P-04-182

Oskarshamn site investigation

Drill hole KSH01A

Uniaxial compression test (HUT)

Pekka Eloranta
Helsinki University of Technology, Rock Engineering

August 2004

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Key words: Rock mechanics, Uniaxial compression test, Poisson's ratio, E-modulus, Strain, Strength, Deformation, Post-peak behaviour.

Abstract

The complete stress-strain behaviour of some rock from SKB's investigation site at Simpevarp was studied with a total of five uniaxial compression tests. The 51 mm diameter samples were taken from the borehole KSH01A at depth level between 300-320 m. Moreover, the rock type was Quartz monzodiorite. 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 2778-2805 kg/m^3, which yields a mean value of 2791 kg/m^3 and the obtained values for the uniaxial compressive strength were in the range 147.5-186.4 MPa with a mean value of 170.3 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 Simpevarp, see map in Figure 1-1. The work was carried out in accordance with activity plan AP PS 400-03-067 (SKB internal controlling document).

Uniaxial compression testing is used to describe the complete stress-strain curve for cylindrical intact rock core samples. Furthermore, it obtains 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 one week and their water-saturated density was determined. The specimens were tested on April 13-15, 2004. The specimens were photographed before and after tests.

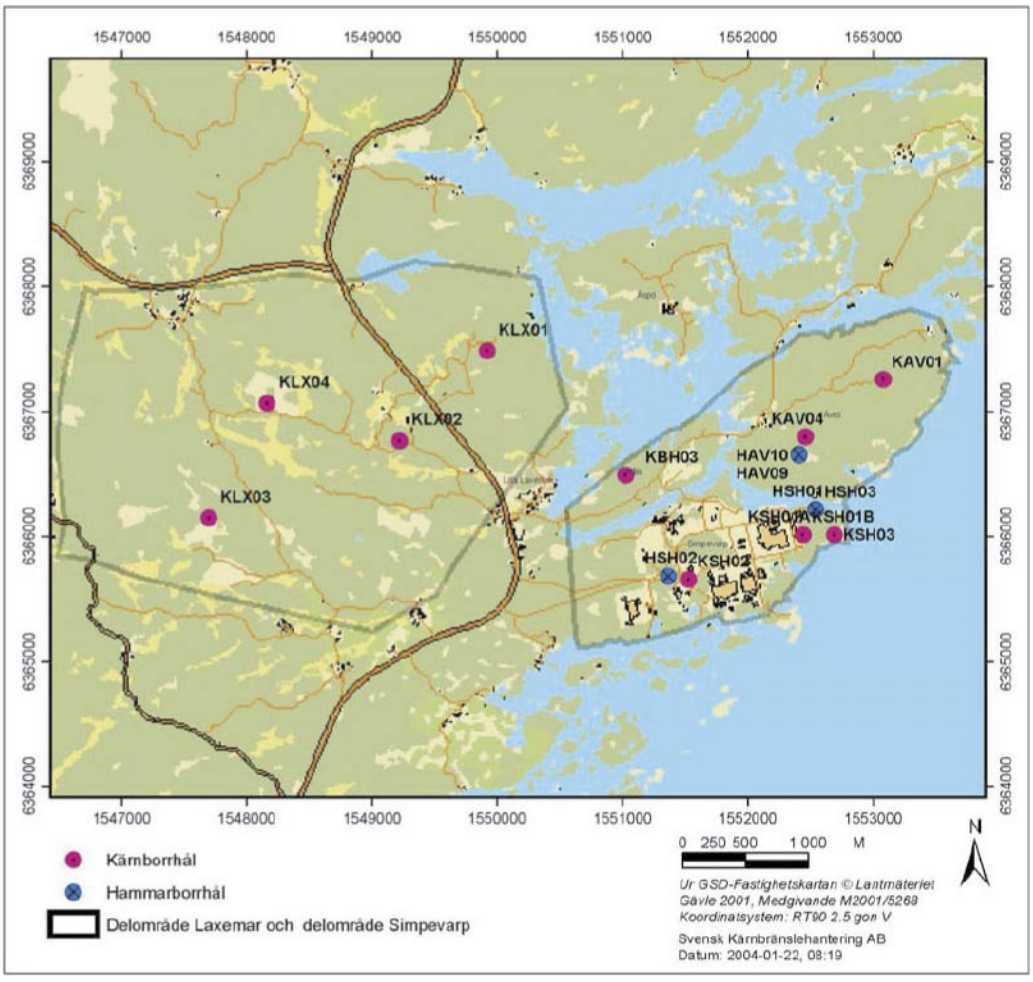


Figure 1-1. *Location of the borehole KSH01A at the Simpevarp site.*

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 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 Oskarshamn.

