P-04-171

Forsmark site investigation

Drill hole KFM01A: Indirect tensile strength test (HUT)

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June 2004

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Abstract

The tensile strength of some rock from SKB's investigation site at Forsmark was studied with a total of 10 standardised indirect tensile tests. The 51 mm diameter samples were collected from the borehole KFM01A. The samples were taken at depth levels between 492–495 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 March 31, 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 2,640–2,670 kg/m^3, which yields a mean value of 2,660 kg/m^3 and the obtained values for the indirect tensile strength were in the range 14.1–16.2 MPa with a mean value of 15.3 MPa.

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1 Introduction

This document reports the data collected by indirect tensile 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).

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 16, 2004. Before testing, the specimens were water-saturated one week and their water-saturated density was determined. The specimens were tested on March 31, 2004. The specimens were photographed before and after tests.

The rock material is characterized by foliations in the rock structure, which may imply an anisotropic mechanical response. The direction of loading is displayed on the specimens by a drawn line on each specimen. The specimens were photographed before and after the mechanical testing.

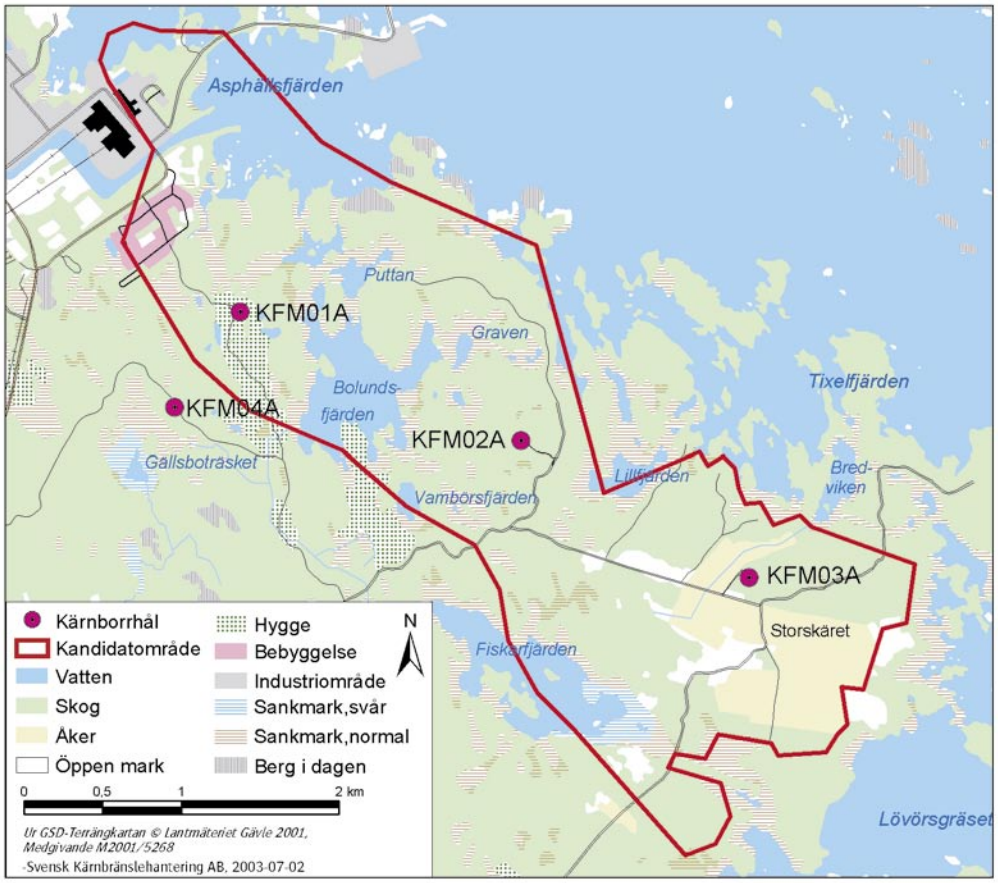


Figure 1-1. *Location of borehole KFM01A at the Forsmark site.*

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 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 equipment was the MTS 815 Rock Mechanics Testing System, 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-built wire basket suspended from the balance by a fine wire.

