ONKALO POSE Experiment -
Uniaxial Compressive Strength Testing Results:
Drill Core Samples from the Experimental Area

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May 2015
ONKALO POSE EXPERIMENT - UNIAXIAL COMPRESSIVE STRENGTH TESTING RESULTS: DRILL CORE SAMPLES FROM THE EXPERIMENTAL AREA

ABSTRACT

The stress-strain behaviour of rock samples was studied for a total of 15 uniaxial compression tests. Posiva Oy selected the samples from boreholes ONK-PP253, ONK-PP254 and ONK-PP260 from ONKALO underground rock characterization facility, located in Olkiluoto. The boreholes were drilled as part of Posiva's Olkiluoto Spalling Experiment (POSE). The samples obtained from these boreholes were classified into veined gneisses and coarse-grained pegmatitic granites depending on the geological structure of the samples. The diameter of the samples was nominally 51 mm. The specimen preparation and tests were carried out at the Laboratory of Rock Engineering, Aalto University, Finland. 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 94.0-121.8 MPa for coarse-grained pegmatitic granite samples and 46.1-93.3 MPa for veined gneiss samples.

Keywords: rock mechanics, uniaxial compression test, Olkiluoto, POSE.
ONKALO POSE-KOE - YKSIAKSIAALISTEN PURISTUMURTOKOEIDEN TULOKSET: KAIRAUSNÄYTTEET KOEALUEELTA

TIIVISTELMÄ


Avainsanat: kalliomekaniikka, yksiaksiaalinen puristusmurto, Olkiluoto, POSE.
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1 INTRODUCTION

The purpose of this document is to report the data collected from 15 uniaxial compression tests on rock samples obtained from boreholes ONK-PP253, ONK-PP254 and ONK-PP260. The boreholes are located in the third experimental niche of the ONKALO underground research facility. The uniaxial compression tests were carried out at the Laboratory of Rock Engineering in Aalto University School of Engineering located at Espoo, Finland. The compression tests were commissioned by Posiva Oy.

Uniaxial compression tests are used to determine the complete stress-strain curve for cylindrical intact rock core specimens.

The core samples were drilled from the third investigation niche (see Figure 1-1) in ONKALO, during April - July 2010 (Toropainen 2010). The holes were drilled as part of Posiva's Olkiluoto Spalling Experiment (POSE) inside the experiment hole ONK-EH1...3 perimeters (see Figures 1-2 and 1-3) which were later bored to the experiment hole diameter of 1.5 m (Valli et al. 2014). Selected core samples from Olkiluoto boreholes ONK-PP253, ONK-PP254 and ONK-PP260 were delivered to the laboratory on September 6, 2012. The test specimens were prepared during February and March 2013 and tested during April 2013. The specimens were photographed before, during and after the tests.

Processing and interpretation of the results was completed in April 2013.

Figure 1-1 Experimental area in the ONKALO underground facility.
Figure 1-2 The drillhole ONK-PP253 is located within the ONK-EH1 and ONK-PP254 within ONK-EH2 perimeter which were later bored. (Valli et al. 2014)

Figure 1-3 The drillhole ONK-PP260 is located within the ONK-EH3 perimeter which was later bored. (Valli et al. 2014)
2 TEST SPECIMENS

2.1 Selection of samples

Posiva Oy selected core samples for this study (Figure 2-1 and Table 2-1). The samples were classified into veined gneisses (VGN) and coarse-grained pegmatitic granites (PGR) (Toropainen 2010). The diameter of the samples was nominally 51 mm.

In the laboratory, the core samples were stored in room conditions at an average 22 °C temperature and 40 - 50% air humidity.

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, Romuvaara tonalite gneiss, Kivetty granite, Kivetty porphyritic granodiorite, Hästholmen pyterlite and Forsmark granitic rocks (Hakala & Heikkilä 1997a, Heikkilä & Hakala 1998a, Heikkilä & Hakala 1998b, Eloranta & Hakala 1998, Eloranta & Hakala 1999 and Hakala et al. 2005, Eloranta 2006, Eloranta 2010).

2.2.1 Specimen identification and tracking

Posiva Oy marked the borehole name and depth on each core sample. There were no downward arrows on the samples, but it was assumed that the downward direction was same as the text direction on the samples (from left to right in Figure 2-1).

An identification number (1-15) was marked on each core sample at the laboratory. During specimen preparation the same identification number was marked on remaining core parts. A longitudinal line with a tick-mark every centimetre was drawn on the core sample before cutting.

The test specimen naming system consists of the borehole name ‘ONK-PP253’ and the depth of the specimen with one centimetre accuracy. e.g. ‘312’. A file form was opened for each specimen (Appendix 1).

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.
Figure 2-1 The core samples from boreholes ONK-PP253, ONK-PP256 and ONK-PP260 before cutting. (P. Eloranta/Aalto ENG)

Table 2-1 Core samples from boreholes ONK-PP253, ONK-PP256 and ONK-PP260. (Average grain size and dip of foliation were estimated on actual test specimens.)

