Uniaxial Compressive Strength Test Results
of ONKALO Borehole ONK-PP68

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Topias Siren (ed.)

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Working Reports contain information on work in progress or pending completion.
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ABSTRACT

The stress-strain behaviour of rock samples was studied for a total of 26 uniaxial compression tests. Posiva Oy selected the samples from borehole ONK-PP68 in Olkiluoto ONKALO underground rock characterization facility. These holes were drilled as part of outlet air shaft grouting. The diameter of the samples was nominally 51 mm. Specimens were tested under water-saturated condition and were photographed before and after the tests. The values obtained for the uniaxial compressive strength were in the range of 53–163 MPa with the mean value of 90 MPa.

Keywords: rock mechanics, uniaxial compression test, Olkiluoto, ONKALO, outlet air shaft.
TIIVISTELMÄ


Avainsanat: kalliomekaniikka, yksiaksiaalinen puristusmurtokoe, Olkiluoto, ONKALO, poistoilmakuilu.
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1 INTRODUCTION

This document reports the uniaxial compressive test data from outlet air shaft grouting hole ONK-PP68. The tests were originally reported as unpublished memo and later edited to Posiva working report. The testing was conducted and original report was written by Pekka Eloranta (Laboratory of Rock Engineering).

The 85 m deep drillhole was cored (see Figure 1-1) between 18.12.2006 and 20.12.2006 from the depth -90.1 m downwards (Rautio 2008). The uniaxial compression tests on were carried out at the Laboratory of Rock Engineering, Aalto University School of Engineering, Finland (at the time of testing Helsinki University of Technology). These tests were commissioned by Posiva Oy.

Uniaxial compression tests are used to determine the complete stress-strain curve for cylindrical intact rock core specimens. 26 core specimens were prepared and tested tested according to the procedures developed for laboratory tests during Posiva site investigation studies (for example Hakala & Heikkilä 1997) based on the suggested methods of ISRM (Brown 1981). The specimens were tested on December 12-19, 2008 with MTS 815 rock mechanics test system.

The specimens were photographed before, during and after the tests.

![Figure 1-1 Location of the ONK-PP68 in the ONKALO underground facility.](image-url)
2 TEST SPECIMENS

2.1 Selection of samples

Posiva Oy selected core samples for this study (Table 2-1). The samples were classified into rock types before testing. The diameter of the samples was nominally 51 mm.

Before testing the specimens were saturated and stored in about 100% humidity for two weeks.

2.2 Specimen handling procedure

During the development and specification of laboratory tests for Posiva site investigation studies, a procedure for specimen handling was introduced (Hakala 1996). This procedure was further improved based on the experience in the testing of Olkiluoto mica gneiss (see for example Hakala & Heikkilä 1997).

2.2.1 Specimen identification and tracking

The test specimen naming system consists of the borehole name ‘ONK-PP68’ and the depth of the specimen with ten centimetres accuracy. e.g. ‘31’.

2.2.2 Specimen preparation

The uniaxial compression test specimens were cut from core samples with a 300 mm diameter diamond saw blade. During sawing, the core is held by hand and the blade pressure is controlled manually. After cutting the specimen, its ends were flattened with a surface grinder.
2.2.3 Conformance on dimensional and shape tolerances

The specimen volume was determined by measuring the diameter and height (ISRM 1981). For diameter the average value of six measurements is used and for height three measurements were taken. The reading accuracy used was 0.01 mm. The length-to-diameter ratio was calculated. In addition, the straightness of the specimen, the parallelism, perpendicularity and flatness of the end surfaces were verified to be within the required tolerances according to the ISRM suggestions (Ulusay & Hudson 2007 p. 153, 225-226). Test specimens with their dimensions and shape parameters after cutting and grinding are listed in Appendix 1.
2.2.4 Water saturation

To determine the wet mass of the tested specimen, it was saturated by water immersion at a pressure of 732±5 mmHg below atmospheric for a period of at least one hour. The ISRM (Brown 1981) suggestion for a vacuum is at least 700 mmHg below atmospheric. The absolute pressure was not determined. After immersion, samples were stored in approximately 100% humidity for two weeks. Before testing, the specimen surface was dried to remove surface water and the mass was determined. The measuring accuracy was 0.1 grams.

2.2.5 Testing

The test instrumentation was reported in the MTS testing system log book. The tests were conducted according to suggested test procedure introduced later in Chapter 3.2.

Prior to loading, information on the test and names of the test control file and resulting data folder was recorded on the MTS testing system log book and on the test information form. The gap between the ends of the circumferential extensometer chain was recorded as an essential value for calculating the radial strain from the measured circumferential displacement.

All the test results were stored in digital form, and only the maximum axial load was recorded in the specimen file form.

2.2.6 Specimen photography

The test specimens were photographed before tests, during tests and after tests. Chapter 3.3 gives more detailed description of procedures used.