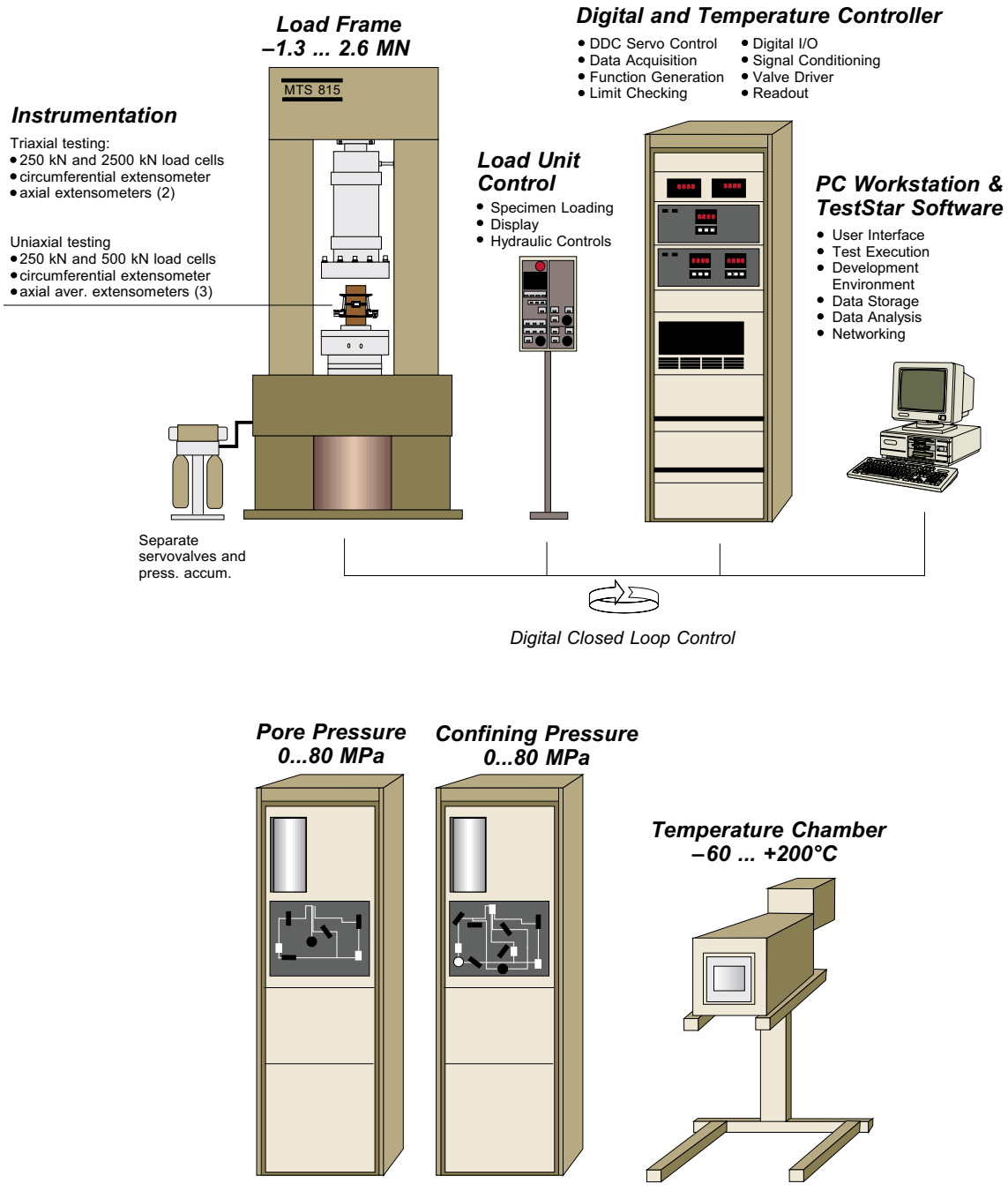


Figure 3-1. *MTS 815 Rock Mechanics Testing System.*

4 Execution

The tests were executed according to the method description SKB MD 190.004, version 1.9 (SKB internal controlling document). The test methodology follows the American Society for Testing and Materials (ASTM) standard D 3967-95a.

The test specimens were water-saturated according to the method description SKB MD 160.002, version 1.9 (SKB internal controlling document). The test methodology follows mainly the standard SFS-EN 13755.

4.1 Description of the samples

The samples are collected from borehole KFM01A at the Forsmark investigation site. The test specimens were labeled at the Swedish National Testing and Research Institutute (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 borehole KFM01A, Forsmark.

Seclow (m)	Specimen ID	Rock Type
491.58	F01-110-15	Meta granodiorite-granite
492.58	F01-110-17	Meta granodiorite-granite
493.08	F01-110-19	Meta granodiorite-granite
494.81	F01-110-21	Meta granodiorite-granite
496.38	F01-110-23	Meta granodiorite-granite
497.06	F01-110-25	Meta granodiorite-granite
498.12	F01-110-27	Meta granodiorite-granite
498.27	F01-110-29	Meta granodiorite-granite
498.35	F01-110-31	Meta granodiorite-granite
494.47	F01-110-33	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 March 16, 2004. The length of each specimen was determined by taking the average of three measurements. The diameter of the specimen was determined by averaging six measurements. The length-to-diameter ratio was calculated, and the smoothness of the circumferential surface as well as 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 to 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 including five specimens each. Water-saturation began on March 22, 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 into 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 then weighed. The water-saturated density was calculated from the volume of the sample and its water-saturated weight (Archimedes' principle).

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 March 31, 2004 in two batches (the first batch in the morning and the second batch in the afternoon).

The specimens were tested on March 31, 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 a 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 were 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.