<table>
<thead>
<tr>
<th>Number</th>
<th>Hole</th>
<th>From (m)</th>
<th>To (m)</th>
<th>Rock type</th>
<th>Average grain size (mm)</th>
<th>Dip of foliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ONK-PP253</td>
<td>3.12</td>
<td>3.40</td>
<td>VGN</td>
<td>&lt; 1</td>
<td>30°</td>
</tr>
<tr>
<td>2</td>
<td>ONK-PP253</td>
<td>3.75</td>
<td>4.03</td>
<td>PGR</td>
<td>2 – 3</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>ONK-PP253</td>
<td>5.32</td>
<td>5.52</td>
<td>VGN</td>
<td>&lt; 1</td>
<td>~ 45°</td>
</tr>
<tr>
<td>4</td>
<td>ONK-PP253</td>
<td>5.90</td>
<td>6.36</td>
<td>VGN</td>
<td>&lt; 1</td>
<td>~ 55°</td>
</tr>
<tr>
<td>5</td>
<td>ONK-PP254</td>
<td>0.64</td>
<td>0.95</td>
<td>VGN</td>
<td>&lt; 1</td>
<td>~ 50°</td>
</tr>
<tr>
<td>6</td>
<td>ONK-PP254</td>
<td>1.93</td>
<td>2.12</td>
<td>PGR</td>
<td>2 – 3</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>ONK-PP254</td>
<td>2.68</td>
<td>2.84</td>
<td>PGR</td>
<td>2 – 3</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>ONK-PP254</td>
<td>2.84</td>
<td>3.18</td>
<td>PGR</td>
<td>4?</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>ONK-PP254</td>
<td>3.48</td>
<td>3.76</td>
<td>VGN</td>
<td>1</td>
<td>60°</td>
</tr>
<tr>
<td>10</td>
<td>ONK-PP254</td>
<td>5.15</td>
<td>5.45</td>
<td>VGN</td>
<td>&lt; 1</td>
<td>~ 45°</td>
</tr>
<tr>
<td>11</td>
<td>ONK-PP254</td>
<td>5.45</td>
<td>5.65</td>
<td>VGN</td>
<td>&lt; 1 and 2 (layers)</td>
<td>~ 45°</td>
</tr>
<tr>
<td>12</td>
<td>ONK-PP260</td>
<td>1.20</td>
<td>1.46</td>
<td>PGR</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>ONK-PP260</td>
<td>1.47</td>
<td>1.84</td>
<td>PGR</td>
<td>2 – 3</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>ONK-PP260</td>
<td>6.73</td>
<td>7.02</td>
<td>VGN</td>
<td>&lt; 1</td>
<td>55°</td>
</tr>
<tr>
<td>15</td>
<td>ONK-PP260</td>
<td>7.02</td>
<td>7.33</td>
<td>VGN</td>
<td>&lt; 1</td>
<td>65°</td>
</tr>
</tbody>
</table>
Figure 2-2 The core samples from boreholes ONK-PP253, ONK-PP256 and ONK-PP260 after cutting. (P. Eloranta/Aalto ENG)

Table 2-2 Test specimens from boreholes ONK-PP253, ONK-PP256 and ONK-PP260.