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 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.

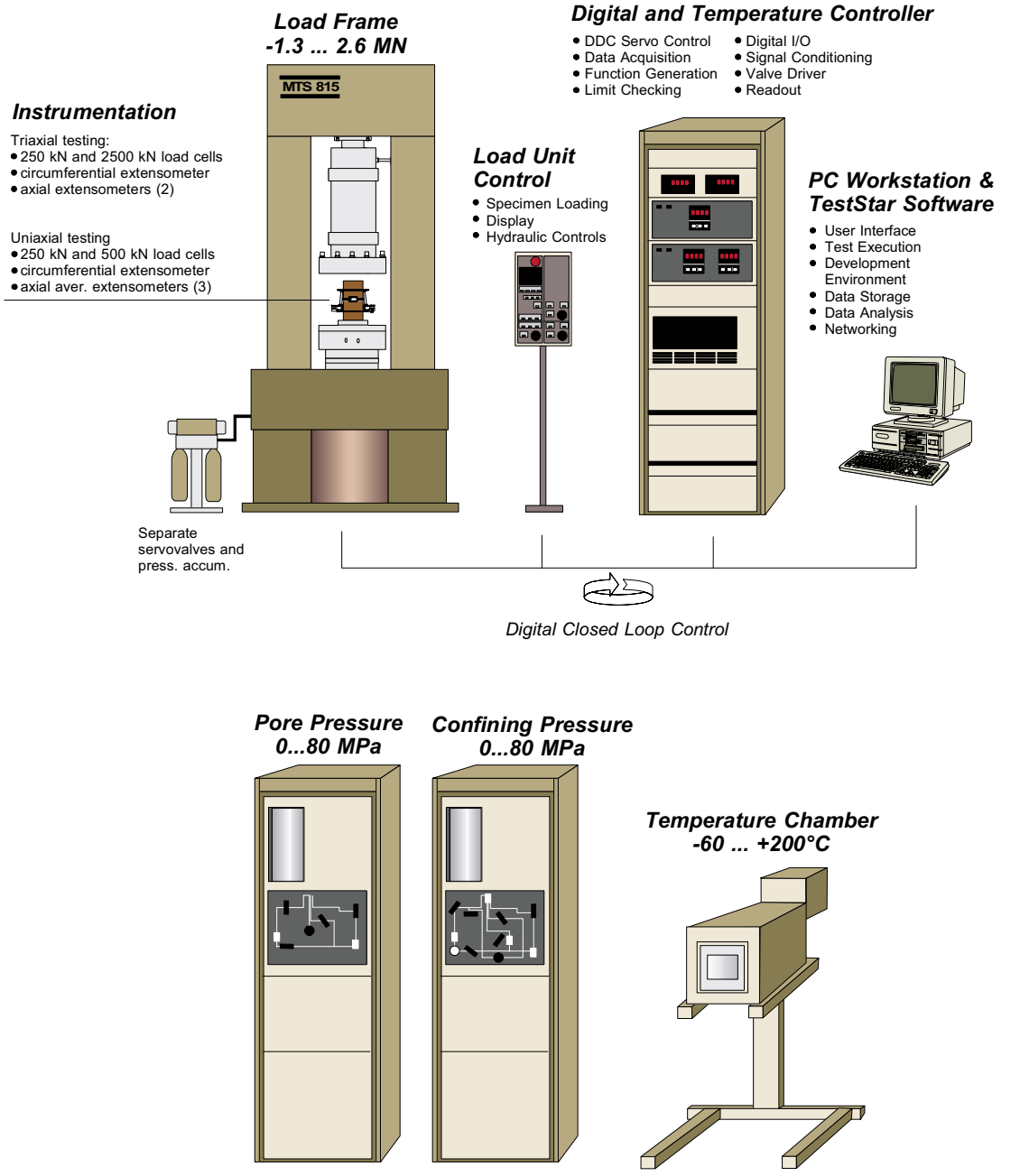


Figure 3-1. *MTS 815 Rock Mechanics Testing System.*

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 trough one spherical seat in order 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-build wire basket suspended from the balance by a fine wire.