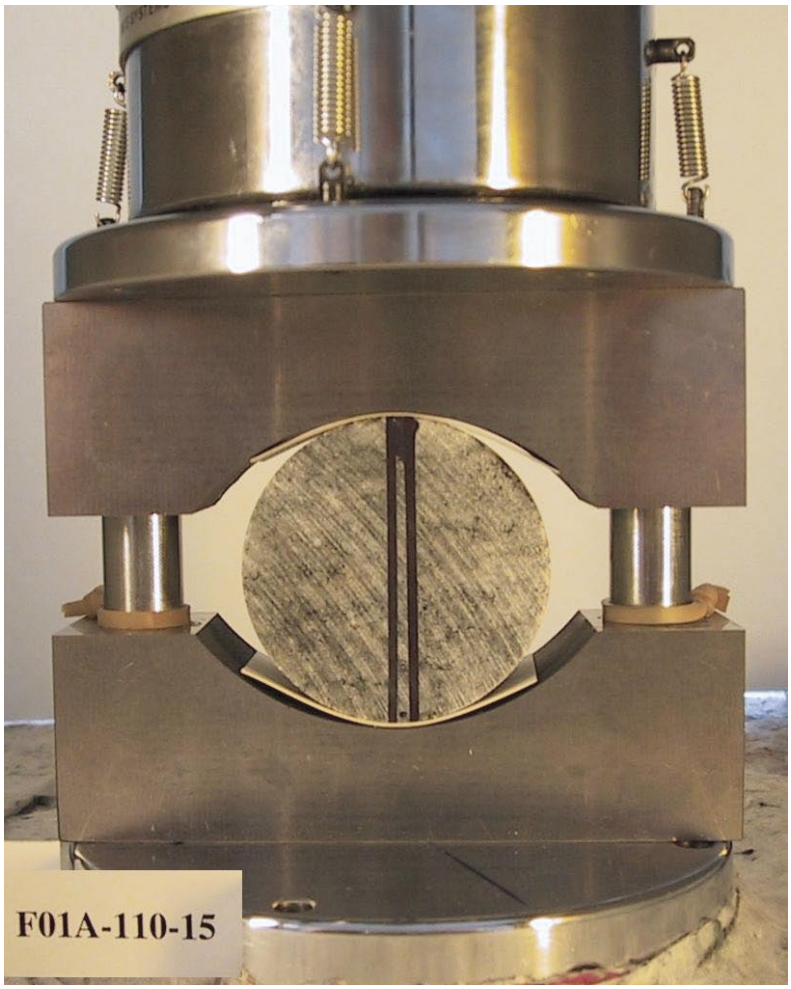


Figure 4-1. *Indirect tensile test configuration (Photo by Pekka Eloranta).*

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

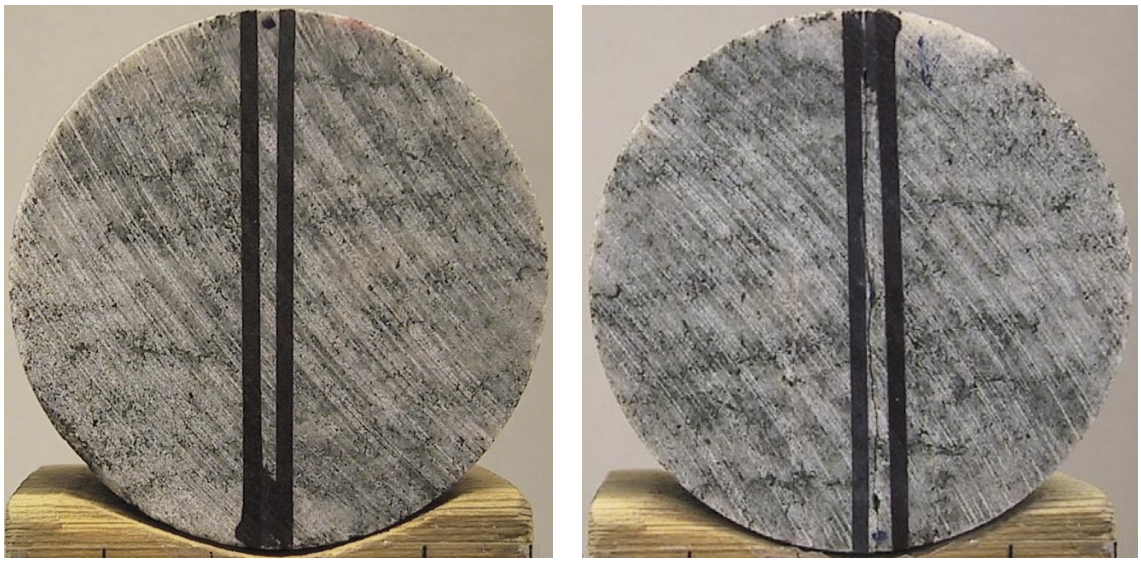
The results of the individual specimens are presented in Section 5.1 and a summary of the results is given in Section 5.2. The original results and data obtained from the testing, were reported to the SICADA database under field note no Forsmark 96.