2.2.7 Storage

The tested specimens were stored in the laboratory until they were returned to Posiva Oy.
3 TEST CONFIGURATION AND PROCEDURES

3.1 Equipment

For all tests, the MTS 815 Rock Mechanics Test System, a computer-controlled servo-controlled hydraulic compression machine, was used. The system consists of a load cell, extensometers for strain measurements, load frame, hydraulic power supply, test controller, test processor and PC micro-computer.

3.2 Uniaxial compression tests

In uniaxial compression tests, axial extensometers are used to measure axial strain. Deformation is measured via a 50 mm gauge length. Radial strain is measured with one circumferential extensometer connected to the roller chain assembly wrapped around the specimen at mid-height. All extensometers are held around the specimen by contact force produced by mounting springs. At the specimen ends, non-lubricated steel end caps are used.

Table 3-1 Procedure for the uniaxial compression test

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drive specimen manually near to contact</td>
</tr>
<tr>
<td></td>
<td>- No axial force is allowed</td>
</tr>
<tr>
<td>2</td>
<td>Reset readings</td>
</tr>
<tr>
<td></td>
<td>- Reset readings of axial and radial extensometer, actuator displacement and axial force</td>
</tr>
<tr>
<td>3</td>
<td>Start programmed test control</td>
</tr>
<tr>
<td>4</td>
<td>Drive specimen to force contact</td>
</tr>
<tr>
<td></td>
<td>- Move actuator up 0.2 mm/min until axial force is 5.0 kN</td>
</tr>
<tr>
<td>5</td>
<td>Axial load ramp to settle the specimen</td>
</tr>
<tr>
<td></td>
<td>- Increase axial load so that loading rate is 0.75 MPa/s until radial strain is -0.01% or</td>
</tr>
<tr>
<td></td>
<td>axial stress is 15 MPa</td>
</tr>
<tr>
<td></td>
<td>- Decrease axial load so that loading rate is 0.75 MPa/s until axial force is 1.0 kN</td>
</tr>
<tr>
<td>6</td>
<td>Axial load ramp to failure</td>
</tr>
<tr>
<td></td>
<td>- Increase axial load so that loading rate is 0.75 MPa/s until radial strain is -0.01% or</td>
</tr>
<tr>
<td></td>
<td>axial stress is 50 MPa</td>
</tr>
<tr>
<td></td>
<td>- Change to radial strain rate control</td>
</tr>
<tr>
<td></td>
<td>- Increase radial strain corresponding to the initial elastic loading rate of 0.75 MPa/s until</td>
</tr>
<tr>
<td></td>
<td>the end of the radial extensometer range is reached or the test is stopped manually</td>
</tr>
<tr>
<td>7</td>
<td>Unloading</td>
</tr>
<tr>
<td></td>
<td>- Remove remaining force by programmed control</td>
</tr>
</tbody>
</table>

The uniaxial compression tests were conducted under a radial strain rate control corresponding to an elastic axial loading rate of about 0.75 MPa/s (Table 3-1). First the specimen is driven to contact under programmed control. One loading ramp in the elastic region is made to ensure a well-settled specimen before the actual loading ramp
to failure. 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.

### 3.3 Photography

Several photographs were taken on test specimens before, during and after testing.

Each uniaxial compression test specimen was photographed before testing.

After testing, each specimen was photographed using the same procedure as before testing. If necessary, additional photographs were taken to show failure mode.

### 3.4 Quality control

To assure that all test phases are made to each specimen in the planned order, and to make it possible to re-analyze possible errors and deviations in results, all preparation and test phases of each specimen were reported on a test information form. The completed test information forms are not included in this report.

Extensometer readings were checked with a 56 mm aluminium specimen before test series using the Young’s modulus and Poisson’s ratio as reference. Both values were determined as a secant from the axial stress level corresponding 0.01% of radial strain to the axial stress level of 50 MPa.
4 ANALYSIS AND INTERPRETATION

Uniaxial compression test data are recorded in ASCII files. The data are imported to a Microsoft Excel template file for analysis. Axial strain and radial strain are plotted against axial stress. In addition, volumetric strain (total volumetric strain and crack volumetric strain) is plotted against axial strain on a separate graph (see Figure 4-1 and Appendix 1).

4.1 Elastic parameters

Young’s modulus ($E$) and Poisson’s ratio ($\nu$), are calculated as tangent modulus at the half of the peak strength ($\sigma_p$). The slopes of the stress-strain curves are determined between 40-60% of the peak strength using linear fit (Microsoft Excel SLOPE function). Young’s modulus is additionally calculated as secant modulus at the half of the peak strength.

4.2 Stress states

The stress states here refer to crack initiation stress ($\sigma_{ci}$), crack damage stress ($\sigma_{cd}$) and peak strength ($\sigma_p$) (Figure 4-1).