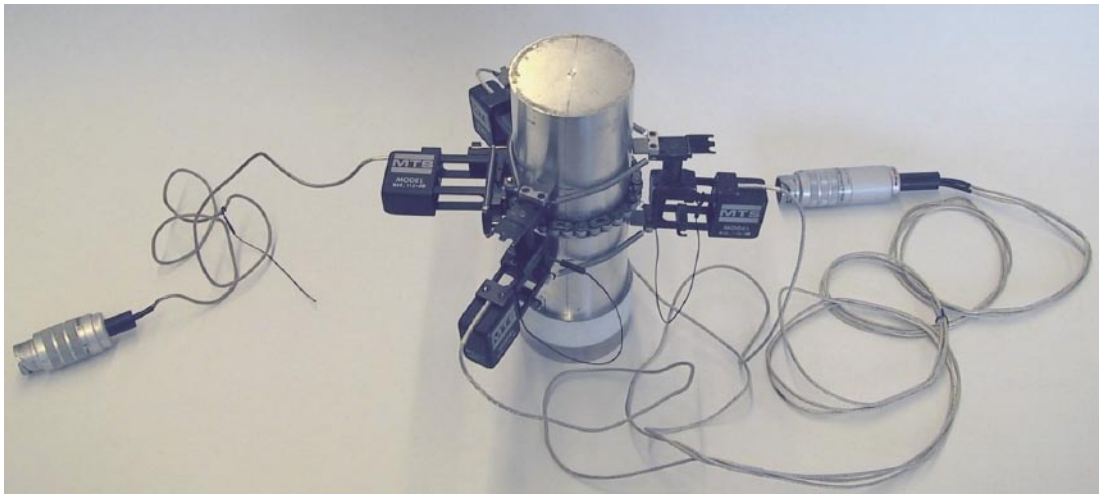


Figure 3-2. *Uniaxial compression test extensometers on the reference aluminum specimen (Photo by Pekka Eloranta).*

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 KSH01A on the Simpevarp investigation site. The test specimens were labeled at the Swedish National Testing and Research Institute (SP) (Table 4-1).

Table 4-1. Uniaxial compression test samples from the hole KSH01A, Simpevarp.

Seclow (m)	Specimen ID	Rock type
300.55	S01A-113-2	Quartz monzodiorite
302.65	S01A-113-4	Quartz monzodiorite
310.03	S01A-113-6	Quartz monzodiorite
318.52	S01A-113-8	Quartz monzodiorite
319.74	S01A-113-10	Quartz monzodiorite

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 the specimen was determined by taking 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, 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 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 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 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 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 April 2003. Their condition is 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, FN 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 (2004-04-02) *(b) After testing (2004-04-14)*

Figure 5-1. *Photographs of the specimen S01A-113-2.*

(a) Before testing (2004-04-02) *(b) After testing (2004-04-14)*

Figure 5-2. *Photographs of the specimen S01A-113-4.*

(a) Before testing (2004-04-02) *(b) After testing (2004-04-14)*

Figure 5-3. *Photographs of the specimen S01A-113-6.*

(a) Before testing (2004-04-02) *(b) After testing (2004-04-15)*

Figure 5-4. *Photographs of the specimen S01A-113-8.*

(a) Before testing (2004-04-02) *(b) After testing (2004-04-15)*

Figure 5-5. *Photographs of the specimen S01A-113-10.*

5.2 Results for the entire test series

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/m^3)	Compressive strength (MPa)	Young's modulus (GPa)	Poisson's ratio
S01A-113-2	300.55	127.7	50.2	2782	169.5	69.0	0.34
S01A-113-4	302.65	127.3	50.2	2787	147.5	55.8	0.33
S01A-113-6	310.03	127.2	50.2	2778	179.1	69.6	0.33
S01A-113-8	310.03	127.2	50.1	2804	169.1	80.5	0.30
S01A-113-10	318.52	127.3	50.1	2805	186.4	73.4	0.32
Mean value				2791	170.3	69.7	0.32

5.3 Discussion

There were no problems with the equipment.

