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Oskarshamn site investigation

Drill hole KSH01A: Indirect tensile strength test (HUT)

Pekka Eloranta
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June 2004

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Keywords: Rock mechanics, Compression testing, Indirect tensile strength.

Abstract

The tensile strength of some rock from SKB's investigation site at Simpevarp was studied with a total of 10 standardised indirect tensile tests. The 51 mm diameter samples were taken from the borehole KSH01A. The samples were taken at depth level between 303-322 m. Moreover, the rock type was Quartz monozodiorite. 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 1, 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 2770-2810 kg/m^3, which yields a mean value of 2790 kg/m^3 and the obtained values for the indirect tensile strength were in the range 13.5 – 16.4 MPa with a mean value of 15.4 MPa.

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1 Introduction

This document reports the data collected by indirect tensile test, 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).

The tensile strength of a cylindrical intact rock core was determined indirectly by loading the rock core diametrically with a linear load until failure. Knowing the geometry of the core and the peak load, the tensile strength can be calculated.

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 March 17, 2004. Before testing the specimens were water-saturated one week and their water-saturated density was determined. The specimens were tested on April 1, 2004. The specimens were photographed before and after tests.

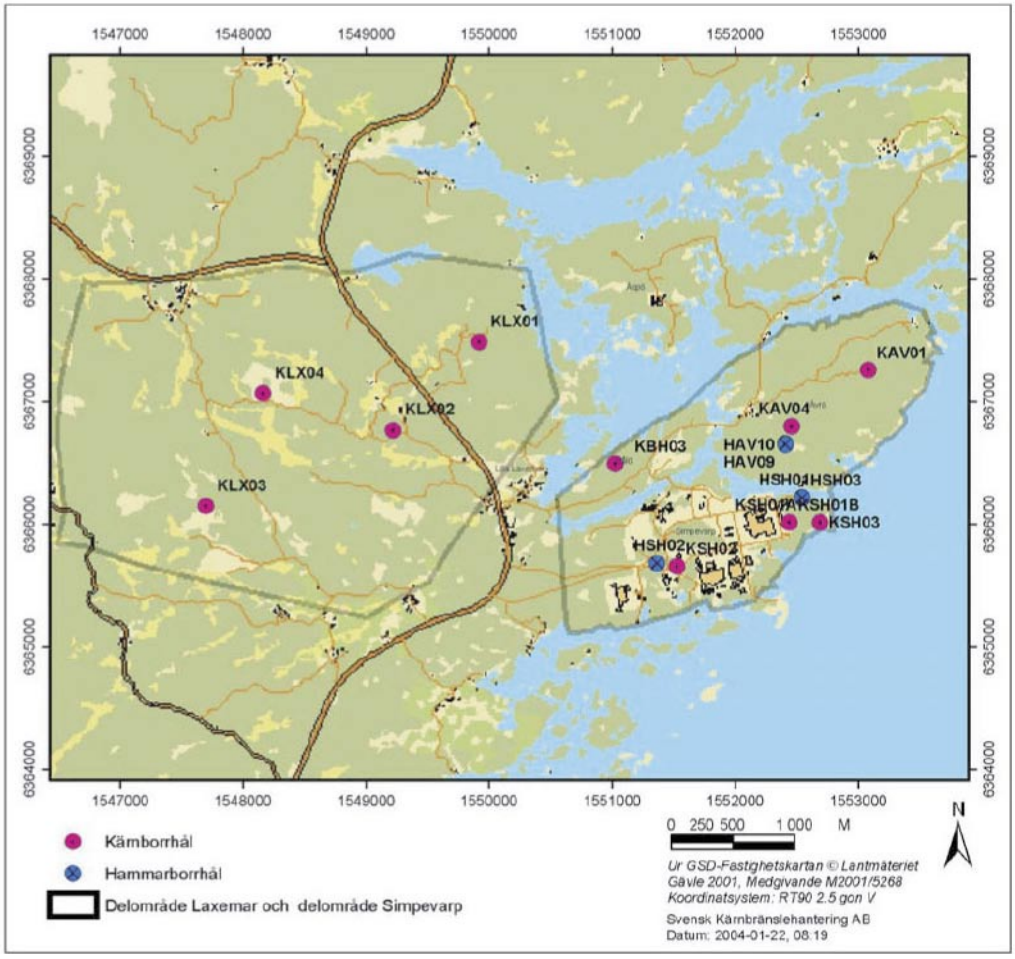


Figure 1-1. *Location of the borehole KSH01A at the Simpevarp site.*

2 Objective and scope

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

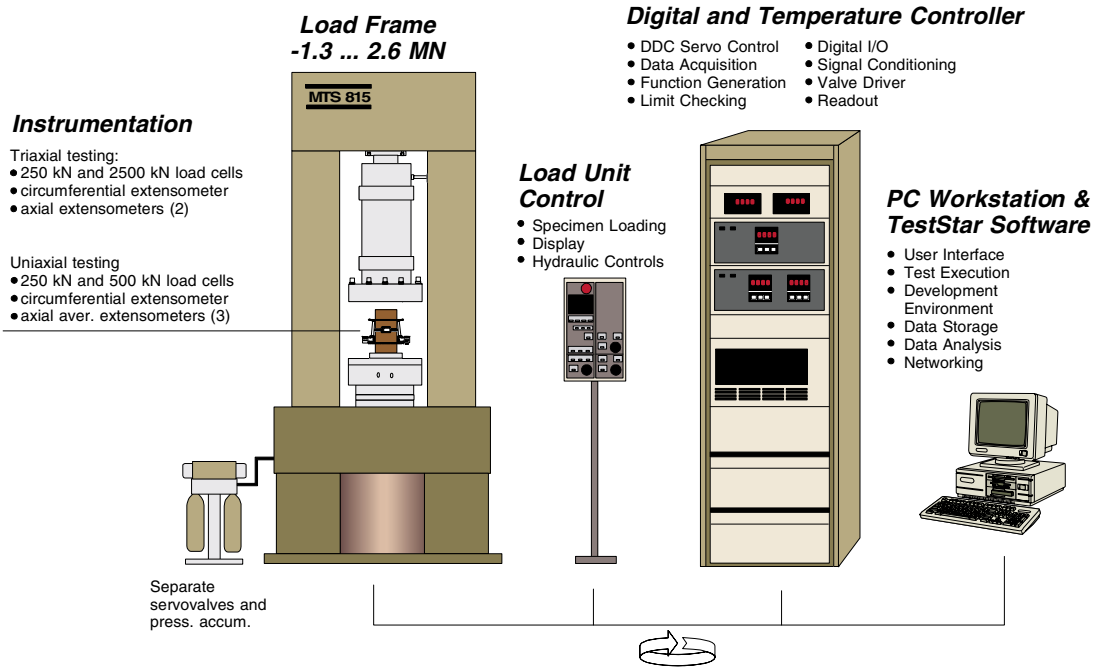
The results from the tests are going to be used in the site descriptive rock mechanics model, which will be established for the candidate area selected for site investigations at Oskarshamn.

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 100 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. The indirect tests of tensile strength were done under actuator displacement control, which is practically the most suitable control mode for them.

The specimen was loaded between two concave steel plates.

The water-saturation equipment included two 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.



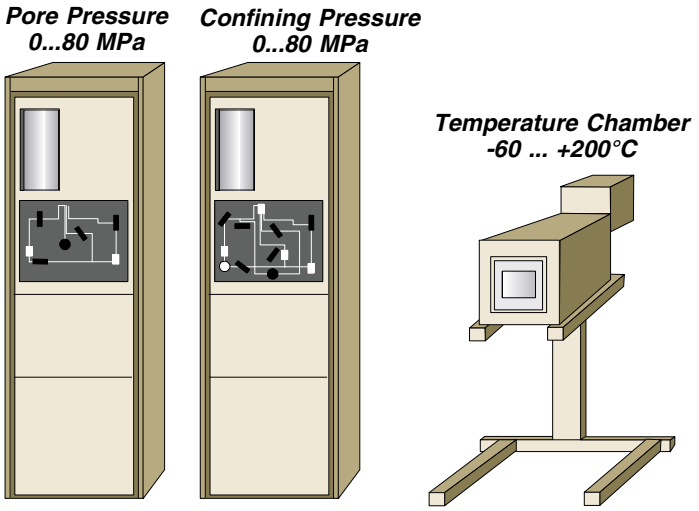


Figure 3-1. *MTS 815 Rock Mechanics Testing System.*

4 Execution

The tests were executed according to the method description SKB MD 190.004 version 1.9. The test methodology follows the American Society for Testing and Materials /ASTM D 3967-95a/.