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 to 5-10 and Figures 5-1 to 5-10).

Table 5-1. The test results of the specimen F01A-110-15.

Order:	10340
Investigation site:	Forsmark
Specimen ID:	**F01A-110-15**
Drill hole:	KFM01A
Depth:	491.58 m
Date of sampling:	2003-02-24
Length:	25.7 mm
Diameter:	50.9 mm
Water-saturated density:	2,668 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	perpendicular to the foliation
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	30.7 kN
Indirect tensile strength:	15.0 MPa
Comments:	none
Date of testing:	2004-03-31

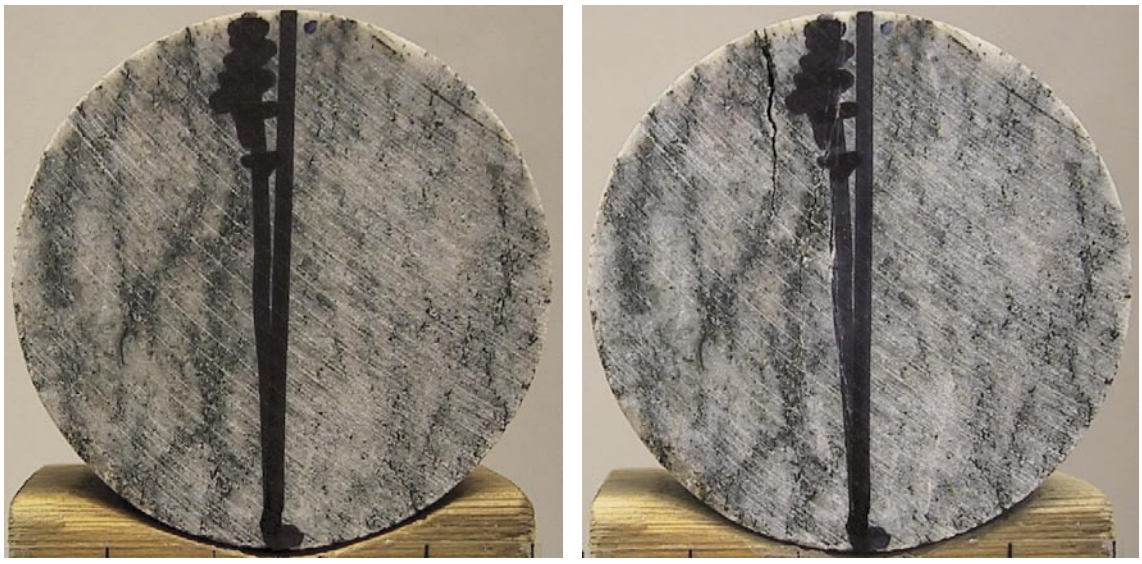


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-1. *Photographs of the specimen F01A-110-15.*

Table 5-2. The test results of the specimen F01A-110-17.

Order:	10340
Investigation site:	Forsmark
Specimen ID:	**F01A-110-17**
Drill hole:	KFM01A
Depth:	492.58 m
Date of sampling:	2003-02-24
Length:	25.6 mm
Diameter:	50.8 mm
Water-saturated density:	2,664 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	parallell to the foliation
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:	15.1 MPa
Comments:	none
Date of testing:	2004-03-31

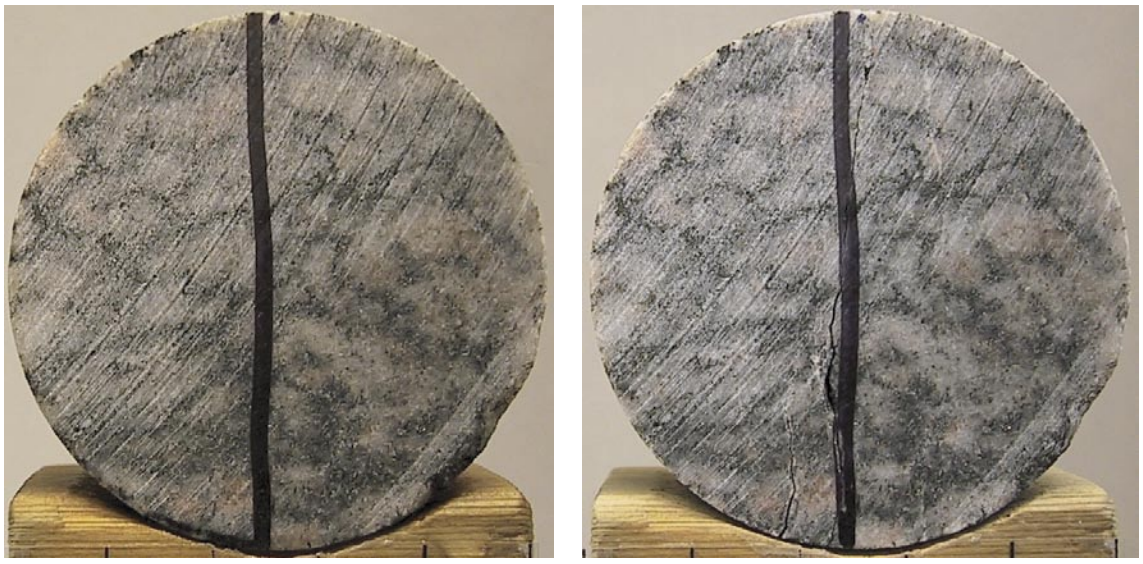


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-2. *Photographs of the specimen F01A-110-17.*

Table 5-3. The test results of the specimen F01A-110-19.