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:* _____

(According to the SKB Boremap mapping) *By:* _____

Remarks: _____

3. Preparation of the specimen

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

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

4. Physical properties of the specimen *Date:* _____

(According to the ASTM D 4543) *By:* _____

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: _____

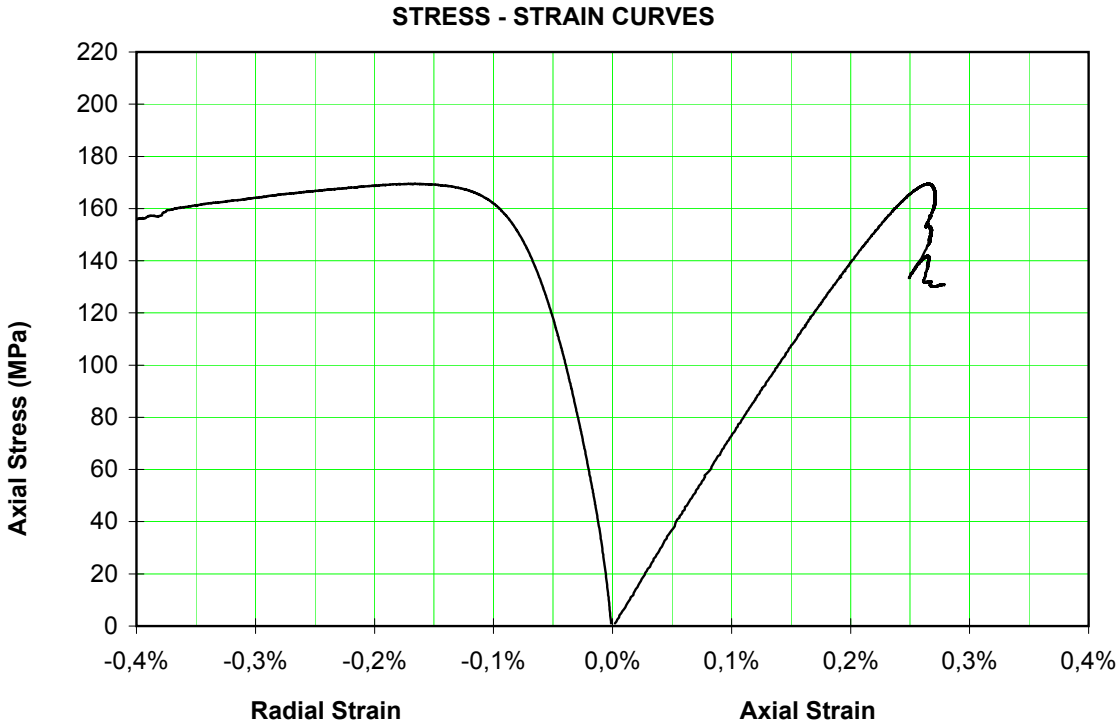
10. Storing the specimen after testing *Date:* _____ *By:* _____

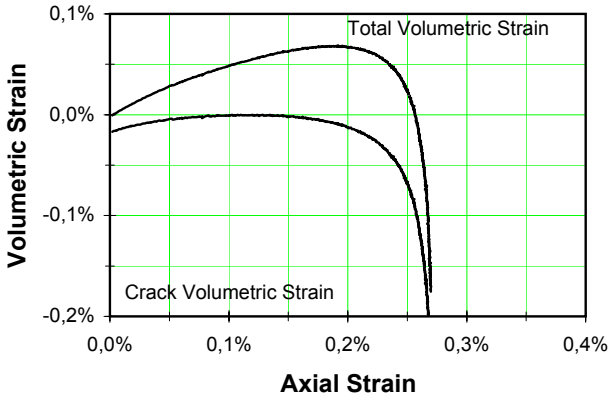
Place: _____

Remarks: _____

Appendix 2

Test results of the specimen S01A-113-2





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	**S01A-113-2**		
Site:	Simpevarp	*Length:*	127,7 mm
Hole:	KSH01A	*Diameter:*	50,2 mm
Depth:	300,55 m	*Saturated Density:*	2782 kg/m^3
Rock Type:	Quartz monzodiorite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	169,5 MPa	*Test Date:*	2004-04-13
Young's Modulus:	69,0 GPa	*Test Duration:*	02:53 (h:min)
Poisson's Ratio:	0,34	*Failure Mode:*	Axial splitting
Remarks:	None		

