P-04-176

Forsmark site investigation

Drill hole KFM01A

Uniaxial compression test (HUT)

Pekka Eloranta
Helsinki University of Technology, Rock Engineering

August 2004

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Abstract

The complete stress-strain behaviour of rock samples from SKB's investigation site at Forsmark was studied with a total of six uniaxial compression tests. The 51 mm diameter samples were taken from the borehole KFM01A at levels between 496-499 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 April 13-15, 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 2642-2664 kg/m^3, which yields a mean value of 2658 kg/m^3 and the obtained values for the uniaxial compressive strength were in the range 234.3-243.7 MPa with a mean value of 238.7 MPa.

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1 Introduction

This document reports the data collected by uniaxial 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).

Uniaxial compression testing is used to describe the complete stress-strain curve for cylindrical intact rock core samples. Furthermore, it provides the uniaxial 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 2, 2004. Before testing, the specimens were water-saturated during one week and their water-saturated density was determined. The specimens were tested on April 15-16, 2004. The specimens were photographed before and after tests.

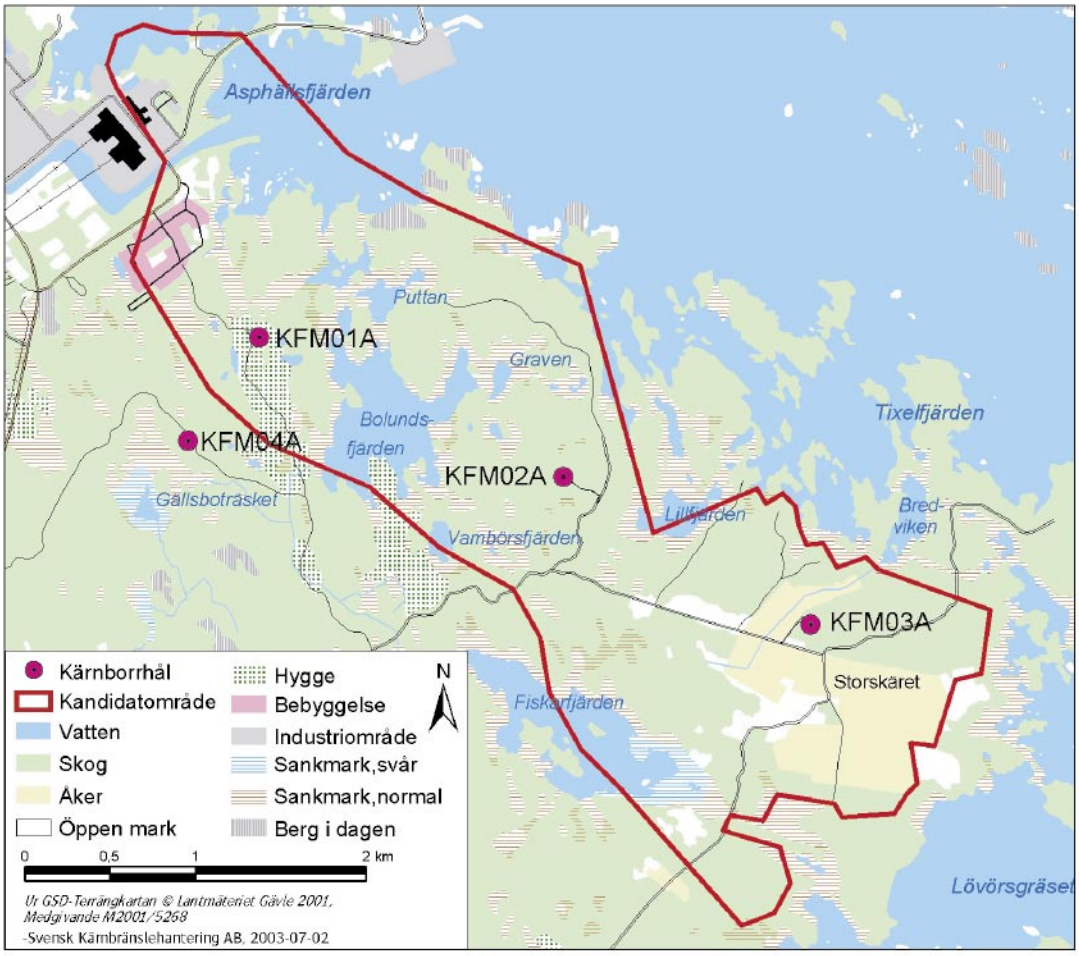


Figure 1-1. *Location of the borehole KFM01A at the Forsmark site.*

2 Objective and scope

The main objective of this experimental work is to compare the uniaxial compression 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 used was the MTS 815 Rock Mechanics Testing System (MTS 815), a computer controlled, servo hydraulic compression machine (Figure 3-1). It consists of a 500 kN load transducer, 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.