The crack initiation stress is defined as the stress level where the crack volumetric strain ($\varepsilon_{v,cr}$) deviates from zero (Figure 4-1). The crack volumetric strain ($\varepsilon_{v,cr}$) is calculated by subtracting the elastic deformations ($\varepsilon_{v,e}$) of the rock matrix from the total volumetric strain ($\varepsilon_v$). The elastic volumetric strain ($\varepsilon_{v,e}$) is defined by Young’s modulus ($E$) and Poisson’s ratio ($\nu$) and the current major ($\sigma_1$) and minor ($\sigma_3$) principal stresses (Equation 4-1).

$$\varepsilon_{v,e} = \frac{1 - 2\nu}{E} (\sigma_1 - \sigma_3) \quad (4-1)$$

After subtracting the elastic volumetric strain ($\varepsilon_{v,e}$) from the total volumetric strain ($\varepsilon_v$), the crack volumetric strain curve is shifted so that the maximum value is zero (Figure 4-1).

The determination of the crack initiation stress ($\sigma_{ci}$) state is not always obvious; therefore, the first guess for $\sigma_{ci}$ is determined as the last point having a crack volumetric strain ($\varepsilon_{v,cr}$) equal to 0.5% of total compaction. This value, checked visually, is to be at the intersection of the horizontal line and the extension of the increasing crack volume.

The crack damage stress ($\sigma_{cd}$) is defined as the reversal of the volumetric strain ($\varepsilon_v$) curve (Figure 4-1). At this point, the total volume of the specimen changes from compaction to dilation. The total volumetric strain ($\varepsilon_v$) is approximated from the axial ($\varepsilon_a$) and radial strains ($\varepsilon_r$) (Equation 4-2).

$$\varepsilon_v = \varepsilon_a + 2\varepsilon_r \quad (4-2)$$
The peak strength ($\sigma_p$) is defined as the highest observed axial stress (Figure 4-1).

**Figure 4-1** Determination of the failure stress states $\sigma_t$, $\sigma_{ci}$, $\sigma_{cd}$ and $\sigma_p$ (Hakala & Heikkilä 1997 after Martin 1994).
5 RESULTS

The values obtained for the uniaxial compressive strength were in the range of 53–163 MPa with the mean value of 90 MPa.

5.1 Description and presentation of the specimens

The photographs of the specimens before and after testing are presented in Appendix 2.

5.2 Stress-strain behaviour

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

Detailed stress-strain curves are presented in Appendix 1.

Table 5-1. Summary of the results.

<table>
<thead>
<tr>
<th>Hole ID</th>
<th>Depth (m)</th>
<th>Rock type</th>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>Density (kg/m³)</th>
<th>Peak strength (MPa)</th>
<th>Young's modulus (GPa)</th>
<th>Poisson's ratio</th>
<th>Crack initiation (MPa)</th>
<th>Crack damage (MPa)</th>
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REFERENCES


APPENDICES

1. Stress-strain curves of uniaxial compression tests
2. Photographs of test specimens before and after testing
Appendix 1. Stress-strain curves of uniaxial compression tests
STRESS - STRAIN CURVES

Failure Pattern

Test Data

Client: Posiva Oy  
Order Number: 9651-08  
Test: Uniaxial  
Equipment: MT3 815

Load Control: Radial strain rate  
Equivalent Loading Rate: 0.75 MPa/s  
Test Date: 2008-12-12  
Test Duration: 0.43 (h:min)

Specimen Data ONK-PP68 - 5.59

Site: Olikiluoto  
Hole: ONK-PP68  
Depth: 5.59 m

Length: 127.4 mm  
Diameter: 50.2 mm  
Saturated Density: 2685 kg/m³

Rock Type: VGN  
Degree of Saturation: Saturated

Test Results

Compressive Strength: 106.5 MPa  
Crack Initiation: 54.1 MPa  
Young's Modulus: 63.5 GPa  
Crack Damage: 106.5 MPa

Poisson's Ratio: 0.17  
Failure Mode: axial splitting

Remarks: none
**Test Data**

- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2008-12-12
- **Test Duration:** 0.33 (h.min)

**Specimen Data**

- **Site:** Olikuoto
- **Hole:** ONK-PP68
- **Depth:** 9.37 m
- **Rock Type:** VGN
- **Length:** 127.3 mm
- **Diameter:** 50.2 mm
- **Saturated Density:** 2735 kg/m³
- **Degree of Saturation:** Saturated

**Test Results**

- **Compressive Strength:** 66.0 MPa
- **Young's Modulus:** 38.8 GPa
- **Poisson's Ratio:** 0.22
- **Crack Initiation:** 33.9 MPa
- **Crack Damage:** 61.2 MPa
- **Failure Mode:** shear failure
- **Remarks:** none
**STRESS - STRAIN CURVES**

- **Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2008-12-12
- **Test Duration:** 0.02 (h.min)