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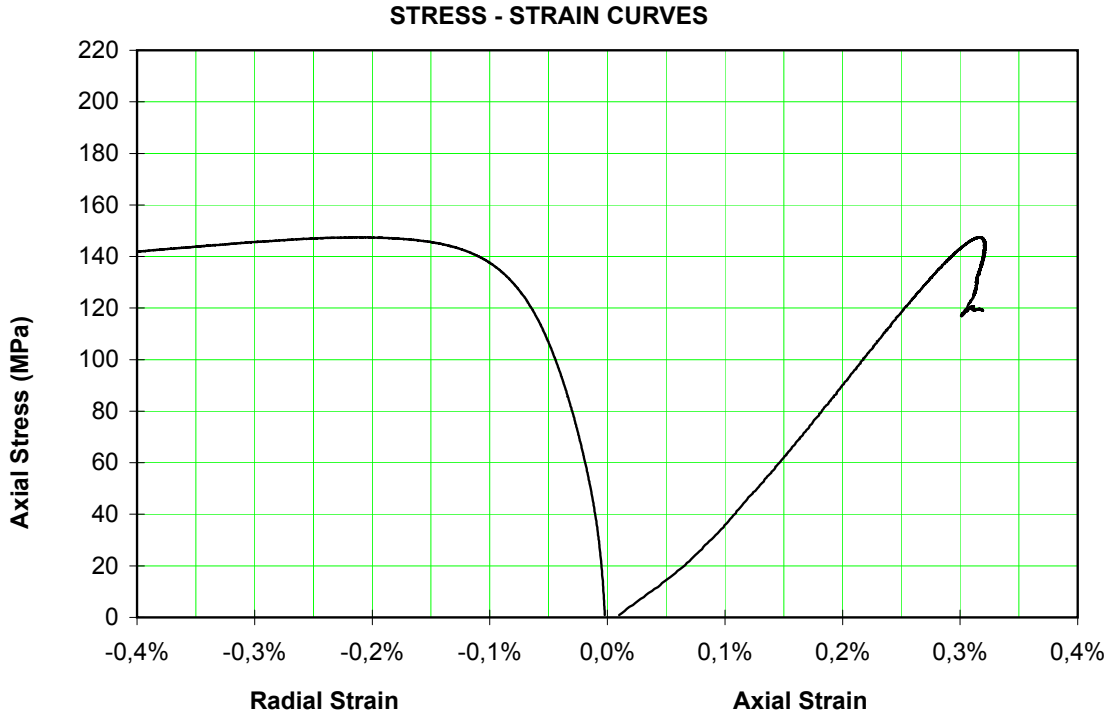
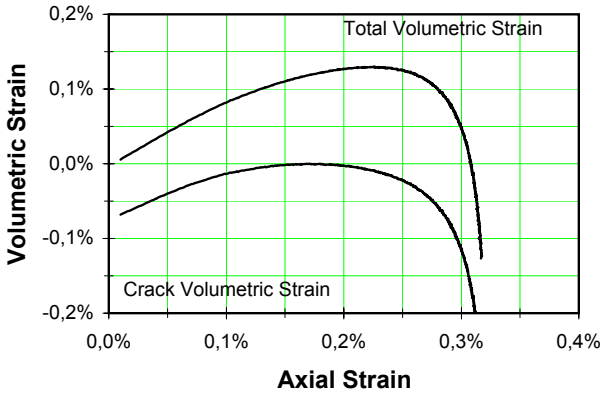
e-mail: rocklab@hut.fi