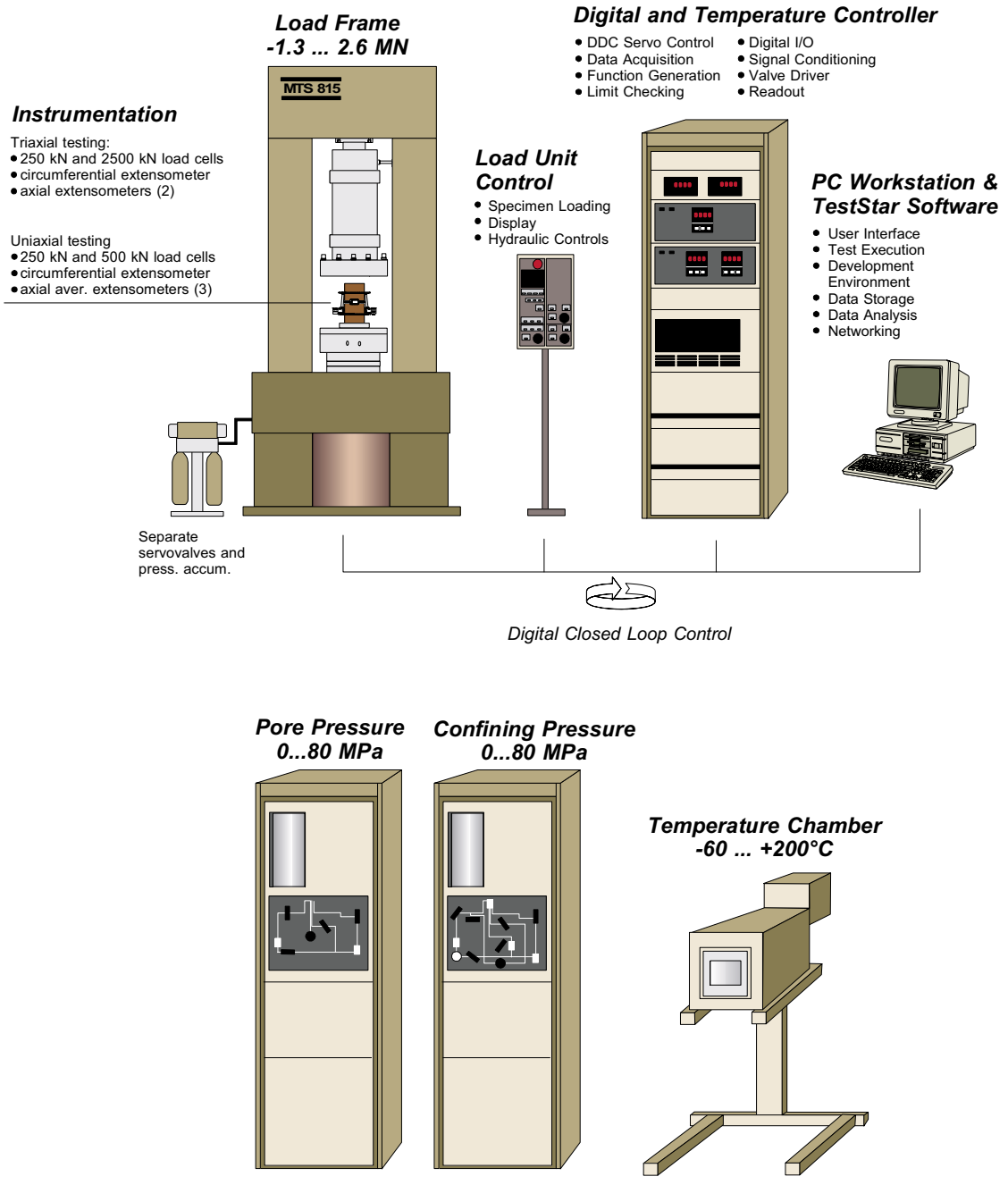


Figure 3-1. *MTS 815 Rock Mechanics Testing System.*

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

Three averaging direct contact axial extensometers are used to measure axial strain. The axial deformation is measured from a 50 mm gage length. The radial strain is measured with one circumferential extensometer connected to a roller chain assembly wrapped around the 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 three 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.

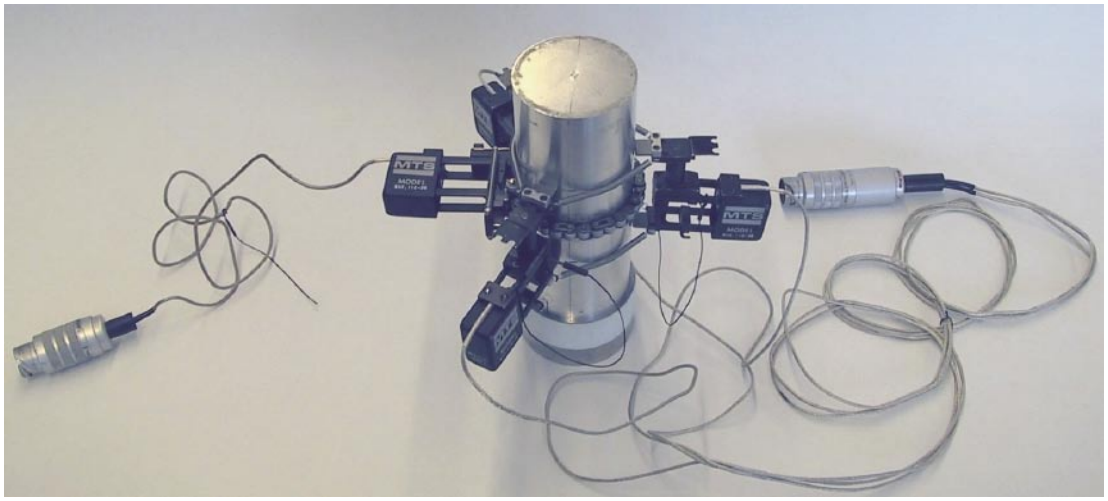


Figure 3-2. *Uniaxial compression test extensometers on the reference aluminum specimen (Photo by Pekka Eloranta).*

4 Execution

The tests were executed according to the method description SKB MD 190.001e, version 1.9. The test methodology follows the International Society of Rock Mechanics (ISRM) suggested method /ISRM, 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 Institutute (SP) (Table 4-1).