<table>
<thead>
<tr>
<th>Number</th>
<th>Specimen ID</th>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>Length/Diameter Ratio</th>
<th>Parallelism of ends (mm)</th>
<th>Straightness of sides (mm)</th>
<th>Density (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ONK-PP253-312</td>
<td>126.3</td>
<td>50.4</td>
<td>2.51</td>
<td>0.020</td>
<td>0.05</td>
<td>2770</td>
</tr>
<tr>
<td>2</td>
<td>ONK-PP253-387</td>
<td>126.4</td>
<td>50.5</td>
<td>2.50</td>
<td>0.015</td>
<td>0.05</td>
<td>2600</td>
</tr>
<tr>
<td>3</td>
<td>ONK-PP253-533</td>
<td>126.4</td>
<td>50.5</td>
<td>2.50</td>
<td>0.010</td>
<td>0.05</td>
<td>2770</td>
</tr>
<tr>
<td>4</td>
<td>ONK-PP253-621</td>
<td>126.4</td>
<td>50.5</td>
<td>2.50</td>
<td>0.010</td>
<td>&lt;0.05</td>
<td>2770</td>
</tr>
<tr>
<td>5</td>
<td>ONK-PP254-067</td>
<td>126.2</td>
<td>50.4</td>
<td>2.51</td>
<td>0.018</td>
<td>0.10</td>
<td>2760</td>
</tr>
<tr>
<td>6</td>
<td>ONK-PP254-198</td>
<td>126.4</td>
<td>50.5</td>
<td>2.50</td>
<td>0.008</td>
<td>0.05</td>
<td>2630</td>
</tr>
<tr>
<td>7</td>
<td>ONK-PP254-269</td>
<td>126.2</td>
<td>50.3</td>
<td>2.51</td>
<td>0.020</td>
<td>0.05</td>
<td>2630</td>
</tr>
<tr>
<td>8</td>
<td>ONK-PP254-287</td>
<td>126.2</td>
<td>50.3</td>
<td>2.51</td>
<td>0.019</td>
<td>0.05</td>
<td>2620</td>
</tr>
<tr>
<td>9</td>
<td>ONK-PP254-363</td>
<td>126.2</td>
<td>50.4</td>
<td>2.50</td>
<td>0.014</td>
<td>0.05</td>
<td>2750</td>
</tr>
<tr>
<td>10</td>
<td>ONK-PP254-530</td>
<td>126.2</td>
<td>50.4</td>
<td>2.51</td>
<td>0.018</td>
<td>0.05</td>
<td>2770</td>
</tr>
<tr>
<td>11</td>
<td>ONK-PP254-546</td>
<td>126.2</td>
<td>50.4</td>
<td>2.50</td>
<td>0.020</td>
<td>&lt;0.05</td>
<td>2730</td>
</tr>
<tr>
<td>12</td>
<td>ONK-PP260-133</td>
<td>125.8</td>
<td>50.3</td>
<td>2.50</td>
<td>0.005</td>
<td>0.30</td>
<td>2630</td>
</tr>
<tr>
<td>13</td>
<td>ONK-PP260-148</td>
<td>126.0</td>
<td>50.3</td>
<td>2.51</td>
<td>0.017</td>
<td>0.15</td>
<td>2640</td>
</tr>
<tr>
<td>14</td>
<td>ONK-PP260-687</td>
<td>126.2</td>
<td>50.4</td>
<td>2.50</td>
<td>0.012</td>
<td>0.05</td>
<td>2800</td>
</tr>
<tr>
<td>15</td>
<td>ONK-PP260-718</td>
<td>126.2</td>
<td>50.4</td>
<td>2.50</td>
<td>0.012</td>
<td>0.05</td>
<td>2770</td>
</tr>
</tbody>
</table>
2.2.3 Conformance on dimensional and shape tolerances

The length of a test specimen was determined by taking the average of three measurements. The diameter of the specimen was measured by averaging two diameters measured at right angles to each other close to the top, the mid-height and the bottom of the specimen. The length-to-diameter ratio was calculated. 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 ASTM D4543-08 standard and to the ISRM suggestions (Ulusay & Hudson 2007 p. 153, 225-226).

The laboratory-air-dry mass of all specimens was recorded and the average grain size was estimated, and if the specimen was foliated the dip of foliation was measured according to Figure 2-3.

![Figure 2-3 Determination of the dip of foliation.](image)

Test specimens with their dimensions and shape parameters after cutting and grinding are listed in Table 2-2.

All length dimensions were measured to 0.02 mm accuracy, and the mass of the samples to 0.05 gram accuracy.

2.2.4 Water saturation

The specimens were water-saturated using procedure described in SFS-EN 17355 standard in Chapter 7. The specimens were stored under water in a sample container with an average temperature of 23 °C for two weeks. The water-saturated surface-dry specimens were weighed before testing. The saturated density of the specimens is listed in Table 2-2.
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 are stored in the laboratory until they are 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, three averaging direct contact 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 (Figure 3-1). At the specimen ends, non-lubricated steel end caps are used.

The axial load is applied to the top end through a spherical seat in order to assure uniform load distribution. The applied load is measured with a 500 kN load cell.

Figure 3-1 Extensometers installed on a specimen. (P. Eloranta/Aalto ENG)
Table 3-1 Procedure for the uniaxial compression test.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
| 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 5.0 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 15 MPa  
  - Decrease axial load so that loading rate is 0.75 MPa/s until axial force is 1.0 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 50 MPa  
  - Change to radial strain rate control  
  - Increase radial strain corresponding to the initial elastic loading rate of 0.75 MPa/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 |

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.

A compact digital camera Canon Power Shot S10 set up on a tripod was used. Its charge-coupled device (CCD) sensor creates full-colour and black and white high-resolution images up to 1,600 x 1,200 pixels (2.1 megapixel). It offers a 2x zoom lens and a range of shooting modes. It uses Compact Flash type I and II memory cards.

All core samples were photographed in a core box before cutting and after cutting (Figures 2-1 and 2-2).
Each uniaxial compression test specimen was photographed before testing. The specimen was rotated clockwise (looking from top) 120 degrees between images A, B and C (Figure 3-2). Specimens were photographed dry and wet. On each photograph a QPcard 101 reference card with neutral white, gray and black patches and a scale was positioned alongside the specimen. No flash or photography lights were used.