Test results of the specimen S01A-113-5





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	**S01A-113-4**		
Site:	Simpevarp	*Length:*	127,3 mm
Hole:	KSH01A	*Diameter:*	50,2 mm
Depth:	003.03 m	*Saturated Density:*	2787 kg/m^3
Rock Type:	Quartz monzodiorite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	147,5 MPa	*Test Date:*	2004-04-13
Young's Modulus:	55,8 GPa	*Test Duration:*	03:00 (h:min)
Poisson's Ratio:	0,33	*Failure Mode:*	Axial splitting
Remarks:	None		

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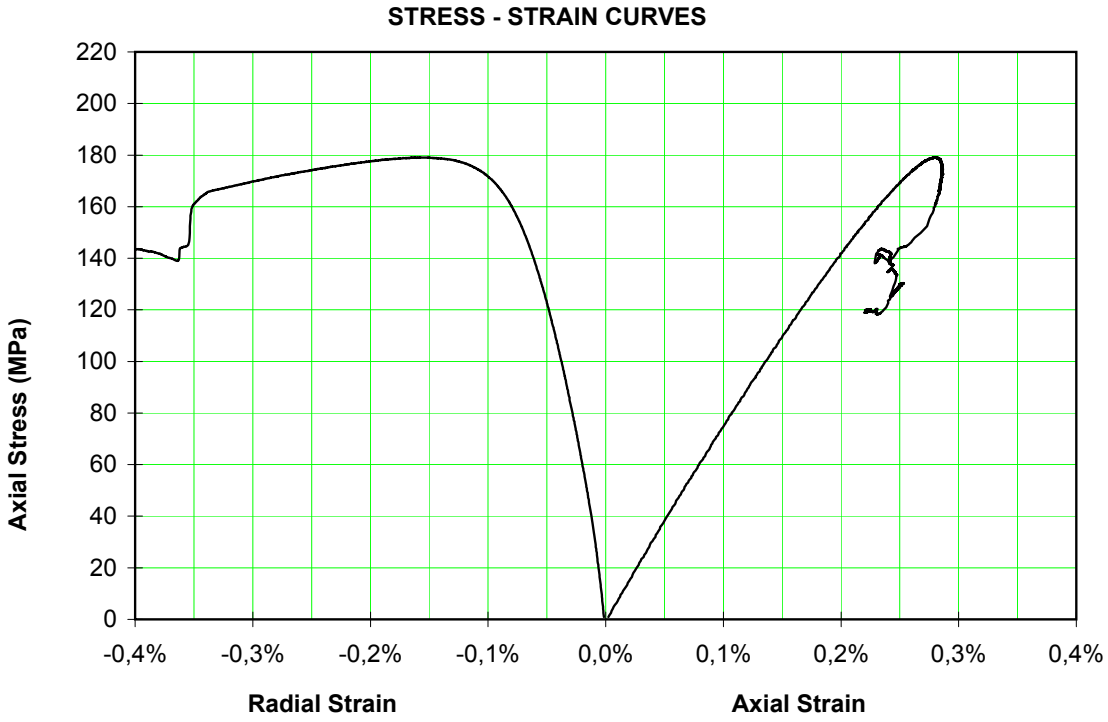
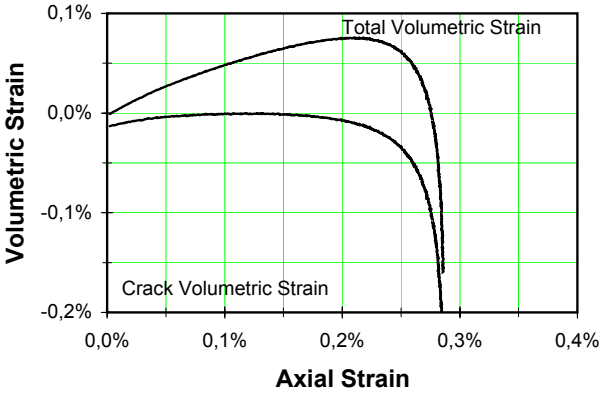
Test results of the specimen S01A-113-6





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	**S01A-113-6**		
Site:	Simpevarp	*Length:*	127,2 mm
Hole:	KSH01A	*Diameter:*	50,2 mm
Depth:	310,03 m	*Saturated Density:*	2778 kg/m^3
Rock Type:	Quartz monzodiorite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	179,1 MPa	*Test Date:*	2004-04-14
Young's Modulus:	69,6 GPa	*Test Duration:*	02:20 (h:min)
Poisson's Ratio:	0,33	*Failure Mode:*	Axial splitting
Remarks:	None		