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

Seclow (m)	Specimen ID	Rock type
496.30	F01A-113-9	Meta granodiorite-granite
496.74	F01A-113-11	Meta granodiorite-granite
495.61	F01A-113-13	Meta granodiorite-granite
497.42	F01A-113-15	Meta granodiorite-granite
497.71	F01A-113-17	Meta granodiorite-granite
498.04	F01A-113-19	Meta granodiorite-granite

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 2, 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 2, 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 three sample containers, two specimens each. Water-saturation began on April 6-7, 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 April 15-16, 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. 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.

The specimens were photographed after testing on April 20, 2004.

Tangent Young's modulus and Poisson's ratio were determined at an axial stress level equal to 50% of the uniaxial 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 axial extensometer was calibrated on January 2003 and the radial extensometer on April 2003. Their condition was monitored before each test series using a reference aluminum specimen. Young's modulus and Poisson's ratio were used as monitoring values. Both values were determined as a secant from the range of 0.01% of radial strain to 50 MPa.

Table 4-2. Uniaxial compression test procedure.

1	**Drive specimen manually near to contact**
	- No axial force is allowed
2	**Reset readings**
	- Reset readings of axial and radial extensometer, actuator displacement and axial force
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	**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 0.5 kN
6	**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
7	**Unloading**
	- Remove remaining force by programmed control

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 – 5-6). The results are presented in Appendices 2-7.

(a) Before testing (2004-04-02) *(b) After testing (2004-04-20)*

Figure 5-1. *Photographs of the specimen F01A-113-9.*

(a) Before testing (2004-04-02) *(b) After testing (2004-04-20)*

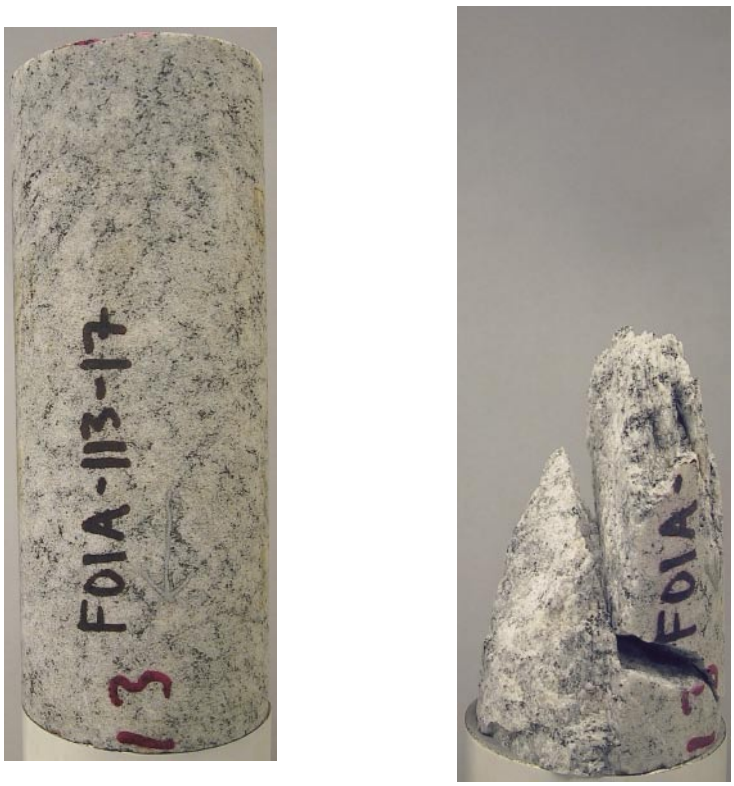
Figure 5-2. *Photographs of the specimen F01A-113-11.*

(a) Before testing (2004-04-02) *(b) After testing (2004-04-20)*

Figure 5-3. *Photographs of the specimen F01A-113-13.*

(a) Before testing (2004-04-02) *(b) After testing (2004-04-20)*

Figure 5-4. *Photographs of the specimen F01A-113-15.*



(a) Before testing (2004-04-02) *(b) After testing (2004-04-20)*

Figure 5-5. *Photographs of the specimen F01A-113-17.*

(a) Before testing (2004-04-02) *(b) After testing (2004-04-20)*

Figure 5-6. *Photographs of the specimen F01A-113-19.*

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	Seclow (m)	Length (mm)	Diameter (mm)	Density (kg/m³)	Compressive strength (MPa)	Young's modulus (GPa)	Poisson's ratio
F01A-113-9	496.30	126.8	50.8	2660	234.3	75.0	0.29
F01A-113-11	496.74	127.3	50.8	2642	247.3	75.9	0.29
F01A-113-13	495.61	126.7	50.8	2662	239.2	74.2	0.29
F01A-113-15	497.42	103.4	50.7	2664	236.9	75.8	0.30
F01A-113-17	497.71	127.1	50.7	2656	237.0	75.0	0.28
F01A-113-19	498.04	127.7	50.8	2661	237.7	75.2	0.30
Mean value				2658	238.7	75.2	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

Surface scaling of the specimens disturbed the axial strain measurement near the peak strength and in the post-peak region (Figure 5-7). The specimen F01A-113-17 failed abruptly when the system became unstable on the post-peak region. The radial extensometer sustained some damage. The damage was considered not to affect the calibration of the extensometer. This assumption was confirmed with an additional aluminum test after the test series.