Fully equipped test specimen was photographed on table and in the load frame before test was started. The specimen was photographed in the load frame immediately after test.

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

All original image files were stored on two separate external hard drives in addition to a 2 GB CompactFlash memory card.

### 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 (Appendix 1). The completed test information forms are not included in this report. They are stored in the laboratory.

The axial extensometer and the circumferential extensometer were calibrated on January 2012. Extensometer readings were checked with a 56 mm aluminium specimen before test series using the Young’s modulus and Poisson’s ratio as reference values (Figure 3-3). 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.
Figure 3-3 Uniaxial compression test extensometers on the reference aluminium specimen. (P. Eloranta/Aalto ENG)
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 3).

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).

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

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 1997b after Martin 1994).
5 RESULTS

5.1 Description and presentation of the specimens

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

Specimen failure is not visible in most specimens without close inspection with a magnifying glass or stereo microscope. Therefore the major failure fracture (or fractures) is marked with a yellow line on the photographs.

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 3.

Table 5-1 Summary of the results.

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>Peak strength (MPa)</th>
<th>Tangent Young's Modulus (GPa)</th>
<th>Poisson's ratio</th>
<th>Crack Initiation stress (MPa)</th>
<th>Crack Damage stress (MPa)</th>
<th>Secant Young's Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONK-PP253-312</td>
<td>75.3</td>
<td>42</td>
<td>0.29</td>
<td>41</td>
<td>63</td>
<td>41</td>
</tr>
<tr>
<td>ONK-PP253-387</td>
<td>110.0</td>
<td>55</td>
<td>0.32</td>
<td>59</td>
<td>84</td>
<td>46</td>
</tr>
<tr>
<td>ONK-PP253-533</td>
<td>70.3</td>
<td>46</td>
<td>0.24</td>
<td>40</td>
<td>62</td>
<td>43</td>
</tr>
<tr>
<td>ONK-PP253-621</td>
<td>73.6</td>
<td>58</td>
<td>0.29</td>
<td>42</td>
<td>65</td>
<td>58</td>
</tr>
<tr>
<td>ONK-PP254-067</td>
<td>77.2</td>
<td>47</td>
<td>0.33</td>
<td>43</td>
<td>56</td>
<td>46</td>
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<tr>
<td>ONK-PP254-198</td>
<td>101.1</td>
<td>63</td>
<td>0.25</td>
<td>54</td>
<td>93</td>
<td>51</td>
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<tr>
<td>ONK-PP254-269</td>
<td>115.6</td>
<td>66</td>
<td>0.28</td>
<td>61</td>
<td>100</td>
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<tr>
<td>ONK-PP254-287</td>
<td>94.0</td>
<td>59</td>
<td>0.27</td>
<td>50</td>
<td>76</td>
<td>44</td>
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<td>45</td>
<td>0.32</td>
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<td>55</td>
<td>0.28</td>
<td>56</td>
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<td>58</td>
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<td>ONK-PP254-546</td>
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<td>83</td>
<td>60</td>
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<tr>
<td>ONK-PP260-133</td>
<td>119.7</td>
<td>60</td>
<td>0.30</td>
<td>63</td>
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<td>121.8</td>
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<td>0.33</td>
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<td>45</td>
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<tr>
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<tr>
<td>ONK-PP260-718</td>
<td>55.0</td>
<td>44</td>
<td>0.32</td>
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<td>42</td>
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</tbody>
</table>
REFERENCES


APPENDICES

1 Test information form
2 Photographs of test specimens before and after testing
3 Stress-strain curves of uniaxial compression tests
## Appendix 1. Test information form

| Title: Test information sheet for uniaxial compression test of intact rock | Date: 28.2.2013 | Order: |
| Date: | 28.2.2013 | Order: |
| Author: Pekka Eloranta | Reference: - |
| Specimen ID: | |

### 1. Reception and arrival at the laboratory

| Date: | By: |
| Remarks: | |

### 2. Geological description of the specimen

| Date: | By: |
| Remarks: | |

### 3. Preparation of the specimen

#### Cutting:

| Equipment: | Date: |
| Remarks: | By: |

#### Grinding:

| Equipment: | Date: |
| Remarks: | By: |

### 4. Physical properties of the specimen

(tolerance limits are from ASTM D-4543-08 standard)

| Height (mm): | Average height (mm): |
| Diameter (mm): | Average diameter (mm): |
| Height/Diameter ratio: | |
| Mass (g): | Straightness (mm): |
| Perpendicularity (mm): | Parallellism (mm): |
| Remarks: none | Flatness (mm): |

### 5. Photographing the specimen before testing

| Date: | By: |
| Equipment: | |
| Filenames: | |
| Remarks: | |

### 6. Water-saturation of the specimen

| Start (t_0): | End: |
| Equipment: [Mettler PM4000, serial number N95274] | Saturated-submerged mass (g): |
| [Mettler PJ3600, serial number M88692] | Saturated-surface-dry mass (g): |
| Remarks: | |
Test information sheet for uniaxial compression test of intact rock