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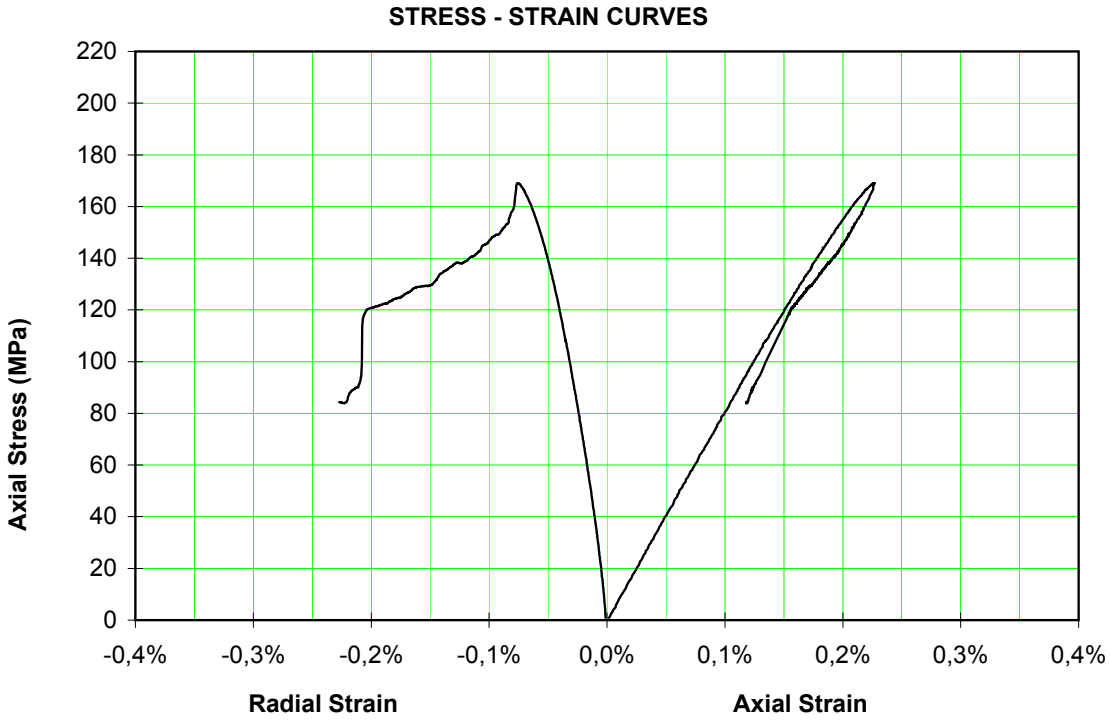
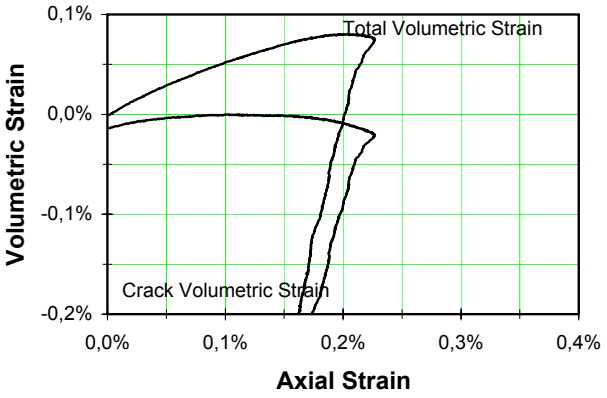
Test results of the specimen S01A-113-8





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	**S01A-113-8**		
Site:	Simpevarp	*Length:*	127,2 mm
Hole:	KSH01A	*Diameter:*	50,1 mm
Depth:	318,52 m	*Saturated Density:*	2804 kg/m^3
Rock Type:	Quartz monzodiorite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	169,1 MPa	*Test Date:*	2004-04-15
Young's Modulus:	80,5 GPa	*Test Duration:*	00:19 (h:min)
Poisson's Ratio:	0,30	*Failure Mode:*	Shear failure
Remarks:	Failure trough probable weakness plane		