Figure 5-7. *The specimen F01A-113-9 is scaling under the knife-edge.*

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, 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 uniaxial compression test

Title: **Test information sheet for uniaxial compression test of intact rock** Page 1 (2)

Date: 2004-04-01 *Order:* _____

Author: Pekka Eloranta

Reference: SKB MD 190.001e 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
[ ] *Uniaxial Low Force* [ ] *Uniaxial High Force*

Force transducer (serial number and range)
[ ] *none* [ ] *103295 (100 kN)* [ ] *0123896 (250 kN)* [ ] *0121628 (500 kN)*

Circumferential strain extensometer (serial number)
[ ] *none* [ ] *790* [ ] *792* [ ] _____

Axial strain extensometer (serial number)
[ ] *none* [ ] *1899 A,B,C* [ ] *788* [ ] _____

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

Run: _____

Raw data: _____

Failure: [ ]

Start: [ ] *time*

Stop: [ ] *time* *Peak load (kN):* [ ]

Remarks: _____

8. Photographing the specimen after testing *Date:* _____ *By:* _____

Equipment: _____

Filenames: _____

Remarks: _____

9. Handling, processing and storage of the measured data *Date:* _____ *By:* _____

Remarks: _____

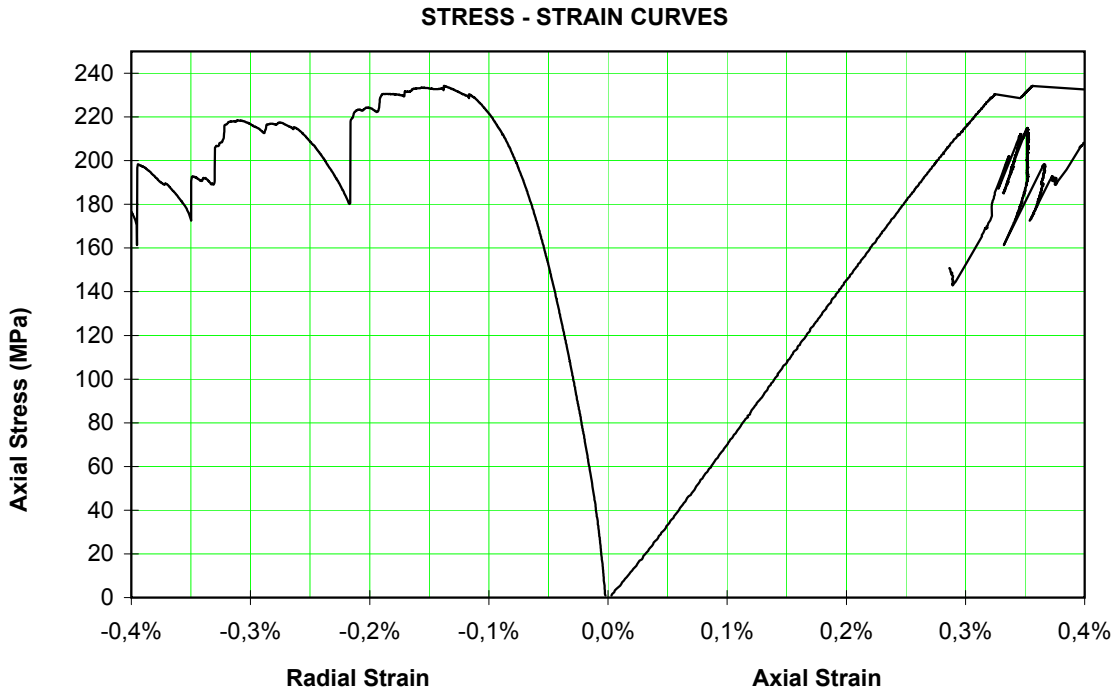
10. Storing the specimen after testing *Date:* _____ *By:* _____

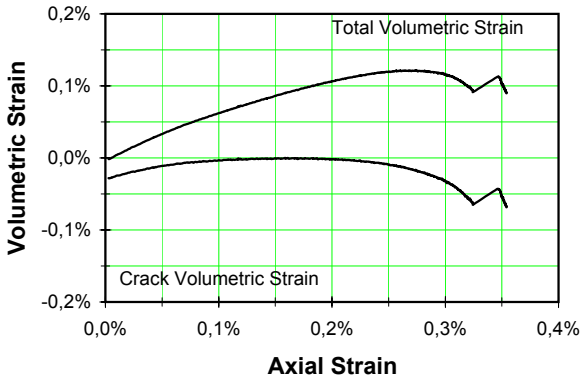
Place: _____

Remarks: _____

Appendix 2

Test results of the specimen F01A-113-9





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Uniaxial		
Equipment:	MTS 815		
Specimen Data	**F01A-113-9**		
Site:	Forsmark	*Length:*	126,8 mm
Hole:	KFM01A	*Diameter:*	50,8 mm
Depth:	496,30 m	*Saturated Density:*	2660 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	234,3 MPa	*Test Date:*	2004-04-15
Young's Modulus:	75,0 GPa	*Test Duration:*	00:50 (h:min)
Poisson's Ratio:	0,29	*Failure Mode:*	Axial splitting
Remarks:	None		