Order:	10340
Investigation site:	Forsmark
Specimen ID:	**F01A-110-19**
Drill hole:	KFM01A
Depth:	493.08 m
Date of sampling:	2003-02-24
Length:	25.4 mm
Diameter:	50.9 mm
Water-saturated density:	2,663 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	perpendicular to the foliation
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	31.6 kN
Indirect tensile strength:	15.5 MPa
Comments:	none
Date of testing:	2004-03-31

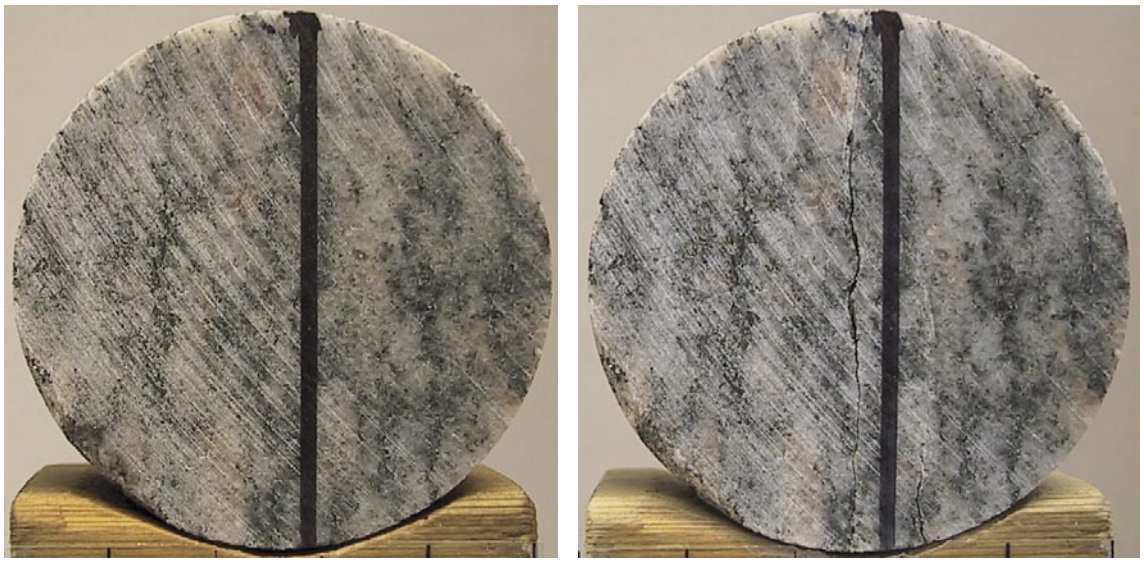


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-3. *Photographs of the specimen F01A-110-19.*

Table 5-4. The test results of the specimen F01A-110-21.

Order:	10340
Investigation site:	Forsmark
Specimen ID:	**F01A-110-21**
Drill hole:	KFM01A
Depth:	494.81 m
Date of sampling:	2003-02-24
Length:	25.4 mm
Diameter:	50.9 mm
Water-saturated density:	2,661 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	parallell to the foliation
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	33.0 kN
Indirect tensile strength:	16.2 MPa
Comments:	none
Date of testing:	2004-03-31