Date: 28.2.2013
Author: Pekka Eloranta
Reference: -
Specimen ID: 

7. Testing the specimen

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: 

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. Photographs of the specimens before and after testing

ONK-PP253 3.12

(a) Before testing (2013-03-18)
View 120°

(b) After testing (2013-04-11)
View 120°
(failure fractures marked with a yellow line)
(a) Before testing (2013-03-18)
View 120°

(b) After testing (2013-04-11)
View 120°
(failure fractures marked with a yellow line)
ONK-PP253 5.33

(a) Before testing (2013-03-18)
View 120°

(b) After testing (2013-04-11)
View 120°
(failure fracture marked with a yellow line)
(a) Before testing (2013-03-18)
   View 120°

(b) After testing (2013-04-11)
   View 120°
   (failure fracture marked with a yellow line)
(a) Before testing (2013-03-18)
View 120°

(b) After testing (2013-04-11)
View 120°
(failure fracture marked with a yellow line)
(a) Before testing (2013-03-18)
View 240°

(b) After testing (2013-04-11)
View 240°
(failure fracture marked with a yellow line)
(a) Before testing (2013-03-18)
View 120°

(b) After testing (2013-04-11)
View 120°
(failure fractures marked with a yellow line)
ONK-PP254 2.87

(a) Before testing (2013-03-18)
View 240°

(b) After testing (2013-04-11)
View 240°
(failure fractures marked with a yellow line)
(a) Before testing (2013-03-18)  
View 240°

(b) After testing (2013-04-11)  
View 240°  
(failure fracture marked with a yellow line)
ONK-PP254 5.30

(a) Before testing (2013-03-18)
   View 240°

(b) After testing (2013-04-11)
   View 240°
   (failure fracture marked with a yellow line)
(a) Before testing (2013-03-18)
View 240°

(b) After testing (2013-04-11)
View 240°
(failure fracture marked with a yellow line)
(a) Before testing (2013-03-18)
View 240°

(b) After testing (2013-04-11)
View 240°
(failure fractures marked with a yellow line)
ONK-PP260 1.48

(a) Before testing (2013-03-18)  
View 240°

(b) After testing (2013-04-11)  
View 240°  
(failure fractures marked with a yellow line)
(a) Before testing (2013-03-18)
View 0°

(b) After testing (2013-04-11)
View 0°
(failure fracture marked with a yellow line)
(a) Before testing (2013-03-18)
View 120°

(b) After testing (2013-04-11)
View 120°
(failure fracture marked with a yellow line)
Appendix 3. Stress-strain curves of uniaxial compression tests

Uniaxial compression test of the specimen ONK-PP253-3.12

![Stress-strain curves graph](image)

**Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9514-12
- **Test:** Uniaxial
- **Equipment:** MTS 815
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2013-04-04
- **Test Duration:** 0:22 (h:min)

**Specimen Data**
- **Site:** Olkiluoto
- **Hole:** ONK-PP253
- **Depth:** 3.12 m
- **Rock Type:** VGN
- **Length:** 126.3 mm
- **Diameter:** 50.4 mm
- **Saturated Density:** 2770 kg/m³
- **Degree of Saturation:** Saturated

**Test Results**
- **Compressive Strength:** 75.3 MPa
- **Crack Initiation:** 40.6 MPa
- **Young’s Modulus:** 42.4 GPa
- **Crack Damage:** 62.8 MPa
- **Poisson’s Ratio:** 0.29
- **Failure Mode:** shear failure
- **Remarks:** dip of foliation 30 degrees
Uniaxial compression test of the specimen ONK-PP253-3.87

STRESS - STRAIN CURVES

Failure Pattern

Test Data
- Client: Posiva Oy
- Load Control: Radial strain rate
- Order Number: 9514-12
- Equivalent Loading Rate: 0.75 MPa/s
- Test: Uniaxial
- Test Date: 2013-04-09
- Equipment: MTS 815
- Test Duration: 1:21 (h:min)

Specimen Data ONK-PP253-387
- Site: Olkiluoto
- Length: 126.4 mm
- Hole: ONK-PP253
- Diameter: 50.5 mm
- Depth: 3.87 m
- Saturated Density: 2600 kg/m³
- Rock Type: PGR
- Degree of Saturation: Saturated

Test Results
- Compressive Strength: 110.0 MPa
- Crack Initiation: 59.4 MPa
- Young’s Modulus: 55.2 GPa
- Crack Damage: 83.8 MPa
- Poisson’s Ratio: 0.32
- Failure Mode: axial splitting
- Remarks: none
Uniaxial compression test of the specimen ONK-PP253-5.33