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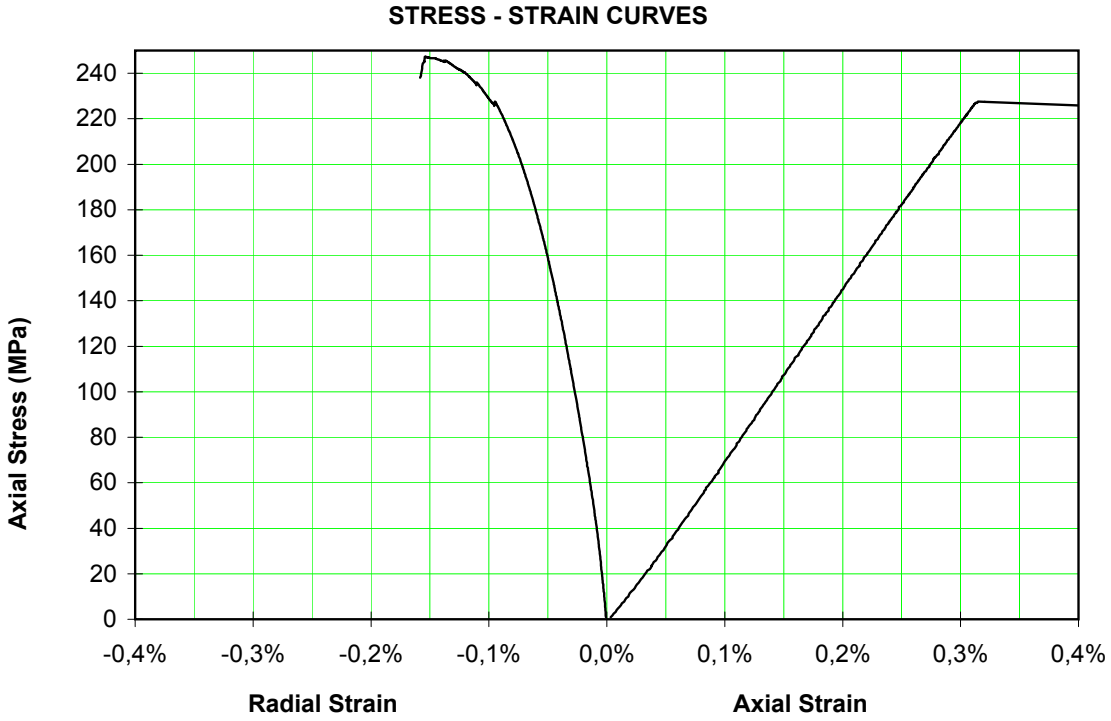
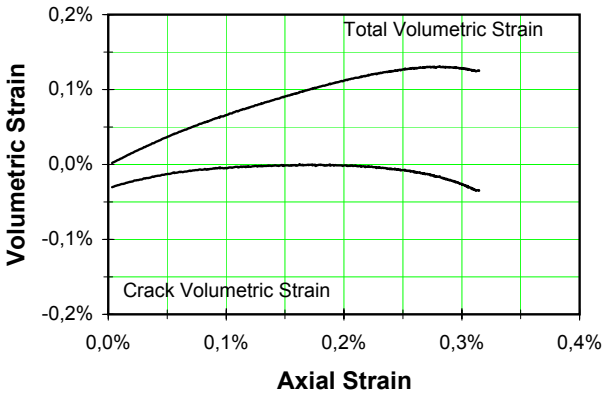
Appendix 3

Test results of the specimen F01A-113-11





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Uniaxial		
Equipment:	MTS 815		
Specimen Data	**F01A-113-11**		
Site:	Forsmark	*Length:*	127,3 mm
Hole:	KFM01A	*Diameter:*	50,8 mm
Depth:	496,74 m	*Saturated Density:*	2642 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	247,3 MPa	*Test Date:*	2004-04-16
Young's Modulus:	75,9 GPa	*Test Duration:*	00:15 (h:min)
Poisson's Ratio:	0,29	*Failure Mode:*	Axial splitting
Remarks:	Surface scaling disturbs axial strain measurement		