The test specimens were water-saturated according to the method description SKB MD 160.002 version 1.9. 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). The load alignment lines were also marked on the specimens at the SP.

Table 4-1. Indirect tensile strength samples from the hole KSH01A, Simpevarp.

Seclow (m)	Specimen ID	Rock type
303.46	S01A-110-2	Quartz monozodiorite
305.26	S01A-110-4	Quartz monozodiorite
306.38	S01A-110-6	Quartz monozodiorite
310.52	S01A-110-8	Quartz monozodiorite
310.62	S01A-110-10	Quartz monozodiorite
313.27	S01A-110-12	Quartz monozodiorite
318.72	S01A-110-14	Quartz monozodiorite
319.20	S01A-110-16	Quartz monozodiorite
320.04	S01A-110-18	Quartz monozodiorite
321.73	S01A-110-20	Quartz monozodiorite

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 March 17, 2004. The length of the specimen was determined by taking average of three measurements. The diameter of the specimen was determined by taking average of six measurements. The length-to-diameter ratio was calculated, the smoothness of the circumferential surface and the parallelism of the end surfaces were verified to fulfil the criteria presented in the ASTM D 3967. In addition the laboratory-air-dry mass of the specimen was recorded.

The specimens were photographed prior water-saturation on March 19, 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 two sample containers five specimens each. Water-saturation began on March 23, 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 on April 1, 2004 in two batches (the first batch in the morning and the second batch in the afternoon).

The specimens were tested on April 1, 2004 in two batches of five specimens (the first batch in the morning and the second batch in the afternoon).

Concave steel plates were used to apply load on the specimen (Figure 4-1). Bearing strips made out of 0.5 mm thick cardboard were used between the plates and the specimen to reduce high stress concentrations. Special care was taken to align the specimen in the middle of the loading apparatus and according to the loading line marked on the specimen at the SP.

The tests were conducted with constant compressive actuator movement (0.2 mm/min) in order to meet the criteria of the standard ASTM 3967 for the failure to occur within 1 to 10 minutes of loading (Table 4-2). The actuator displacement and force data was acquired four times in a second (every 0.25 seconds). Test was stopped manually after the primary fracture occurred. The failure load was the highest value recorded.

The specimens were photographed after testing on April 5, 2004.

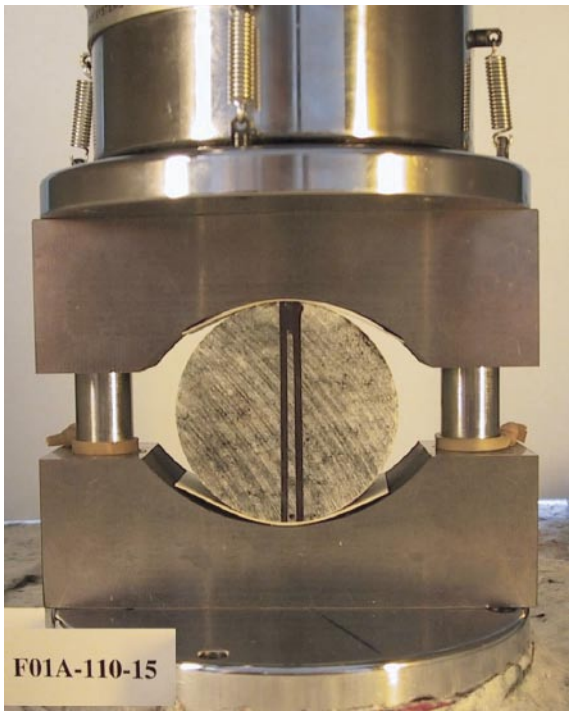


Figure 4-1. *Indirect tensile test configuration (Photo by Pekka Eloranta).*

Table 4-2. Indirect tensile test procedure.