**Specimen Data**
- **Site:** Olikuoto
- **Hole:** ONK-PP68
- **Depth:** 16.42 m
- **Rock Type:** PGR
- **Length:** 126.9 mm
- **Diameter:** 50.3 mm
- **Saturated Density:** 2670 kg/m³
- **Degree of Saturation:** Saturated

**Test Results**
- **Compressive Strength:** 54.3 MPa
- **Young's Modulus:** 54.7 GPa
- **Poisson's Ratio:** 0.13
- **Crack Initiation:** - MPa
- **Crack Damage:** 54.2 MPa
- **Failure Mode:** shear failure

**Remarks:** failure along mica rich foliation
### Test Data

- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2008-12-12
- **Test Duration:** 1.00 (h:min)

### Specimen Data

- **Site:** Olikuoto
- **Hole:** ONK-PP68
- **Depth:** 16.79 m
- **Rock Type:** PGR
- **Length:** 126.9 mm
- **Diameter:** 50.3 mm
- **Saturated Density:** 2758 kg/m³
- **Degree of Saturation:** Saturated

### Test Results

- **Compressive Strength:** 67.5 MPa
- **Crack Initiation:** 31.5 MPa
- **Young's Modulus:** 43.9 GPa
- **Crack Damage:** 69.9 MPa
- **Poisson's Ratio:** 0.23
- **Failure Mode:** axial splitting
- **Remarks:** none
**Stress - Strain Curves**

- **Axial Stress (MPa)**
  - 0 to 180

- **Radial Strain**
  - -0.4% to 0.4%

- **Axial Strain**
  - -0.4% to 0.4%

**Failure Pattern**

**Test Data**

- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615

**Load Control:** Radial strain rate
**Equivalent Loading Rate:** 0.75 MPa/s
**Test Date:** 2008-12-15
**Test Duration:** 0.24 (h:min)

**Specimen Data**

- **Site:** Olikuoto
- **Hole:** ONK-PP68
- **Depth:** 20.51 m
- **Rock Type:** DGN

**Length:** 127.1 mm
**Diameter:** 50.4 mm
**Saturated Density:** 2739 kg/m³
**Degree of Saturation:** Saturated

**Test Results**

- **Compressive Strength:** 103.2 MPa
- **Young's Modulus:** 59.8 GPa
- **Poisson's Ratio:** 0.24

- **Crack Initiation:** 60.7 MPa
- **Crack Damage:** 90.5 MPa
- **Failure Mode:** shear failure

**Remarks:** none
### Test Data

<table>
<thead>
<tr>
<th>Client</th>
<th>Posiva Oy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order Number</td>
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<tr>
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<td>Uniaxial</td>
</tr>
<tr>
<td>Equipment</td>
<td>MT3 615</td>
</tr>
<tr>
<td>Load Control</td>
<td>Radial strain rate</td>
</tr>
<tr>
<td>Equivalent Loading Rate</td>
<td>0.75 MPa/s</td>
</tr>
<tr>
<td>Test Date</td>
<td>2008-12-15</td>
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<tr>
<td>Test Duration</td>
<td>0.30 (h.min)</td>
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### Specimen Data

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<tbody>
<tr>
<td>Hole</td>
<td>ONK-PP68</td>
</tr>
<tr>
<td>Depth</td>
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<tr>
<td>Rock Type</td>
<td>DGN</td>
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<tr>
<td>Length</td>
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<tr>
<td>Diameter</td>
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<tr>
<td>Saturated Density</td>
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### Test Results

<table>
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<tr>
<th>Compressive Strength</th>
<th>78.5 MPa</th>
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<tbody>
<tr>
<td>Crack Initiation</td>
<td>48.3 MPa</td>
</tr>
<tr>
<td>Young's Modulus</td>
<td>54.0 GPa</td>
</tr>
<tr>
<td>Crack Damage</td>
<td>78.4 MPa</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.20</td>
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<tr>
<td>Failure Mode</td>
<td>mixed</td>
</tr>
<tr>
<td>Remarks</td>
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</tr>
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</table>
**Test Data**

- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2008-12-19
- **Test Duration:** 0.49 (h:min)

**Specimen Data**

- **Site:** Olikuoto
- **Hole:** ONK-PP68
- **Depth:** 35.64 m
- **Rock Type:** PGR
- **Length:** 126.7 mm
- **Diameter:** 50.5 mm
- **Saturated Density:** 2616 kg/m³
- **Degree of Saturation:** Saturated

**Test Results**

- **Compressive Strength:** 162.6 MPa
- **Young's Modulus:** 66.9 GPa
- **Poisson's Ratio:** 0.28
- **Crack Initiation:** 79.2 MPa
- **Crack Damage:** 119.1 MPa
- **Failure Mode:** axial splitting
- **Remarks:** none
**Test Data**

- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Duration:** 0.37 (h.min)
- **Test Date:** 2008-12-16