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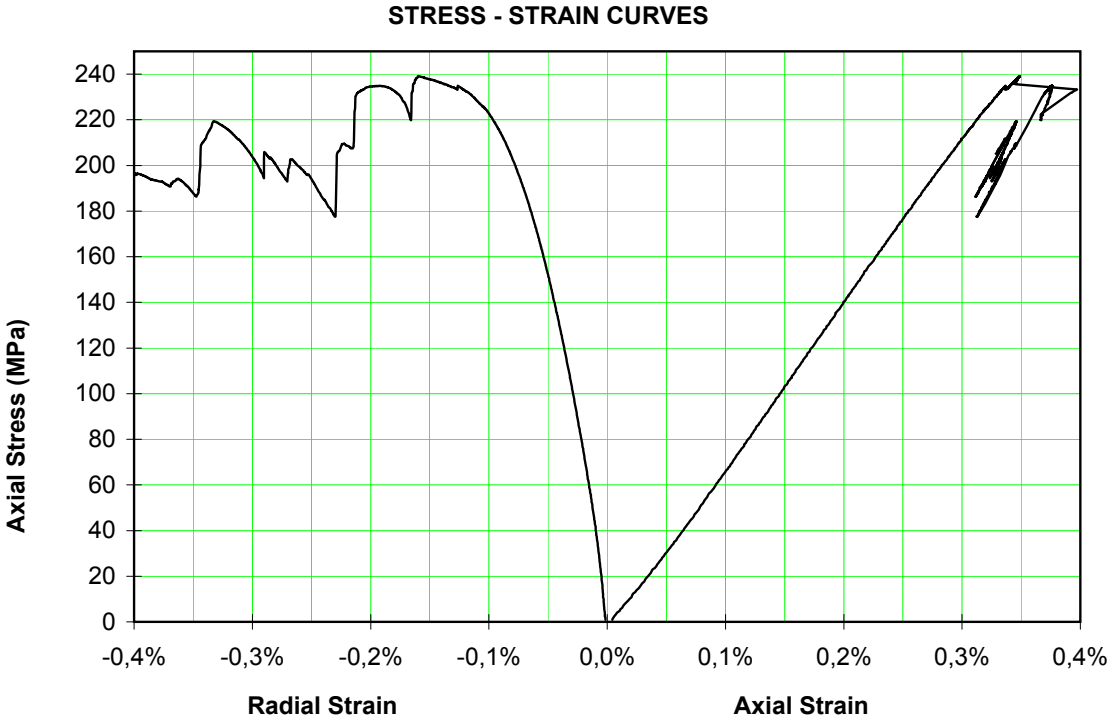
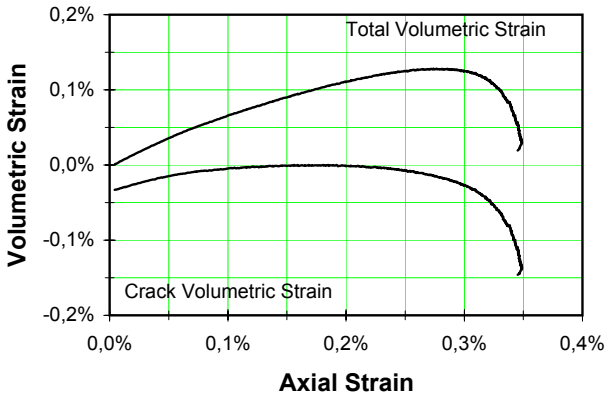
Test results of the specimen F01A-113-13





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Uniaxial		
Equipment:	MTS 815		
Specimen Data	**F01A-113-13**		
Site:	Forsmark	*Length:*	126,7 mm
Hole:	KFM01A	*Diameter:*	50,8 mm
Depth:	495,61 m	*Saturated Density:*	2662 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	239,2 MPa	*Test Date:*	2004-04-16
Young's Modulus:	74,2 GPa	*Test Duration:*	00:35 (h:min)
Poisson's Ratio:	0,29	*Failure Mode:*	Axial splitting
Remarks:	None		

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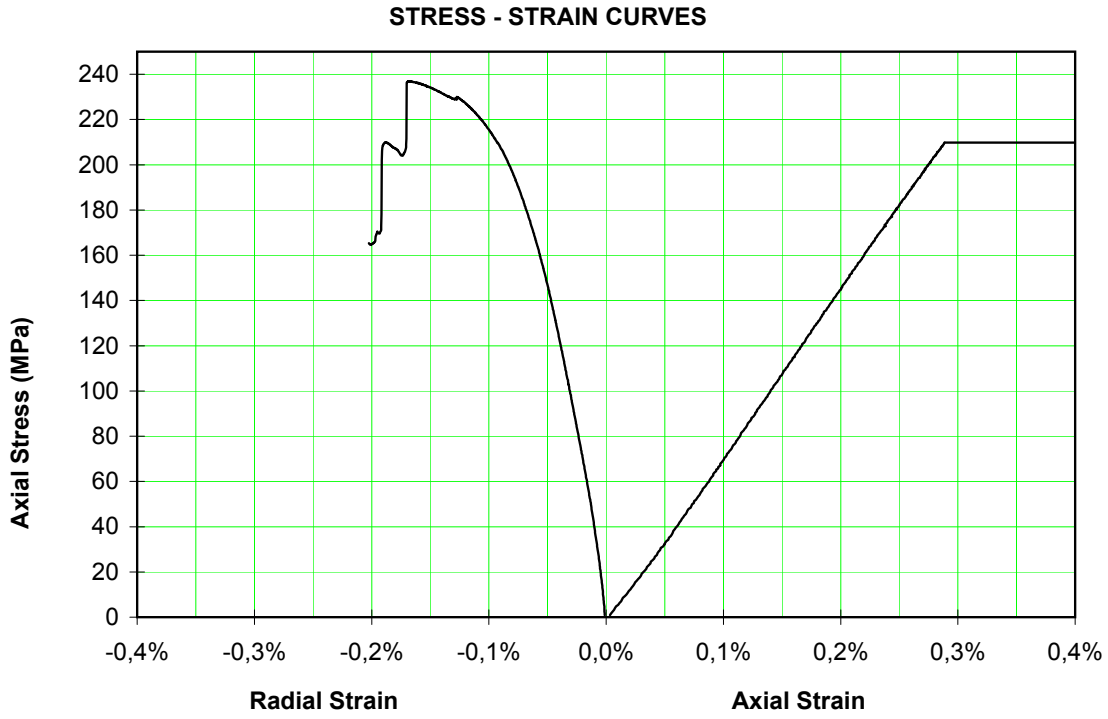
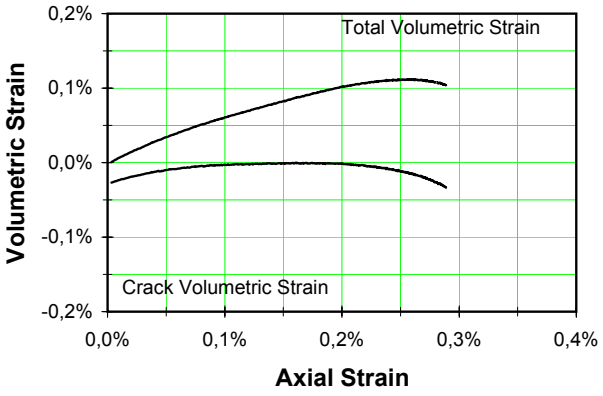
Appendix 5