1	Drive specimen manually to contact
	- No axial force is allowed
2	Reset readings
	- Reset readings of actuator displacement and axial force
3	Start programmed test control
4	Axial loading to failure
	- Increase axial load by moving actuator up 0.2 mm/min
5	Stop the test manually
	- Stop the test after the primary failure
	- Remove remaining force by lowering the actuator

5 Results

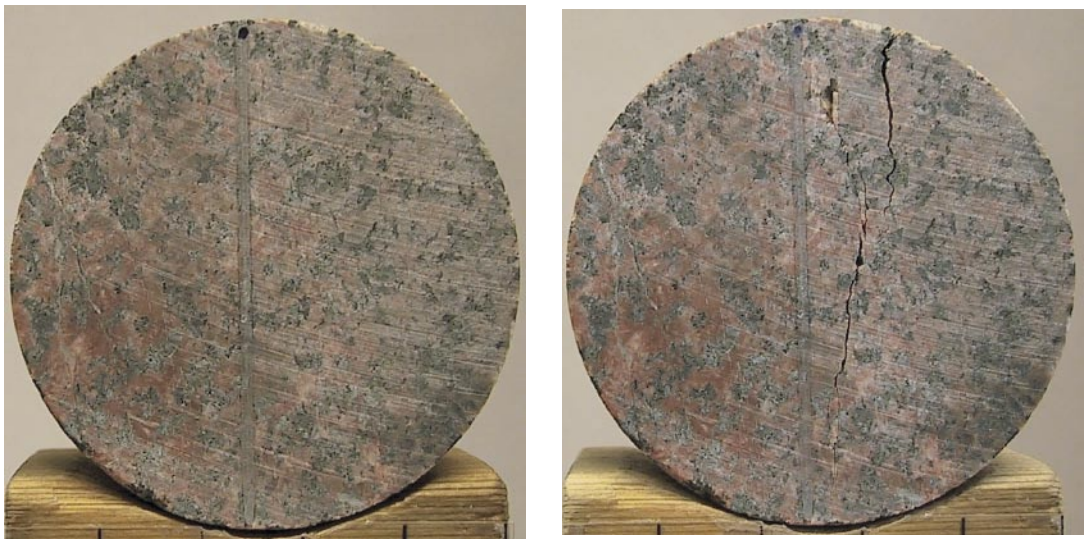
The results of the individual specimens are presented in Section 5.1 and a summary of the results is given in Section 5.2. The original results and data obtained from the testing, were reported to the SICADA database, FN 96.

5.1 Description and presentation of the specimen

The description and test results of each specimen are presented in the following pages (Tables 5-1 – 5-10 and Figures 5-1 – 5-10).

Table 5-1. The test results of the specimen S01A-110-2.

Order:	10340
Investigation site:	Simpevarp
Specimen ID:	**S01A-110-2**
Drill hole:	KSH01A
Depth:	303.46 m
Date of sampling:	2003-05-13
Length:	26.2 mm
Diameter:	50.2 mm
Water-saturated density:	2780 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	no anisotropy
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	32.2 kN
Indirect tensile strength:	15.6 MPa
Comments:	none
Date of testing:	2004-04-01



(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-1. *Photographs of the specimen S01A-110-2.*

Table 5-2. The test results of the specimen S01A-110-4.

Order:	10340
Investigation site:	Simpevarp
Specimen ID:	**S01A-110-4**
Drill hole:	KSH01A
Depth:	305.26 m
Date of sampling:	2003-05-13
Length:	26.3 mm
Diameter:	50.2 mm
Water-saturated density:	2786 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	no anisotropy
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	32.4 kN
Indirect tensile strength:	15.6 MPa
Comments:	none
Date of testing:	2004-04-01

(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-2. *Photographs of the specimen S01A-110-2.*

Table 5-3. The test results of the specimen S01A-110-6.