**Specimen Data**

- **Site:** Olikluto
- **Hole:** ONK-PP68
- **Depth:** 38.89 m
- **Rock Type:** DGN
- **Length:** 127.1 mm
- **Diameter:** 50.5 mm
- **Saturated Density:** 2691 kg/m³
- **Degree of Saturation:** Saturated

**Test Results**

- **Compressive Strength:** 53.0 MPa
- **Crack Initiation:** 36.2 MPa
- **Young's Modulus:** 35.0 GPa
- **Crack Damage:** 52.7 MPa
- **Poisson's Ratio:** 0.15
- **Failure Mode:** shear failure

**Remarks:** settling ramp was omitted due to a weakness zone
**STRESS - STRAIN CURVES**

**Failure Pattern**

**Test Data**

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<thead>
<tr>
<th>Client:</th>
<th>Posiva Oy</th>
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<th>Radial strain rate</th>
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<td>Equivalent Loading Rate:</td>
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<tr>
<td>Test:</td>
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<tr>
<td>Equipment:</td>
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<td>Test Duration:</td>
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<td><strong>Specimen Data</strong></td>
<td><strong>ONK-PP68 - 42.53</strong></td>
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<tr>
<td>Site:</td>
<td>Olikiuto</td>
<td>Length:</td>
<td>126.5 mm</td>
</tr>
<tr>
<td>Hole:</td>
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<td>Diameter:</td>
<td>50.1 mm</td>
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<tr>
<td>Depth:</td>
<td>42.53 m</td>
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<td>2682 kg/m³</td>
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<td>Rock Type:</td>
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**Test Results**

<table>
<thead>
<tr>
<th>Compressive Strength:</th>
<th>102.9 MPa</th>
<th>Crack Initiation:</th>
<th>54.7 MPa</th>
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</thead>
<tbody>
<tr>
<td>Young's Modulus:</td>
<td>61.7 GPa</td>
<td>Crack Damage:</td>
<td>95.3 MPa</td>
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<tr>
<td>Poisson's Ratio:</td>
<td>0.24</td>
<td>Failure Mode:</td>
<td>shear failure</td>
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<tr>
<td>Remarks:</td>
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</table>
**STRESS - STRAIN CURVES**

**Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615

**Specimen Data**
- **Site:** Olikuoto
- **Hole:** ONK-PP68
- **Depth:** 42.88 m
- **Type:** DGN

**Load Control:** Radial strain rate
**Equivalent Loading Rate:** 0.75 MPa/s
**Test Date:** 2008-12-16
**Test Duration:** 1.54 (h:min)

**Test Results**
- **Compressive Strength:** 99.3 MPa
- **Young's Modulus:** 58.7 GPa
- **Poisson's Ratio:** 0.21
- **Crack Initiation:** 56.8 MPa
- **Crack Damage:** 88.3 MPa
- **Failure Mode:** mixed
- **Remarks:** a rather long test
**Test Data**

Client: Posiva Oy  
Load Control: Radial strain rate

Order Number: 9651-08  
Equivalent Loading Rate: 0.75 MPa/s

Test: Uniaxial  
Test Date: 2008-12-17

Equipment: MT3 815  
Test Duration: 1.24 (h.min)

**Specimen Data**  
ONK-PP68 - 45.86

Site: Oikiluoto  
Length: 126.9 mm

Hole: ONK-PP68  
Diameter: 50.1 mm

Depth: 45.86 m  
Saturated Density: 2668 kg/m³

Rock Type: DGN  
Degree of Saturation: Saturated

**Test Results**

Compressive Strength: 71.0 MPa  
Crack Initiation: 35.9 MPa

Young's Modulus: 50.1 GPa  
Crack Damage: 62.2 MPa

Poisson's Ratio: 0.27  
Failure Mode: shear failure

Remarks: none
### Test Data

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<tbody>
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<td>Equipment:</td>
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<td>Test Duration:</td>
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### Specimen Data

- **ONK-PP68 - 53.44**
- **Site:** Olikuoto
- **Length:** 126.7 mm
- **Hole:** ONK-PP68
- **Diameter:** 50.3 mm
- **Depth:** 53.44 m
- **Saturated Density:** 2659 kg/m³
- **Rock Type:** DGN
- **Degree of Saturation:** Saturated

### Test Results

- **Compressive Strength:** 98.2 MPa
- **Crack Initiation:** 53.5 MPa
- **Young's Modulus:** 57.9 GPa
- **Crack Damage:** 73.4 MPa
- **Poisson's Ratio:** 0.25
- **Failure Mode:** mixed
- **Remarks:** none
## Test Data

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<th>Radial strain rate</th>
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<tbody>
<tr>
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<tr>
<td>Test:</td>
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<td>Equipment:</td>
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### Specimen Data

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<tr>
<td>Hole:</td>
<td>ONK-PP68</td>
<td>Diameter:</td>
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<tr>
<td>Depth:</td>
<td>56.65 m</td>
<td>Saturated Density:</td>
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### Test Results