Test results of the specimen F01A-113-15





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Uniaxial		
Equipment:	MTS 815		
Specimen Data	**F01A-113-15**		
Site:	Forsmark	*Length:*	103,4 mm
Hole:	KFM01A	*Diameter:*	50,7 mm
Depth:	497,42 m	*Saturated Density:*	2664 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	236,9 MPa	*Test Date:*	2004-04-16
Young's Modulus:	75,8 GPa	*Test Duration:*	00:17 (h:min)
Poisson's Ratio:	0,30	*Failure Mode:*	Axial splitting
Remarks:	large chip disturbs axial strain measurement at 210 MPa		

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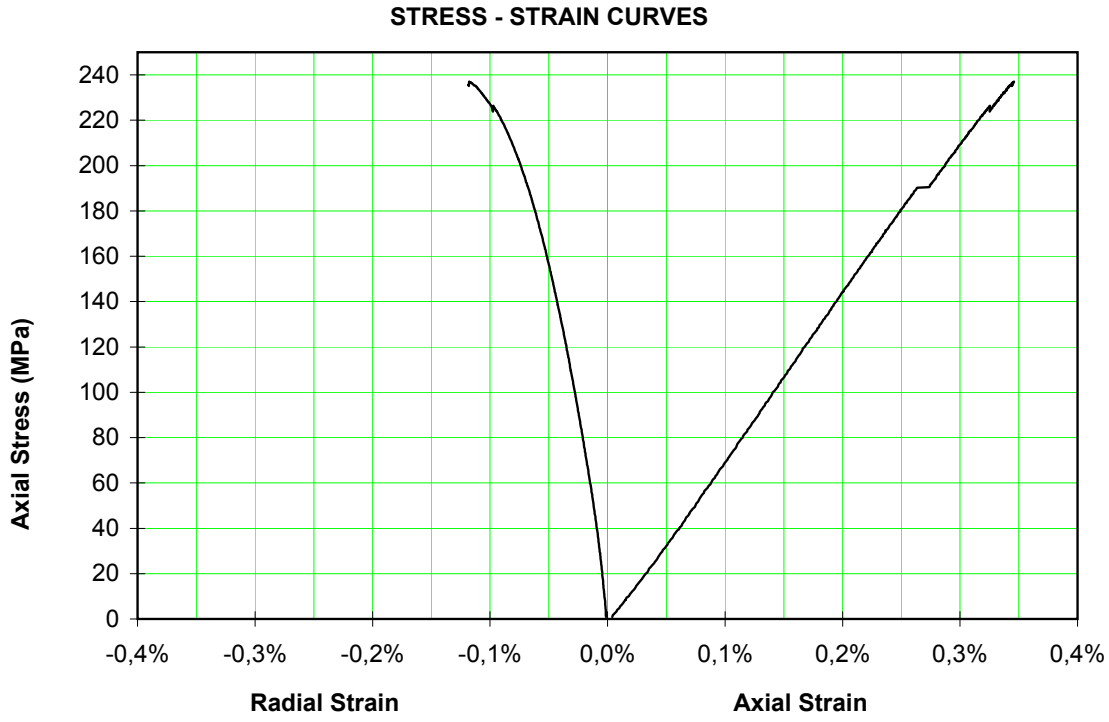
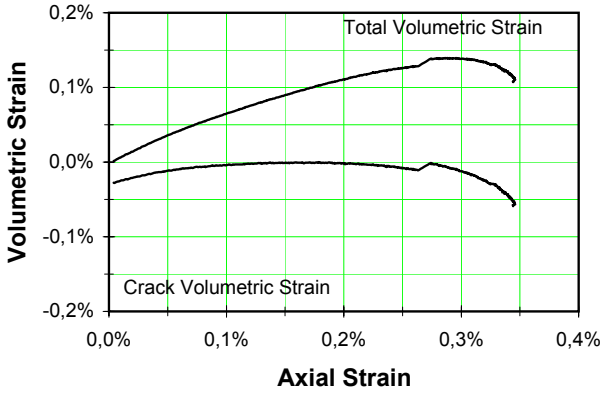
Appendix 6