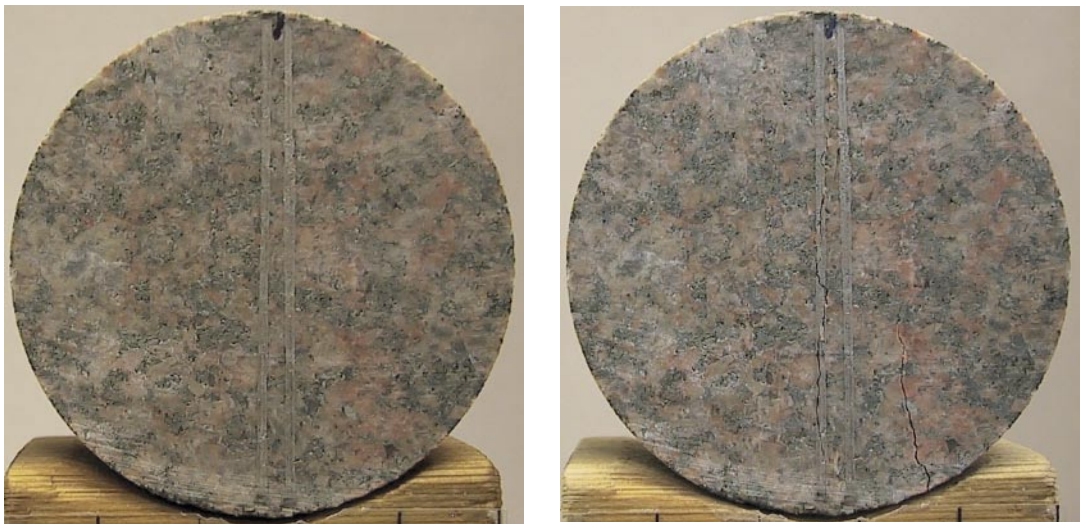
Order:	10340
Investigation site:	Simpevarp
Specimen ID:	**S01A-110-6**
Drill hole:	KSH01A
Depth:	306.38 m
Date of sampling:	2003-05-13
Length:	26.3 mm
Diameter:	50.2 mm
Water-saturated density:	2792 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	no anisotropy
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	33.6 kN
Indirect tensile strength:	16.2 MPa
Comments:	none
Date of testing:	2004-04-01

(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-3. *Photographs of the specimen S01A-110-6.*

Table 5-4. The test results of the specimen S01A-110-8.

Order:	10340
Investigation site:	Simpevarp
Specimen ID:	**S01A-110-8**
Drill hole:	KSH01A
Depth:	310.52 m
Date of sampling:	2003-05-13
Length:	26.2 mm
Diameter:	50.2 mm
Water-saturated density:	2771 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	no anisotropy
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	33.6 kN
Indirect tensile strength:	16.3 MPa
Comments:	none
Date of testing:	2004-04-01



(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-4. *Photographs of the specimen S01A-110-8.*

Table 5-5. The test results of the specimen S01A-110-10.

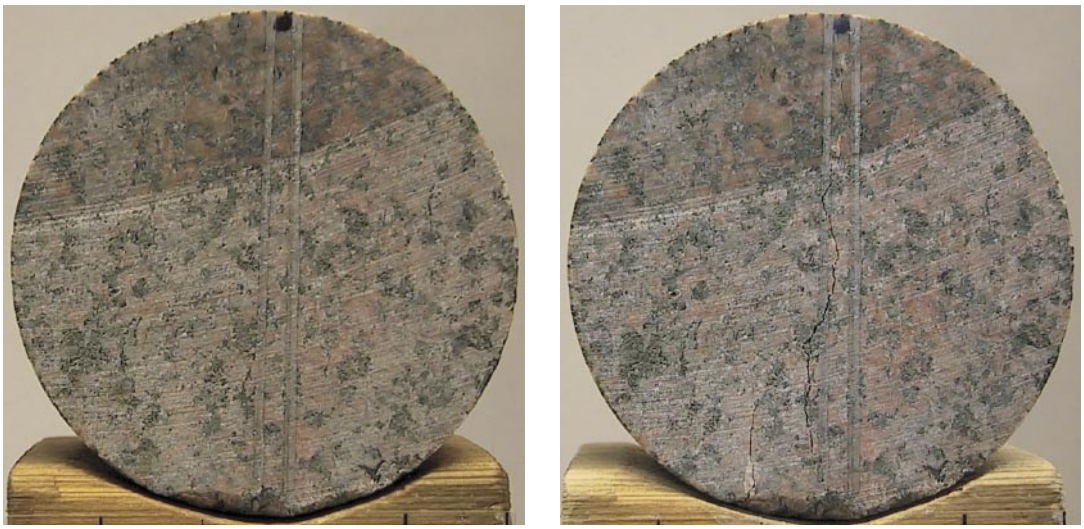
Order:	10340
Investigation site:	Simpevarp
Specimen ID:	**S01A-110-10**
Drill hole:	KSH01A
Depth:	310.62 m
Date of sampling:	2003-05-13
Length:	26.2 mm
Diameter:	50.2 mm
Water-saturated density:	2766 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	no anisotropy
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	31.3 kN
Indirect tensile strength:	15.1 MPa
Comments:	none
Date of testing:	2004-04-01