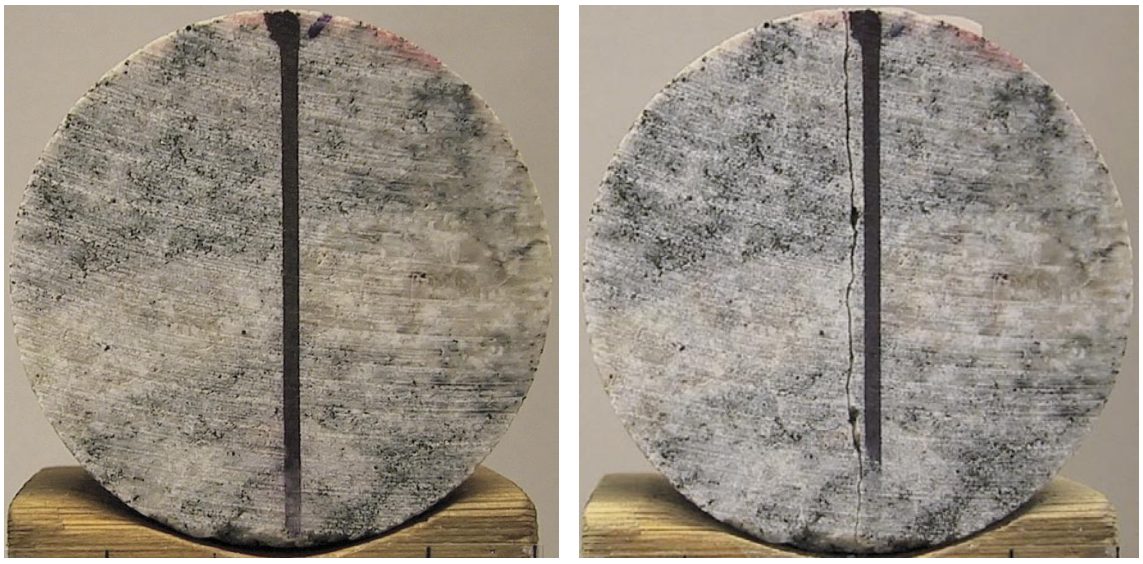


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-4. *Photographs of the specimen F01A-110-21.*

Table 5-5. The test results of the specimen F01A-110-23.

Order:	10340
Investigation site:	Forsmark
Specimen ID:	**F01A-110-23**
Drill hole:	KFM01A
Depth:	496.38 m
Date of sampling:	2003-02-24
Length:	25.5 mm
Diameter:	50.8 mm
Water-saturated density:	2,643 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	perpendicular to the foliation
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	30.8 kN
Indirect tensile strength:	15.2 MPa
Comments:	none
Date of testing:	2004-03-31

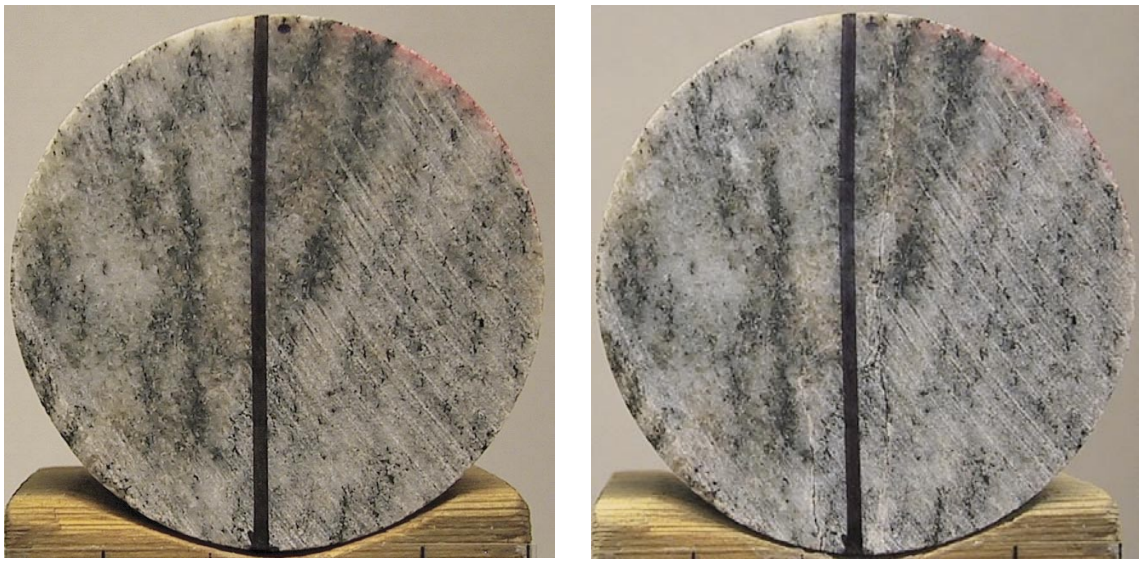


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-5. *Photographs of the specimen F01A-110-23.*

Table 5-6. The test results of the specimen F01A-110-25.

Order:	10340
Investigation site:	Forsmark
Specimen ID:	**F01A-110-25**
Drill hole:	KFM01A
Depth:	497.06 m
Date of sampling:	2003-02-24
Length:	25.6 mm
Diameter:	50.6 mm
Water-saturated density:	2,650 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	parallell to the foliation
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	28.8 kN
Indirect tensile strength:	14.1 MPa
Comments:	none
Date of testing:	2004-03-31