**STRESS - STRAIN CURVES**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9514-12
- **Test:** Uniaxial
- **Equipment:** MTS 815
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2013-04-05
- **Test Duration:** 0:17 (h:min)

**Specimen Data**
- **Site:** Olkiluoto
- **Hole:** ONK-PP253
- **Depth:** 5.33 m
- **Rock Type:** VGN
- **Length:** 126.4 mm
- **Diameter:** 50.5 mm
- **Saturated Density:** 2770 kg/m³
- **Degree of Saturation:** Saturated

**Test Results**
- **Compressive Strength:** 70.3 MPa
- **Crack Initiation:** 40.1 MPa
- **Young’s Modulus:** 45.6 GPa
- **Crack Damage:** 61.6 MPa
- **Poisson’s Ratio:** 0.24
- **Failure Mode:** shear failure
- **Remarks:** dip of foliation about 45 degrees
Uniaxial compression test of the specimen ONK-PP253-6.21

**STRESS - STRAIN CURVES**

<table>
<thead>
<tr>
<th><strong>Radial Strain</strong></th>
<th><strong>Axial Strain</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>-0.1%</td>
<td>-0.1%</td>
</tr>
<tr>
<td>-0.2%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>-0.3%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>-0.4%</td>
<td>-0.4%</td>
</tr>
</tbody>
</table>

**Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9514-12
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test:** Uniaxial
- **Test Date:** 2013-04-05
- **Equipment:** MTS 815
- **Test Duration:** 0:15 (h:min)

**Specimen Data**
- **Site:** Olkiluoto
- **Hole:** ONK-PP253
- **Depth:** 6.21 m
- **Rock Type:** VGN
- **Length:** 126.4 mm
- **Diameter:** 50.5 mm
- **Saturated Density:** 2770 kg/m³
- **Degree of Saturation:** Saturated

**Test Results**
- **Compressive Strength:** 73.6 MPa
- **Young's Modulus:** 57.6 GPa
- **Poisson's Ratio:** 0.29
- **Crack Initiation:** 41.7 MPa
- **Crack Damage:** 64.5 MPa
- **Failure Mode:** shear failure
- **Remarks:** dip of foliation 55 degrees
Uniaxial compression test of the specimen ONK-PP254-0.67

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9514-12
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test:** Uniaxial
- **Test Date:** 2013-04-04
- **Equipment:** MTS 815
- **Test Duration:** 0:30 (h:min)

**Specimen Data**
- **Site:** Olkiluoto
- **Length:** 126.2 mm
- **Hole:** ONK-PP254
- **Diameter:** 50.4 mm
- **Depth:** 0.67 m
- **Saturated Density:** 2760 kg/m³
- **Rock Type:** VGN
- **Degree of Saturation:** Saturated

**Test Results**
- **Compressive Strength:** 77.2 MPa
- **Crack Initiation:** 42.7 MPa
- **Young’s Modulus:** 47.3 GPa
- **Crack Damage:** 55.7 MPa
- **Poisson’s Ratio:** 0.33
- **Failure Mode:** shear failure
- **Remarks:** dip of foliation about 60 degrees
Uniaxial compression test of the specimen ONK-PP254-198

**STRESS - STRAIN CURVES**

**Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9514-12
- **Test:** Uniaxial
- **Equipment:** MTS 815
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2013-04-09
- **Test Duration:** 0:32 (h:min)

**Specimen Data**
- **ONK-PP254-198**
  - **Site:** Olkiluoto
  - **Hole:** ONK-PP254
  - **Depth:** 1.98 m
  - **Rock Type:** PGR
  - **Length:** 126.4 mm
  - **Diameter:** 50.5 mm
  - **Saturated Density:** 2630 kg/m³
  - **Degree of Saturation:** Saturated

**Test Results**
- **Compressive Strength:** 101.1 MPa
- **Crack Initiation:** 53.8 MPa
- **Young’s Modulus:** 62.6 GPa
- **Crack Damage:** 93.0 MPa
- **Poisson’s Ratio:** 0.25
- **Failure Mode:** shear failure
- **Remarks:** none
Uniaxial compression test of the specimen ONK-PP254-2.69

**STRESS - STRAIN CURVES**

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<th>Axial Stress (MPa)</th>
<th>Radial Strain</th>
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<td>140</td>
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<tr>
<td>120</td>
<td>0.3%</td>
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<tr>
<td>100</td>
<td>0.2%</td>
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<tr>
<td>80</td>
<td>0.1%</td>
</tr>
<tr>
<td>60</td>
<td>0.0%</td>
</tr>
<tr>
<td>40</td>
<td>-0.1%</td>
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<tr>
<td>20</td>
<td>-0.2%</td>
</tr>
<tr>
<td>0</td>
<td>-0.3%</td>
</tr>
</tbody>
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**Failure Pattern**