(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-5. *Photographs of the specimen S01A-110-10.*

Table 5-6. The test results of the specimen S01A-110-12.

Order:	10340
Investigation site:	Simpevarp
Specimen ID:	**S01A-110-12**
Drill hole:	KSH01A
Depth:	313.27 m
Date of sampling:	2003-05-13
Length:	26.1 mm
Diameter:	50.1 mm
Water-saturated density:	2786 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	no anisotropy
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	29.4 kN
Indirect tensile strength:	14.3 MPa
Comments:	none
Date of testing:	2004-04-01

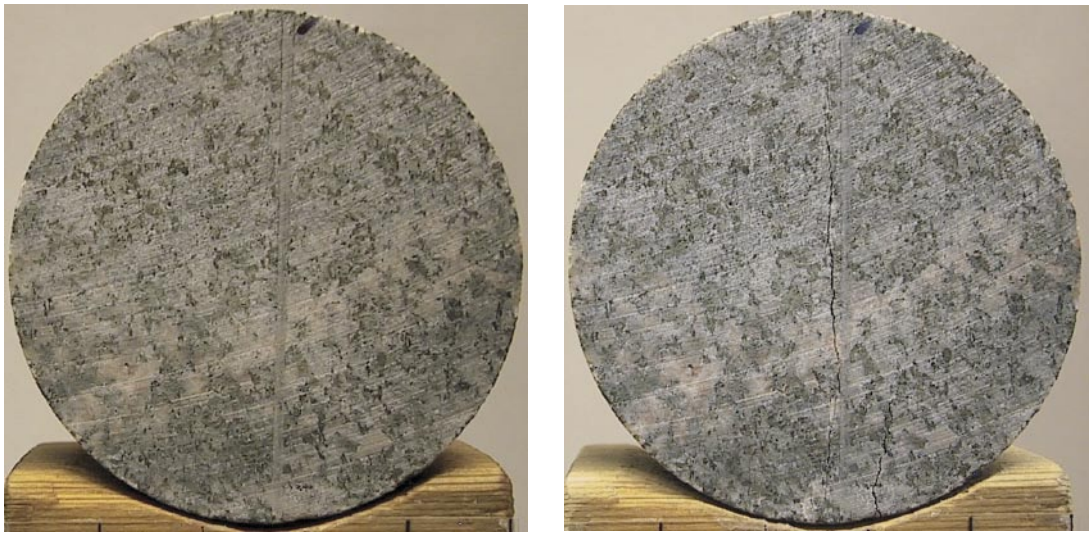


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-6. *Photographs of the specimen S01A-110-12.*

Table 5-7. The test results of the specimen S01A-110-14.