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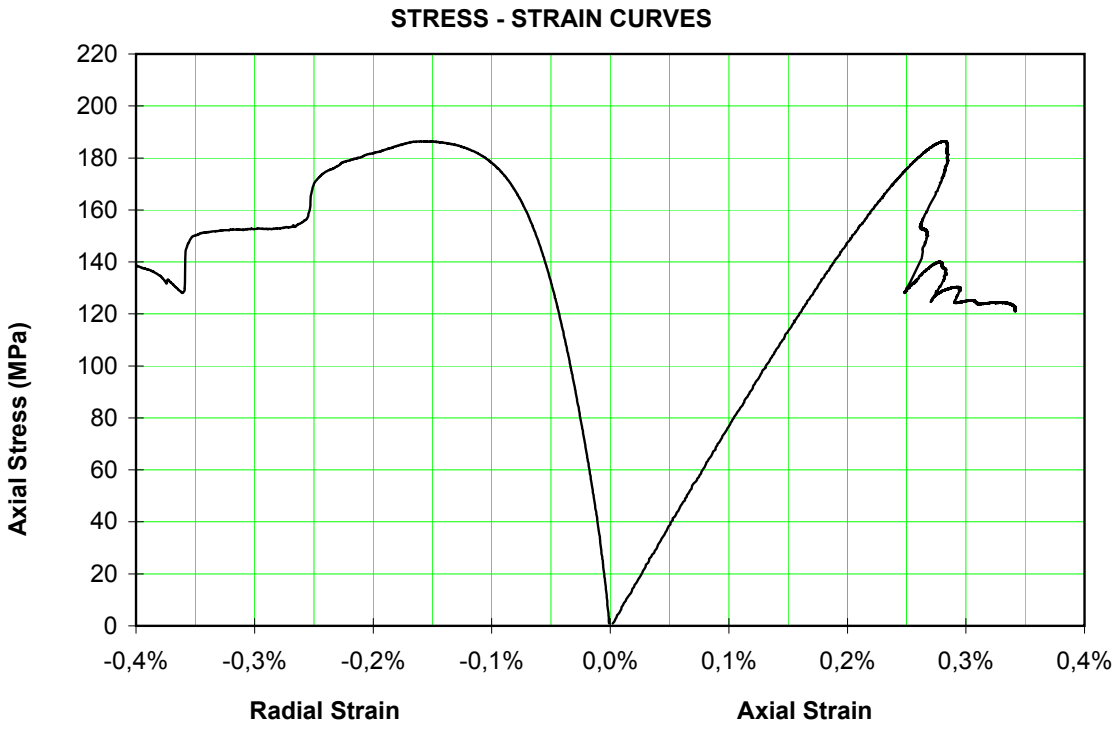
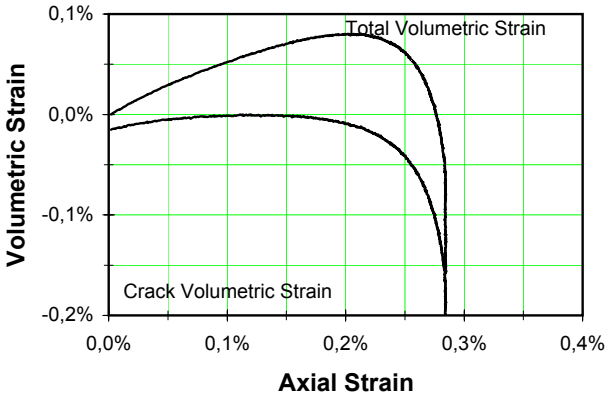
Test results of the specimen S01A-113-10





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	**S01A-113-10**		
Site:	Simpevarp	*Length:*	127,3 mm
Hole:	KSH01A	*Diameter:*	50,1 mm
Depth:	319,74 m	*Saturated Density:*	2805 kg/m^3
Rock Type:	Quartz monzodiorite	*Degree of Saturation:*	Fully saturated
Test Results			
Compressive Strength:	186,4 MPa	*Test Date:*	2004-04-15
Young's Modulus:	73,4 GPa	*Test Duration:*	01:18 (h:min)
Poisson's Ratio:	0,32	*Failure Mode:*	Axial splitting
Remarks:	None		

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