**Test Data**

- **Client:** Posiva Oy
- **Load Control:** Radial strain rate
- **Order Number:** 9514-12
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test:** Uniaxial
- **Test Date:** 2013-04-09
- **Equipment:** MTS 815
- **Test Duration:** 0:40 (h:min)

**Specimen Data**

- **Site:** Olkiluoto
- **Length:** 126.2 mm
- **Hole:** ONK-PP254
- **Diameter:** 50.3 mm
- **Depth:** 2.69 m
- **Saturated Density:** 2630 kg/m³
- **Rock Type:** PGR
- **Degree of Saturation:** Saturated

**Test Results**

- **Compressive Strength:** 115.6 MPa
- **Crack Initiation:** 60.7 MPa
- **Young's Modulus:** 66.1 GPa
- **Crack Damage:** 100.0 MPa
- **Poisson's Ratio:** 0.28
- **Failure Mode:** shear failure
- **Remarks:** none
Uniaxial compression test of the specimen ONK-PP254-2.87

STRESS - STRAIN CURVES

Axial Stress (MPa)
Radial Strain
Axial Strain
Failure Pattern

Test Data
Client: Posiva Oy
Order Number: 9514-12
Test: Uniaxial
Equipment: MTS 815
Load Control: Radial strain rate
Equivalent Loading Rate: 0.75 MPa/s
Test Date: 2013-04-09
Test Duration: 1:04 (h:min)

Specimen Data ONK-PP254-287
Site: Olkiluoto
Hole: ONK-PP254
Depth: 2.87 m
Rock Type: PGR
Length: 126.2 mm
Diameter: 50.3 mm
Saturated Density: 2620 kg/m³
Degree of Saturation: Saturated

Test Results
Compressive Strength: 94.0 MPa
Young's Modulus: 59.0 GPa
Poisson’s Ratio: 0.27
Crack Initiation: 50.3 MPa
Crack Damage: 75.8 MPa
Failure Mode: mixed
Remarks: none
Uniaxial compression test of the specimen ONK-PP254-3.63

**STRESS - STRAIN CURVES**

- **Axial Stress (MPa)**
- **Radial Strain**
- **Axial Strain**

**Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9514-12
- **Test:** Uniaxial
- **Equipment:** MTS 815

**Equivalent Loading Rate:** 0.75 MPa/s
**Test Date:** 2013-04-05
**Test Duration:** 0:14 (h:min)

**Specimen Data**
- **Site:** Olkiluoto
- **Hole:** ONK-PP254
- **Depth:** 3.63 m
- **Rock Type:** VGN

**Length:** 126.2 mm
**Diameter:** 50.4 mm
**Saturated Density:** 2750 kg/m³
**Degree of Saturation:** Saturated

**Test Results**
- **Compressive Strength:** 65.6 MPa
- **Young's Modulus:** 44.6 GPa
- **Poisson's Ratio:** 0.32
- **Crack Initiation:** 34.9 MPa
- **Crack Damage:** 52.2 MPa
- **Failure Mode:** shear failure

**Remarks:** dip of foliation 60 degrees
Uniaxial compression test of the specimen ONK-PP254-5.30

**STRESS - STRAIN CURVES**

**Failure Pattern**

**Test Data**
- **Client:** Posiva Oy
- **Order Number:** 9514-12
- **Test:** Uniaxial
- **Equipment:** MTS 815

**Equivalent Loading Rate:** 0.75 MPa/s
**Test Date:** 2013-04-05
**Test Duration:** 0:16 (h:min)

**Specimen Data**
- **Site:** Olkiluoto
- **Hole:** ONK-PP254
- **Depth:** 5.30 m
- **Rock Type:** VGN

**Length:** 126.2 mm
**Diameter:** 50.4 mm
**Saturated Density:** 2770 kg/m³
**Degree of Saturation:** Saturated

**Test Results**
- **Compressive Strength:** 93.3 MPa
- **Young's Modulus:** 55.2 GPa
- **Poisson's Ratio:** 0.28

**Crack Initiation:** 55.7 MPa
**Crack Damage:** 81.8 MPa
**Failure Mode:** shear failure

**Remarks:** dip of foliation about 45 degrees
### Test Data

<table>
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<tr>
<th>Client:</th>
<th>Posiva Oy</th>
<th>Load Control:</th>
<th>Radial strain rate</th>
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<tbody>
<tr>
<td>Order Number:</td>
<td>9514-12</td>
<td>Equivalent Loading Rate:</td>
<td>0.75 MPa/s</td>
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<tr>
<td>Test:</td>
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<tr>
<td>Equipment:</td>
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### Specimen Data

<table>
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<td>Hole:</td>
<td>ONK-PP254</td>
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<tr>
<td>Depth:</td>
<td>5.46 m</td>
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<tr>
<td>Rock Type:</td>
<td>VGN</td>
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### Test Results