Order:	10340
Investigation site:	Simpevarp
Specimen ID:	**S01A-110-14**
Drill hole:	KSH01A
Depth:	318.72 m
Date of sampling:	2003-05-13
Length:	26.3 mm
Diameter:	50.1 mm
Water-saturated density:	2802 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	no anisotropy
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	33.5 kN
Indirect tensile strength:	16.2 MPa
Comments:	none
Date of testing:	2004-04-01

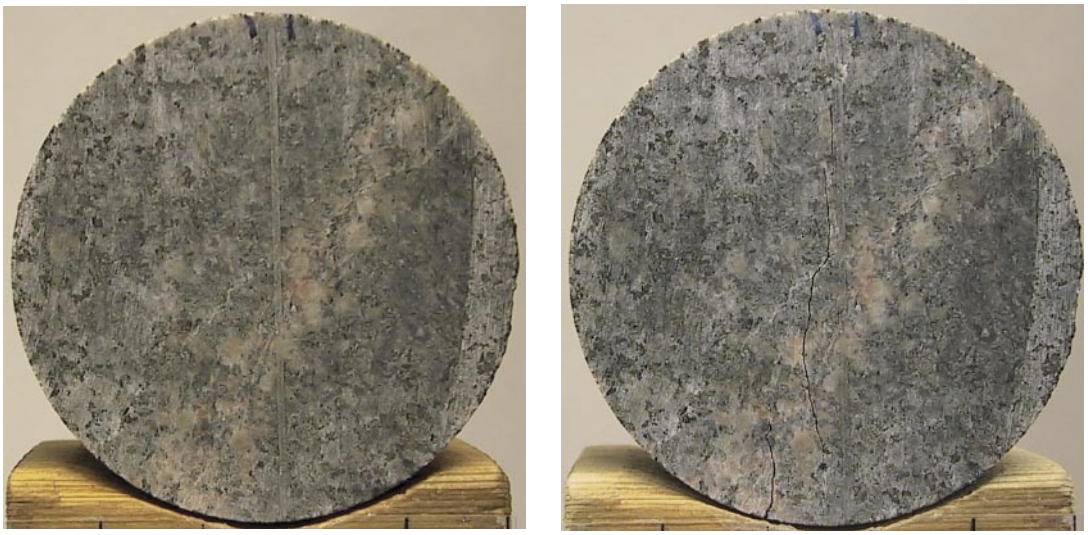


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-7. *Photographs of the specimen S01A-110-14.*

Table 5-8. The test results of the specimen S01A-110-16.

Order:	10340
Investigation site:	Simpevarp
Specimen ID:	**S01A-110-16**
Drill hole:	KSH01A
Depth:	319.20 m
Date of sampling:	2003-05-13
Length:	26.3 mm
Diameter:	50.0 mm
Water-saturated density:	2802 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	no anisotropy
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	30.9 kN
Indirect tensile strength:	14.9 MPa
Comments:	none
Date of testing:	2004-04-01

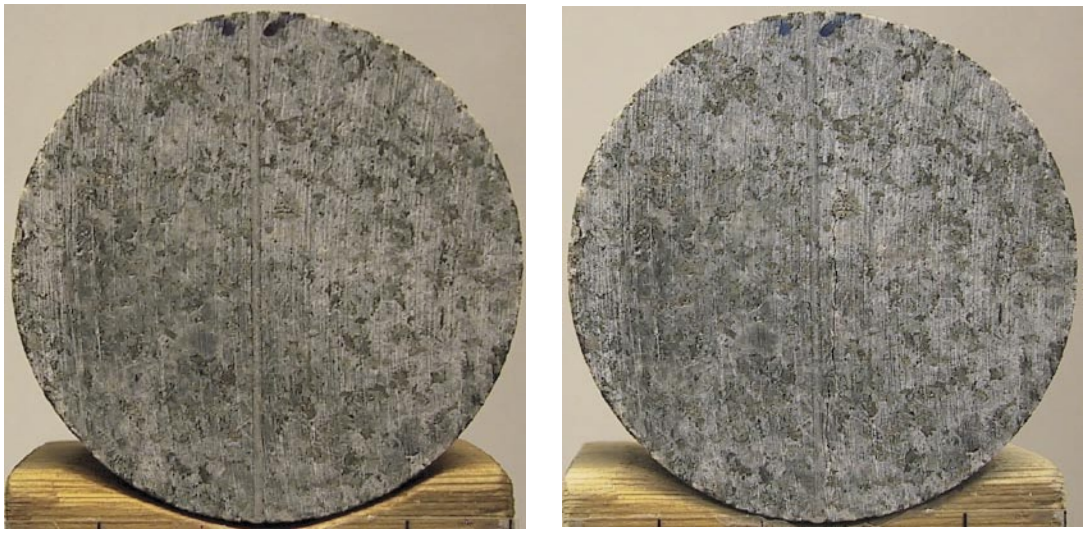


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-8. *Photographs of the specimen S01A-110-16.*

Table 5-9. The test results of the specimen S01A-110-18.