Test results of the specimen F01A-113-17





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Uniaxial		
Equipment:	MTS 815		
Specimen Data	**F01A-113-17**		
Site:	Forsmark	*Length:*	127,1 mm
Hole:	KFM01A	*Diameter:*	50,7 mm
Depth:	497,71 m	*Saturated Density:*	2656 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	237,0 MPa	*Test Date:*	2004-04-16
Young's Modulus:	75,0 GPa	*Test Duration:*	00:12 (h:min)
Poisson's Ratio:	0,28	*Failure Mode:*	Axial splitting
Remarks:	Failed abruptly at peak strength		

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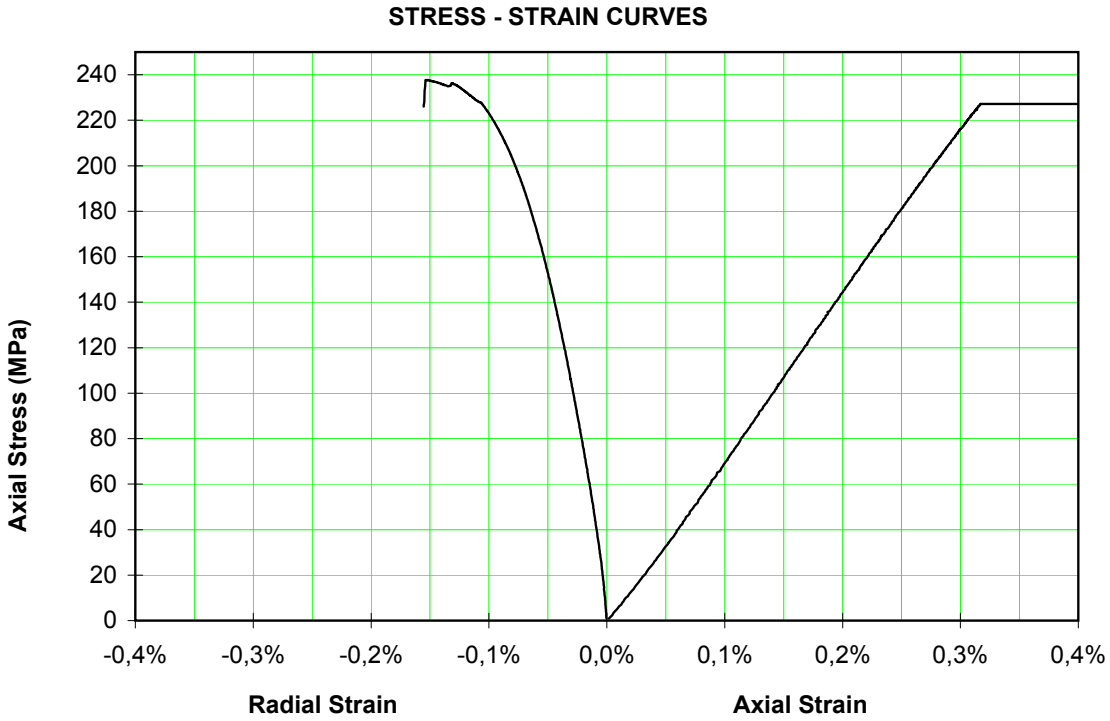
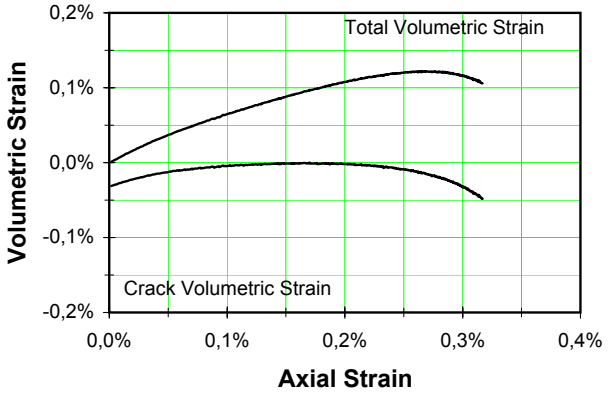
Test results of the specimen F01A-113-19





Test Data			
Client:	SKB	*Load Control:*	Radial strain rate
Order Number:	10340	*Equivalent Loading Rate:*	0.75 MPa/s
Test:	Uniaxial		
Equipment:	MTS 815		
Specimen Data	**F01A-113-19**		
Site:	Forsmark	*Length:*	127,7 mm
Hole:	KFM01A	*Diameter:*	50,8 mm
Depth:	498,04 m	*Saturated Density:*	2661 kg/m^3
Rock Type:	Metagranodiorite - granite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	237,7 MPa	*Test Date:*	2004-04-16
Young's Modulus:	75,2 GPa	*Test Duration:*	00:14 (h:min)
Poisson's Ratio:	0,30	*Failure Mode:*	Axial splitting
Remarks:	Surface scaling disturbs axial strain measurement		

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