<table>
<thead>
<tr>
<th>Compressive Strength:</th>
<th>101.6 MPa</th>
<th>Crack Initiation:</th>
<th>57.0 MPa</th>
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<tbody>
<tr>
<td>Young's Modulus:</td>
<td>62.8 GPa</td>
<td>Crack Damage:</td>
<td>94.4 MPa</td>
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<td>Poisson’s Ratio:</td>
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STRESS - STRAIN CURVES

Failure Pattern

Test Data
Client: Posiva Oy
Order Number: 9651-08
Test: Uniaxial
Equipment: MT3 615

Load Control: Radial strain rate
Equivalent Loading Rate: 0.75 MPa/s
Test Date: 2008-12-15
Test Duration: 0.53 (h.min)

Specimen Data
ONK-PP68 - 57.02
Site: Olikuoto
Hole: ONK-PP68
Depth: 57.02 m
Rock Type: DGN

Length: 127.3 mm
Diameter: 50.3 mm
Saturated Density: 2691 kg/m³
Degree of Saturation: Saturated

Test Results
Compressive Strength: 84.9 MPa
Young’s Modulus: 55.6 GPa
Poisson’s Ratio: 0.21

Crack Initiation: 48.2 MPa
Crack Damage: 73.8 MPa
Failure Mode: shear failure

Remarks: none
### Test Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
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<tbody>
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<td>Client</td>
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<td>Test</td>
<td>Uniaxial</td>
</tr>
<tr>
<td>Equipment</td>
<td>MT3 615</td>
</tr>
<tr>
<td>Load Control</td>
<td>Radial strain rate</td>
</tr>
<tr>
<td>Equivalent Loading Rate</td>
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<td>Test Duration</td>
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### Specimen Data

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<tbody>
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<td>Site</td>
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<tr>
<td>Hole</td>
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<tr>
<td>Depth</td>
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<tr>
<td>Rock Type</td>
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<tr>
<td>Length</td>
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<tr>
<td>Diameter</td>
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<td>Saturated Density</td>
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### Test Results

<table>
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<tr>
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<th>Details</th>
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<td>Compressive Strength</td>
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<td>Young's Modulus</td>
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<td>Poisson’s Ratio</td>
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<td>Crack Initiation</td>
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<td>Crack Damage</td>
<td>65.8 MPa</td>
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<td>Failure Mode</td>
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Remarks: none
**Test Data**

- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615

**Specimen Data**

- **Site:** Olkiluoto
- **Hole:** ONK-PP68
- **Depth:** 63.76 m
- **Rock Type:** DGN

**Test Results**

- **Compressive Strength:** 68.3 MPa
- **Young’s Modulus:** 44.7 GPa
- **Poisson’s Ratio:** 0.29

**Remarks:** none

**Load Control:** Radial strain rate
**Equivalent Loading Rate:** 0.75 MPa/s
**Test Date:** 2008-12-15
**Test Duration:** 1.01 (h.min)

**Saturated Density:** 2849 kg/m³
**Degree of Saturation:** Saturated

**Crack Initiation:** 34.2 MPa
**Crack Damage:** 50.9 MPa
**Failure Mode:** axial splitting
**Test Data**

- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615

**Load Control:** Radial strain rate

**Equivalent Loading Rate:** 0.75 MPa/s

**Test Date:** 2008-12-16

**Test Duration:** 0.12 (h.min)

**Specimen Data**

- **Site:** Olikuoto
- **Hole:** ONK-PP68
- **Depth:** 64.07 m
- **Rock Type:** DGN

**Length:** 127.3 mm

**Diameter:** 50.4 mm

**Saturated Density:** 2800 kg/m³

**Degree of Saturation:** Saturated

**Test Results**

- **Compressive Strength:** 55.7 MPa
- **Young's Modulus:** 37.4 GPa
- **Poisson's Ratio:** 0.23
- **Crack Initiation:** 32.4 MPa
- **Crack Damage:** 46.4 MPa
- **Failure Mode:** shear failure

**Remarks:** none
STRESS - STRAIN CURVES

Failure Pattern

Test Data

Client: Posiva Oy
Order Number: 9651-08
Test: Uniaxial
Equipment: MT3 015

Load Control: Radial strain rate
Equivalent Loading Rate: 0.75 MPa/s
Test Date: 2008-12-19
Test Duration: 0.30 (h.min)

Specimen Data

ONK-PP68 - 67.28
Site: Olkiluoto
Hole: ONK-PP68
Depth: 67.28 m
Rock Type: PGR

Length: 127.6 mm
Diameter: 50.5 mm
Saturated Density: 2621 kg/m³
Degree of Saturation: Saturated