Order:	10340
Investigation site:	Simpevarp
Specimen ID:	**S01A-110-18**
Drill hole:	KSH01A
Depth:	320.04 m
Date of sampling:	2003-05-13
Length:	26.3 mm
Diameter:	50.2 mm
Water-saturated density:	2806 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	no anisotropy
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	28.0 kN
Indirect tensile strength:	13.5 MPa
Comments:	none
Date of testing:	2004-04-01



(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-9. *Photographs of the specimen S01A-110-18.*

Table 5-10. The test results of the specimen S01A-110-20.

Order:	10340
Investigation site:	Simpevarp
Specimen ID:	**S01A-110-20**
Drill hole:	KSH01A
Depth:	321.73 m
Date of sampling:	2003-05-13
Length:	26.1 mm
Diameter:	50.2 mm
Water-saturated density:	2810 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	no anisotropy
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	33.7 kN
Indirect tensile strength:	16.4 MPa
Comments:	none
Date of testing:	2004-04-01

(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-10. *Photographs of the specimen S01A-110-20.*

5.2 Results for the entire test series

Summary of the results is presented in Table 5-11.

Table 5-11. Summary of the results.

Specimen ID	Seclow (m)	Length (mm)	Diameter (mm)	Saturated-density (kg/m³)	Force (kN)	Tensile strength (MPa)
S01A-110-2	303.46	26.2	50.2	2780	32.2	15.6
S01A-110-4	305.26	26.3	50.2	2786	32.4	15.6
S01A-110-6	306.38	26.3	50.2	2792	33.6	16.2
S01A-110-8	310.52	26.2	50.2	2771	33.6	16.3
S01A-110-10	310.62	26.2	50.1	2766	31.3	15.1
S01A-110-12	313.27	26.1	50.1	2786	29.4	14.3
S01A-110-14	318.72	26.3	50.1	2802	33.5	16.2
S01A-110-16	319.20	26.3	50.1	2802	30.9	14.9
S01A-110-18	320.04	26.3	50.1	2806	28.0	13.5
S01A-110-20	321.73	26.1	50.2	2810	33.7	16.4
Mean value				2790		15.4

5.3 Discussion

There were no problems with the equipment.

References

ASTM D 3967-95a. Standard test method for splitting tensile strength of intact rock core specimens.

ISRM, 1979. Suggested Method for Determining Water Content, Porosity, Density, Absorption and Related Properties and Swelling and Slake-durability Index Properties.

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

Appendix 1

Test information sheet for indirect test of tensile strength.

Title: **Test information sheet for indirect test of tensile strength** Page 1 (2)

Date: 2004-03-08 *Order:* _____

Author: Pekka Eloranta

Reference: SKB MD 190.004e 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 3967) *By:* _____

Length (mm): [ ] [ ] [ ] (1 2 3) *Average length (mm):* [ ]

Diameter (mm): [ ] [ ] [ ] (1 2 3)

[ ] [ ] [ ] (4 5 6) *Average diameter (mm):* [ ]

Mass (g): [ ] *(laboratory air-dry)* *Length/Diameter ratio:* [ ]

Straightness (to 0.50 mm): [Yes / No] *Parallellism 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* *Saturated-submerged mass (g):* [ ]

[ ] *Mettler PJ3600, serial number M88692*

[ ] _____ *Saturated-surface-dry mass (g):* [ ]

Remarks: _____

7. Testing the specimen *Date:* _____
(According to the ASTM D 3967) *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* [ ] _____

Run: _____

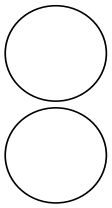
Raw data: _____

Start: _____ *time*

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: _____