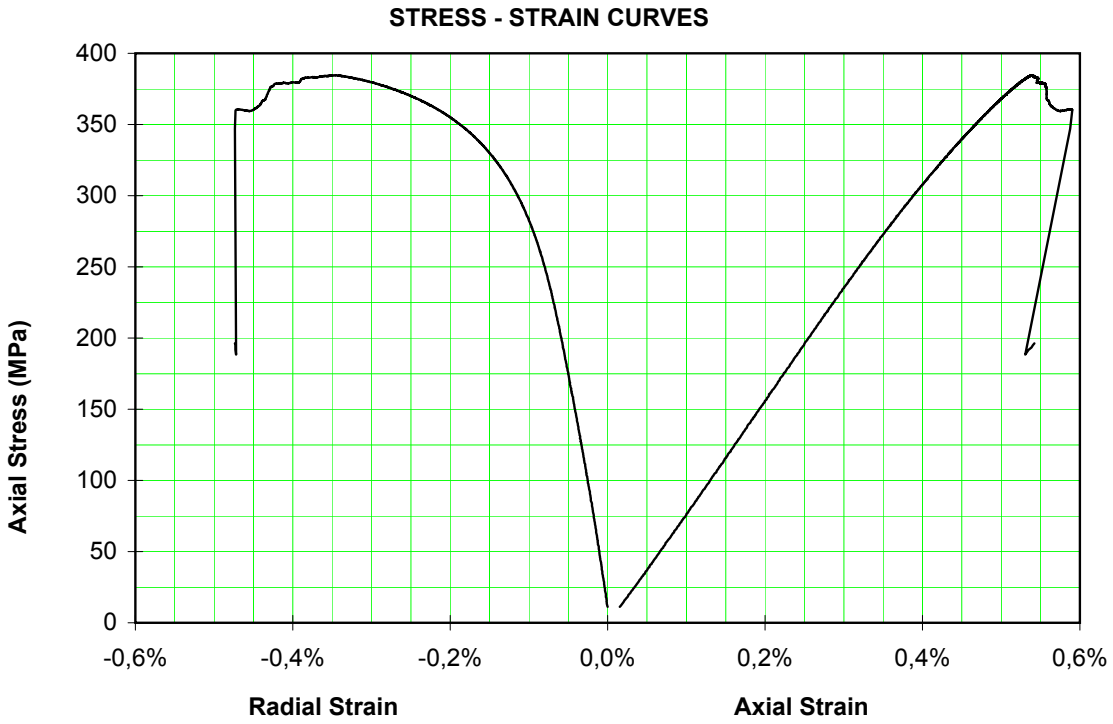
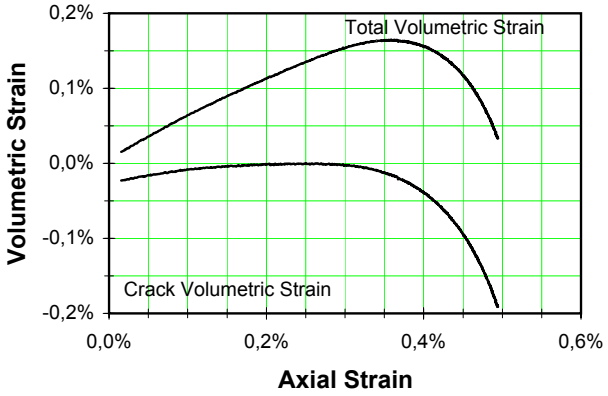
Appendix 6

Test results of the specimen F01A-115-14





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Triaxial	*Confining Pressure:*	10 MPa
Equipment:	MTS 815		
Specimen Data	**F01A-115-14**		
Site:	Forsmark	*Length:*	126,4 mm
Hole:	KFM01A	*Diameter:*	50,9 mm
Depth:	495,29 m	*Saturated Density:*	2655 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	384,7 MPa	*Test Date:*	2002-05-13
Young's Modulus:	79,6 GPa	*Test Duration:*	00:59 (h:min)
Poisson's Ratio:	0,29	*Failure Mode:*	Axial splitting
Remarks:	None		

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