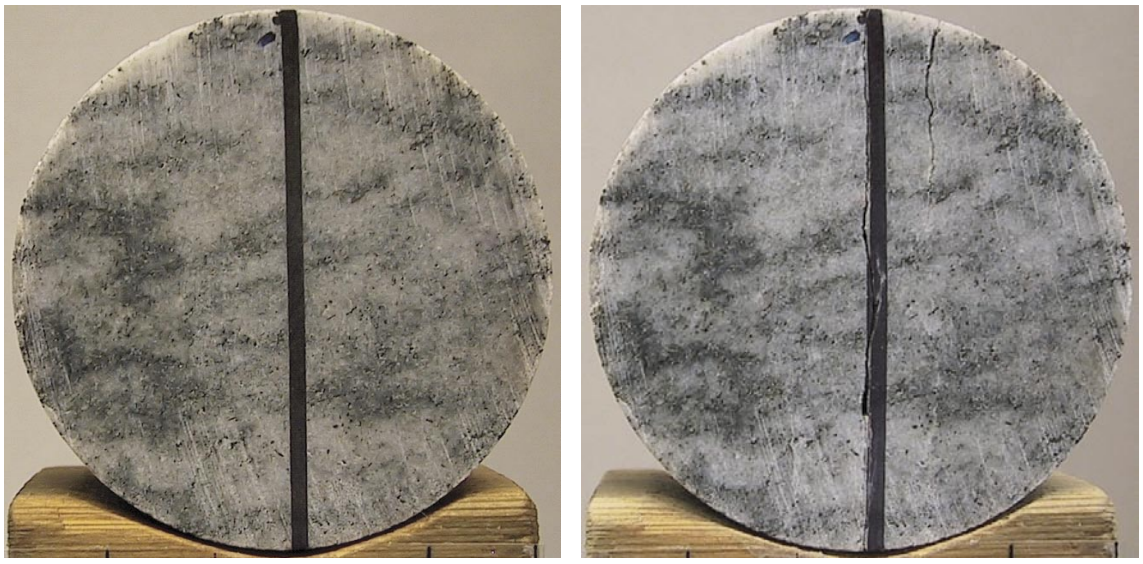


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-6. *Photographs of the specimen F01A-110-25.*

Table 5-7. The test results of the specimen F01A-110-27.

Order:	10340
Investigation site:	Forsmark
Specimen ID:	**F01A-110-27**
Drill hole:	KFM01A
Depth:	498.12 m
Date of sampling:	2003-02-24
Length:	26.0 mm
Diameter:	50.8 mm
Water-saturated density:	2,666 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	perpendicular to the foliation
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:	16.2 MPa
Comments:	none
Date of testing:	2004-03-31

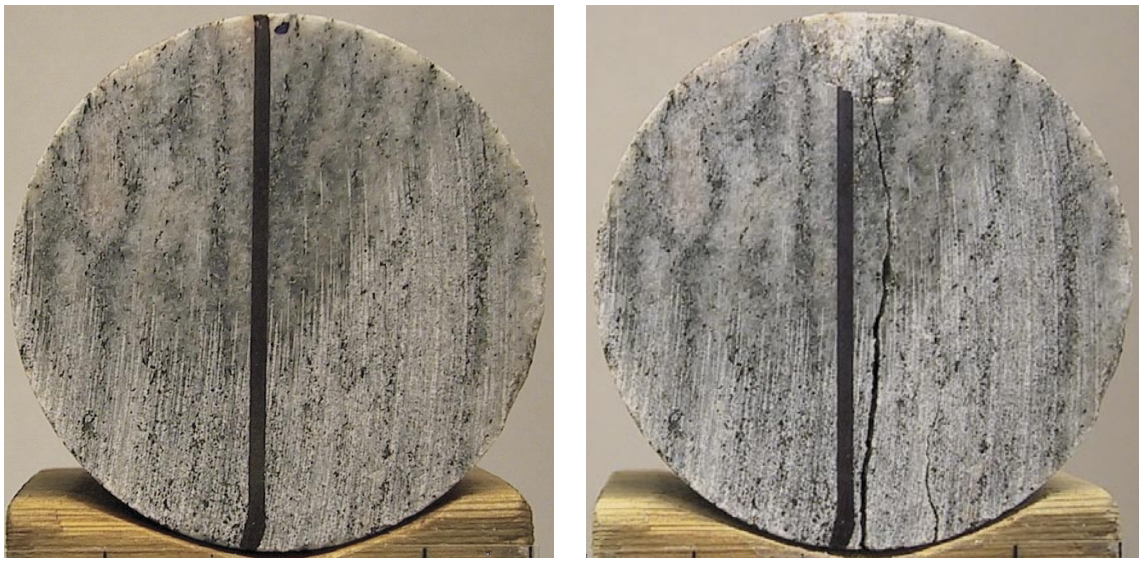


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-7. *Photographs of the specimen F01A-110-27.*

Table 5-8. The test results of the specimen F01A-110-29.