<table>
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<tr>
<th>Test Results</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength:</td>
<td>85.5 MPa</td>
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<tr>
<td>Crack Initiation:</td>
<td>48.9 MPa</td>
</tr>
<tr>
<td>Young's Modulus:</td>
<td>60.7 GPa</td>
</tr>
<tr>
<td>Crack Damage:</td>
<td>83.0 MPa</td>
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<tr>
<td>Poisson's Ratio:</td>
<td>0.25</td>
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<tr>
<td>Failure Mode:</td>
<td>shear failure</td>
</tr>
</tbody>
</table>

### Remarks

- dip of foliation about 45 degrees
Uniaxial compression test of the specimen ONK-PP260-133

**STRESS - STRAIN CURVES**

**Axial Stress (MPa)**

**Radial Strain**

**Axial Strain**

**Failure Pattern**

**Test Data**

- **Client:** Posiva Oy
- **Order Number:** 9514-12
- **Test:** Uniaxial
- **Equipment:** MTS 815
- **Load Control:** Radial strain rate
- **Equivalent Loading Rate:** 0.75 MPa/s
- **Test Date:** 2013-04-10
- **Test Duration:** 0:48 (h:min)

**Specimen Data**

- **Site:** Olkiluoto
- **Hole:** ONK-PP260
- **Depth:** 1.33 m
- **Rock Type:** PGR
- **Length:** 125.8 mm
- **Diameter:** 50.3 mm
- **Saturated Density:** 2630 kg/m³
- **Degree of Saturation:** Saturated

**Test Results**

- **Compressive Strength:** 119.7 MPa
- **Crack Initiation:** 63.2 MPa
- **Young's Modulus:** 59.7 GPa
- **Crack Damage:** 91.8 MPa
- **Poisson’s Ratio:** 0.30
- **Failure Mode:** axial splitting
- **Remarks:** none
Uniaxial compression test of the specimen ONK-PP260-1.48

STRESS - STRAIN CURVES

Axial Stress (MPa)
Radial Strain
Axial Strain
Failure Pattern

Test Data
Client: Posiva Oy
Order Number: 9514-12
Test: Uniaxial
Equipment: MTS 815

Load Control: Radial strain rate
Equivalent Loading Rate: 0.75 MPa/s
Test Date: 2013-04-10
Test Duration: 1:13 (h:min)

Specimen Data
ONK-PP260-148

Site: Olkiluoto
Hole: ONK-PP260
Depth: 1.48 m
Rock Type: PGR

Length: 126.0 mm
Diameter: 50.3 mm
Saturated Density: 2640 kg/m³
Degree of Saturation: Saturated

Compressive Strength: 121.8 MPa
Young’s Modulus: 61.0 GPa
Poisson’s Ratio: 0.33

Crack Initiation: 63.5 MPa
Crack Damage: 82.5 MPa
Failure Mode: axial splitting
Remarks: none
Uniaxial compression test of the specimen ONK-PP260-6.87

STRESS - STRAIN CURVES

Failure Pattern

Test Data
Client: Posiva Oy
Order Number: 9514-12
Test: Uniaxial
Equipment: MTS 815

Load Control: Radial strain rate
Equivalent Loading Rate: 0.75 MPa/s
Test Date: 2013-04-04
Test Duration: 0:18 (h:min)

Specimen Data
Site: Olkiluoto
Hole: ONK-PP260
Depth: 6.87 m
Rock Type: VGN

Length: 126.2 mm
Diameter: 50.4 mm
Saturated Density: 2800 kg/m³
Degree of Saturation: Saturated

Test Results
Compressive Strength: 46.1 MPa
Young's Modulus: 47.9 GPa
Poisson's Ratio: 0.24
Crack Initiation: 27.6 MPa
Crack Damage: 46.1 MPa
Failure Mode: shear failure
Remarks: dip of foliation 55 degrees
Uniaxial compression test of the specimen ONK-PP260-7.18

STRESS - STRAIN CURVES

Axial Stress (MPa) vs. Radial Strain and Axial Strain

Failure Pattern

Test Data
- Client: Posiva Oy
- Load Control: Radial strain rate
- Equivalent Loading Rate: 0.75 MPa/s
- Order Number: 9514-12
- Test: Uniaxial
- Test Date: 2013-04-04
- Equipment: MTS 815
- Test Duration: 0:10 (h:min)

Specimen Data
- ONK-PP260-718
- Site: Olkiluoto
- Length: 126.2 mm
- Hole: ONK-PP260
- Diameter: 50.4 mm
- Depth: 7.18 m
- Saturated Density: 2770 kg/m³
- Rock Type: VGN
- Degree of Saturation: Saturated

Test Results
- Compressive Strength: 55.0 MPa
- Crack Initiation: 30.8 MPa
- Young’s Modulus: 44.4 GPa
- Crack Damage: 41.5 MPa
- Poisson’s Ratio: 0.32
- Failure Mode: shear failure
- Remarks: dip of foliation 65 degrees