Test Results

Compressive Strength: 110.3 MPa
Young's Modulus: 66.0 GPa
Poisson's Ratio: 0.24

Crack Initiation: 63.4 MPa
Crack Damage: 90.3 MPa
Failure Mode: mixed, shear

Remarks: none
**STRESS - STRAIN CURVES**

**Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2008-12-19
- **Test Duration:** 2.19 (h:min)

**Specimen Data**
- **Site:** Olikuoto
- **Hole:** ONK-PP68
- **Depth:** 67.62 m
- **Rock Type:** PGR
- **Length:** 127.3 mm
- **Diameter:** 50.4 mm
- **Saturated Density:** 2596 kg/m³
- **Degree of Saturation:** Saturated

**Test Results**
- **Compressive Strength:** 103.0 MPa
- **Crack Initiation:** 52.8 MPa
- **Young's Modulus:** 54.0 GPa
- **Crack Damage:** 77.2 MPa
- **Poisson's Ratio:** 0.25
- **Failure Mode:** Axial splitting
- **Remarks:** a rather long test
**Stress-Strain Curves**

**Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615
- **Specimen Data:** ONK-PP68 - 71.09
  - **Site:** Olikuoto
  - **Hole:** ONK-PP68
  - **Depth:** 71.09 m
  - **Rock Type:** PGR
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2008-12-19
- **Test Duration:** 0.49 (h.min)

**Test Results**
- **Compressive Strength:** 86.0 MPa
- **Young's Modulus:** 56.6 GPa
- **Poisson's Ratio:** 0.17
- **Crack Initiation:** 49.9 MPa
- **Crack Damage:** 81.8 MPa
- **Failure Mode:** shear failure
- **Saturated Density:** 2619 kg/m³
- **Degree of Saturation:** Saturated
- **Length:** 127.0 mm
- **Diameter:** 50.5 mm

**Remarks:** none
STRESS - STRAIN CURVES

Failure Pattern

Test Data

Client: Posiva Oy
Order Number: 9651-08
Test: Uniaxial
Equipment: MT3 615

Load Control: Radial strain rate
Equivalent Loading Rate: 0.75 MPa/s
Test Date: 2008-12-18
Test Duration: 1.44 (h.min)

Specimen Data

ONK-PP68 - 71.47
Site: Olikuoto
Hole: ONK-PP68
Depth: 71.47 m
Rock Type: PGR

Length: 127.0 mm
Diameter: 50.5 mm
Saturated Density: 2610 kg/m³
Degree of Saturation: Saturated

Test Results

Compressive Strength: 95.5 MPa
Young's Modulus: 52.7 GPa
Poisson's Ratio: 0.22

Crack Initiation: 55.9 MPa
Crack Damage: 82.9 MPa
Failure Mode: shear failure

Remarks: none
STRESS - STRAIN CURVES

Failure Pattern

Test Data

Client: Posiva Oy  
Order Number: 9651-08  
Test: Uniaxial  
Equipment: MT3 615

Load Control: Radial strain rate  
Equivalent Loading Rate: 0.75 MPa/s  
Test Date: 2008-12-17  
Test Duration: 0.29 (h:min)

Specimen Data

Site: Olikuoto  
Hole: ONK-PP68  
Depth: 75.14 m  
Rock Type: VGN

Length: 126.9 mm  
Diameter: 50.2 mm  
Saturated Density: 2717 kg/m³  
Degree of Saturation: Saturated

Test Results

Compressive Strength: 87.9 MPa  
Young's Modulus: 55.4 GPa  
Poisson's Ratio: 0.23

Crack Initiation: 54.1 MPa  
Crack Damage: 77.7 MPa  
Failure Mode: shear failure

Remarks: none
**Test Data**

**Client:** Posiva Oy  
**Order Number:** 9651-08  
**Test:** Uniaxial  
**Equipment:** MT3 615  
**Load Control:** Radial strain rate  
**Equivalent Loading Rate:** 0.75 MPa/s  
**Test Date:** 2008-12-17  
**Test Duration:** 1.10 (h.min)

**Specimen Data**  
**Site:** Olikuoto  
**Hole:** ONK-PP68  
**Depth:** 75.63 m  
**Rock Type:** VGN  
**Length:** 127.1 mm  
**Diameter:** 50.3 mm  
**Saturated Density:** 2676 kg/m³  
**Degree of Saturation:** Saturated

**Test Results**

**Compressive Strength:** 93.5 MPa  
**Crack Initiation:** 63.1 MPa  
**Young's Modulus:** 65.1 GPa  
**Crack Damage:** 82.7 MPa  
**Poisson’s Ratio:** 0.17  
**Failure Mode:** mixed  
**Remarks:** none
**STRESS - STRAIN CURVES**

**Radial Strain** vs **Axial Strain**

**Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 815
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2008-12-18
- **Test Duration:** 0.27 (h:min)

**Specimen Data**
- **Site:** Olkiluoto
- **Hole:** ONK-PP68
- **Depth:** 79.34 m
- **Rock Type:** DGN
- **Length:** 127.3 mm
- **Diameter:** 50.4 mm
- **Saturated Density:** 2679 kg/m³
- **Degree of Saturation:** Saturated