Order:	10340
Investigation site:	Forsmark
Specimen ID:	**F01A-110-29**
Drill hole:	KFM01A
Depth:	498.27 m
Date of sampling:	2003-02-24
Length:	25.8 mm
Diameter:	50.8 mm
Water-saturated density:	2,661 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	parallell to the foliation
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	30.8 kN
Indirect tensile strength:	15.0 MPa
Comments:	none
Date of testing:	2004-03-31

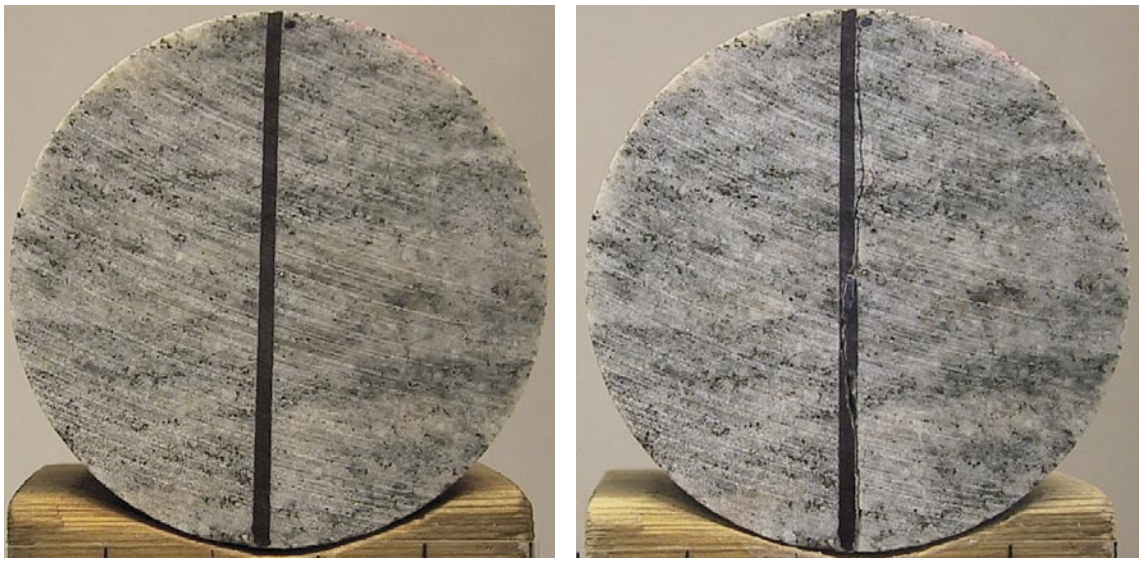


(a) Before testing (2004-03-19) *(b) After testing (2004-04-05)*

Figure 5-8. *Photographs of the specimen F01A-110-29.*

Table 5-9. The test results of the specimen F01A-110-31.

Order:	10340
Investigation site:	Forsmark
Specimen ID:	**F01A-110-31**
Drill hole:	KFM01A
Depth:	498.35 m
Date of sampling:	2003-02-24
Length:	25.7 mm
Diameter:	50.8 mm
Water-saturated density:	2,659 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	perpendicular to the foliation
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	31.7 kN
Indirect tensile strength:	15.4 MPa
Comments:	none
Date of testing:	2004-03-31



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

Figure 5-9. *Photographs of the specimen F01A-110-31.*

Table 5-10. The test results of the specimen F01A-110-33.

Order:	10340
Investigation site:	Forsmark
Specimen ID:	**F01A-110-33**
Drill hole:	KFM01A
Depth:	494.47 m
Date of sampling:	2003-02-24
Length:	25.9 mm
Diameter:	50.8 mm
Water-saturated density:	2,656 kg/m³
Moisture condition at time of test:	saturated
Direction of loading (if anisotropy exists):	parallell to the foliation
Rate of loading (actuator displacement):	0.2 mm/min
Type of contact:	concave plates with bearing strips
Failure load:	31.0 kN
Indirect tensile strength:	15.0 MPa
Comments:	none
Date of testing:	2004-03-31

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

Figure 5-10. *Photographs of the specimen F01A-110-33.*

5.2 Results for the entire test series

A 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/m^3)	Force (kN)	Tensile strength (MPa) Across (⊥) foliation	Along (∥) foliation
F01A-110-15	491.58	25.7	50.9	2,668	30.7	15.0	
F01A-110-17	492.58	25.6	50.8	2,664	30.9		15.1
F01A-110-19	493.08	25.4	50.8	2,663	31.6	15.5	
F01A-110-21	494.81	25.4	50.9	2,661	33.0		16.2
F01A-110-23	496.38	25.5	50.8	2,643	30.8	15.2	
F01A-110-25	497.06	25.6	50.6	2,650	28.8		14.1
F01A-110-27	498.12	26.0	50.8	2,666	33.7	16.2	
F01A-110-29	498.27	25.8	50.8	2,661	30.8		15.0
F01A-110-31	498.35	25.7	50.8	2,659	31.7	15.4	
F01A-110-33	494.47	25.9	50.8	2,656	31.0		15.0
Mean value				2,659		15.1	15.5

5.3 Nonconformities

There were no problems with the testing and equipment.

References

ASTM 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*
[ ] *Mettler PJ3600, serial number M88692*
[ ] _____

Saturated-submerged mass (g): _____

Saturated-surface-dry mass (g): _____

Remarks: _____

Date: 2004-03-08 Order: _____

Author: Pekka Eloranta

Reference: SKB MD 190.004e Appendix 5 Specimen ID: _____

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* *Failure:*

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: _____