**Test Results**
- **Compressive Strength:** 57.9 MPa
- **Young's Modulus:** 55.1 GPa
- **Poisson's Ratio:** 0.14
- **Crack Initiation:** 37.3 MPa
- **Crack Damage:** 50.8 MPa
- **Failure Mode:** shear failure
- **Remarks:** none
**Test Data**

<table>
<thead>
<tr>
<th>Client:</th>
<th>Posiva Oy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order Number:</td>
<td>9651-08</td>
</tr>
<tr>
<td>Test:</td>
<td>Uniaxial</td>
</tr>
<tr>
<td>Equipment:</td>
<td>MT3 815</td>
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<tr>
<td>Load Control:</td>
<td>Radial strain rate</td>
</tr>
<tr>
<td>Equivalent Loading Rate:</td>
<td>0.75 MPa/s</td>
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<tr>
<td>Test Date:</td>
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<td>Test Duration:</td>
<td>0.48 (h:min)</td>
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**Specimen Data**

<table>
<thead>
<tr>
<th>Site:</th>
<th>Olikuoto</th>
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<tbody>
<tr>
<td>Hole:</td>
<td>ONK-PP68</td>
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<tr>
<td>Depth:</td>
<td>82.76 m</td>
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<tr>
<td>Rock Type:</td>
<td>PGR</td>
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<tr>
<td>Length:</td>
<td>126.9 mm</td>
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<tr>
<td>Diameter:</td>
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<td>Saturated Density:</td>
<td>2625 kg/m³</td>
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<td>Degree of Saturation:</td>
<td>Saturated</td>
</tr>
</tbody>
</table>

**Test Results**

| Compressive Strength: | 125.7 MPa                          |
| Crack Initiation:     | 65.3 MPa                            |
| Young's Modulus:      | 64.8 GPa                            |
| Crack Damage:         | 100.3 MPa                           |
| Poisson's Ratio:      | 0.28                                 |
| Failure Mode:         | axial splitting                      |
| Remarks:              | none                                 |
**Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9651-08
- **Test:** Uniaxial
- **Equipment:** MT3 615

**Specimen Data**
- **Site:** Olikuoto
- **Hole:** ONK-PP68
- **Depth:** 83.07 m
- **Rock Type:** PGR

**Test Results**
- **Compressive Strength:** 126.7 MPa
- **Young's Modulus:** 59.7 GPa
- **Poisson's Ratio:** 0.27
- **Crack Initiation:** 66.1 MPa
- **Crack Damage:** 95.9 MPa
- **Failure Mode:** mixed

**Remarks:** shear failure with axial splitting, some spalling
Appendix 2. Photographs of the specimens before and after testing
(a) Before testing (2008-11-24)  (b) After testing (2008-12-22)

ONK-PP68 16.42

(a) Before testing (2008-11-24)  (b) After testing (2008-12-22)

ONK-PP68 16.78
(a) Before testing (2008-11-24)  (b) After testing (2008-12-22)

ONK-PP68 20.51

(a) Before testing (2008-11-24)  (b) After testing (2008-12-22)

ONK-PP68 31.32
(a) Before testing (2008-11-24)  
(b) After testing (2008-12-22)

ONK-PP68 35.64

(a) Before testing (2008-11-24)  
(b) After testing (2008-12-22)

ONK-PP68 38.89
(a) Before testing (2008-11-24)    (b) After testing (2008-12-22)

ONK-PP68 42.53

(a) Before testing (2008-11-24)    (b) After testing (2008-12-22)

ONK-PP68 42.88
(a) Before testing (2008-11-24)  
(b) After testing (2008-12-22)  

ONK-PP68 45.86

(a) Before testing (2008-11-24)  
(b) After testing (2008-12-22)  

ONK-PP68 53.44
(a) Before testing (2008-11-24)  (b) After testing (2008-12-22)

ONK-PP68 60.08

(a) Before testing (2008-11-24)  (b) After testing (2008-12-22)

ONK-PP68 63.76
(a) Before testing (2008-11-24)  (b) After testing (2008-12-22)

ONK-PP68 64.07

(a) Before testing (2008-11-24)  (b) After testing (2008-12-22)

ONK-PP68 67.28
(a) Before testing (2008-11-24)  
(b) After testing (2008-12-22)

ONK-PP68 67.62

(a) Before testing (2008-11-24)  
(b) After testing (2008-12-22)

ONK-PP68 71.09
(a) Before testing (2008-11-24)        (b) After testing (2008-12-22)

ONK-PP68 71.47

(a) Before testing (2008-11-24)        (b) After testing (2008-12-22)

ONK-PP68 75.14
(a) Before testing (2008-11-24)  (b) After testing (2008-12-22)

ONK-PP68 75.63

(a) Before testing (2008-11-24)  (b) After testing (2008-12-22)

ONK-PP68 79.34