P-04-185

Oskarshamn site investigation

Drill hole: KSH01A

The normal stress and shear tests on joints

Panayiotis Chryssanthakis
Norwegian Geotechnical Institute

March 2004

Reviewed by Toralv Berre

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1651-4416
SKB P-04-185

Oskarshamn site investigation

Drill hole: KSH01A

The normal stress and shear tests on joints

Panayiotis Chryssanthakis
Norwegian Geotechnical Institute

March 2004

Reviewed by Toralv Berre

Keywords: Rock mechanics, Joint test, Normal and shear behaviour, Normal and shear displacement, Peak shear stress, Residual shear stress.

Abstract

On behalf of Swedish Nuclear & Waste Management Co (SKB), the Norwegian Geotechnical Institute (NGI) has carried out seven direct shear tests on joints from borehole KSH01A. The main objective of this study has been to compare these results with the results of similar tests performed by Swedish National Testing and Research Institute (SP), in Borås Sweden.

The tested specimen was of Fine-grained diorite and Quartz monozodiorite. They were specially prepared in a hard epoxy mix in order to fit the direct shear apparatus at NGI, which can take specimens up to 80 mm in diameter and 55 mm in height. The specimens were tested with shear displacements that varied from 3 to 9 mm. The specimens were subjected to three normal stress levels: 0.5, 5.0 and 20.0 MPa. All specimens were tested in natural dry condition at room temperature (i.e. at about 19° C) and according to ISRM standards /1981/ for direct shear testing.

The mean value of the peak shear stress obtained is 1.56 MPa for the normal stress level of 0.5 MPa, 4.56 MPa for the normal stress level of 5.0 MPa and 15.35 MPa for the normal stress level of 20 MPa.

Contents

1 Introduction

This document reports the data collected by site investigation, which is one of the activities performed as part of the site investigation at Simpevarp. The work was carried out in accordance with activity plan AP PF 400-04-05 (SKB´s internal controlling document) and method description MD 1900.005e version 1.9 (SKB´s internal controlling document).

Specimens from borehole KSH01A, see Figure 1-1, were taken from the Simpevarp site on 13 May 2003 by SKB and Swedish National Testing and Research Institute (SP). The Field Note number in SKB´s database is FN 96. The specimens were taken from four levels in the rock core: level 1 between 299 and 306 m, level 2 between 399 and 415 m, level 3 between 479 and 497 m, and level 4 between 703 and 713.

The rock cores were transported by SP from Simpevarp and arrived to SP 14 May 2003. The cores were marked and cut in SP laboratory. Seven specimens (joints), from level 3 and 4, were send to NGI for direct shear testing, in 2 February 2004. The specimens were tested in accordance to ISRM standards (1981) for direct shear testing.

All tests were performed at the rock mechanics laboratory of the Norwegian Geotechnical Institute (NGI), during March 2004, by Panayiotis Chryssanthakis with Toralv Berre as responsible for the calibration of the equipment and the quality assurance of the performed work. Technical personnel that participated in different stages of the direct shear tests were Pawel Jankowski, Sven Vanbæk and James Oloka.

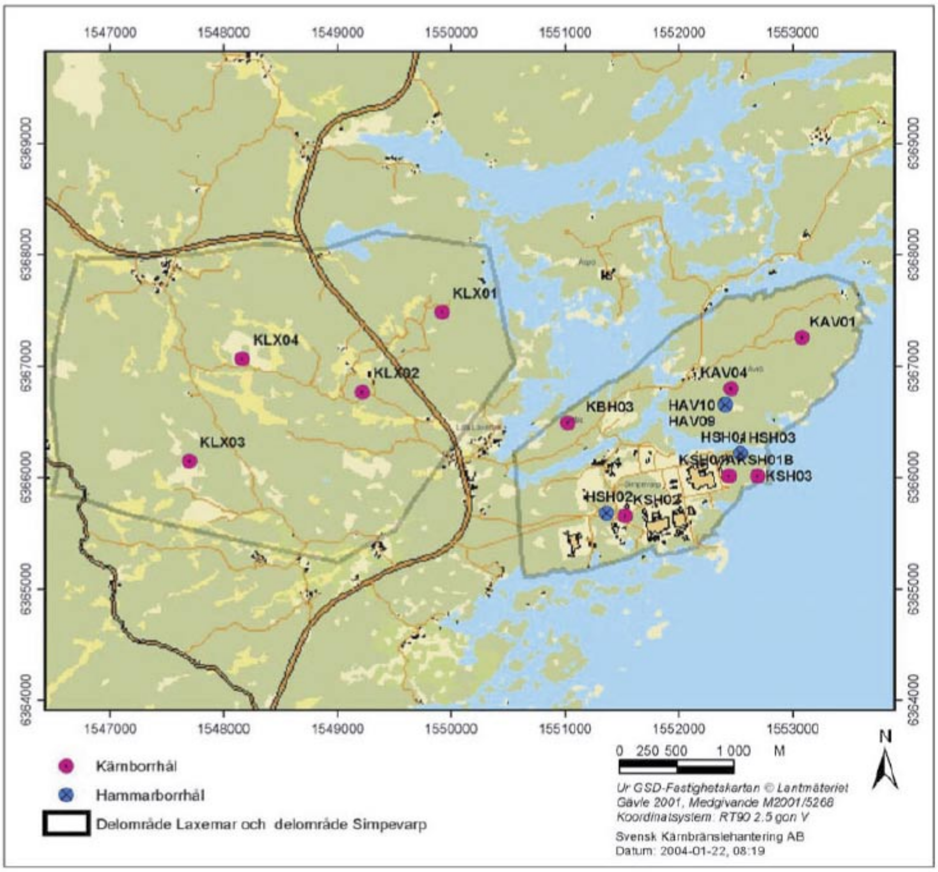


Figure 1-1. *Map over the investigation site.*

2 Objective and scope

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

The nature of direct shear tests on natural fractures is such, that there do not exist two exactly identical specimens. Each specimen is unique. This means that comparison of the results with other laboratories should be in terms of tendency lines. The choice of test specimens has been ruled by the two following facts:

- The comparison of test results is limited to the dominating rock types in borehole KSH01A and the most representative out of these again.
- The testing is concentrated at a representative depth and several normal stress levels are applied on each test specimen.

The results are also used in the rock mechanical model, which will be established for the candidate area selected for site investigations at Simpevarp

3 Equipment

3.1

The direct shear test apparatus (DST), see Figure 3-1, for high stresses was designed and built at NGI in cooperation with the department of Geology University of Oslo for testing un-cemented sands at high stresses /Kjeldstad et. al. 2003/. A soil or rock specimen to be tested in this apparatus can have diameter up to 80 mm (i.e. a cross section area of 50 cm^2) and a thickness up to about 55 mm. Drainage can take place through filter disks at top and bottom of the specimen, and P and S-wave velocities can be measured. The following loads can be applied to the specimen through actuators fixed to the reaction frame and driven by electronically controlled hydraulic pumps:

Maximum vertical load = 275 kN,
Maximum horizontal load = 184 kN.

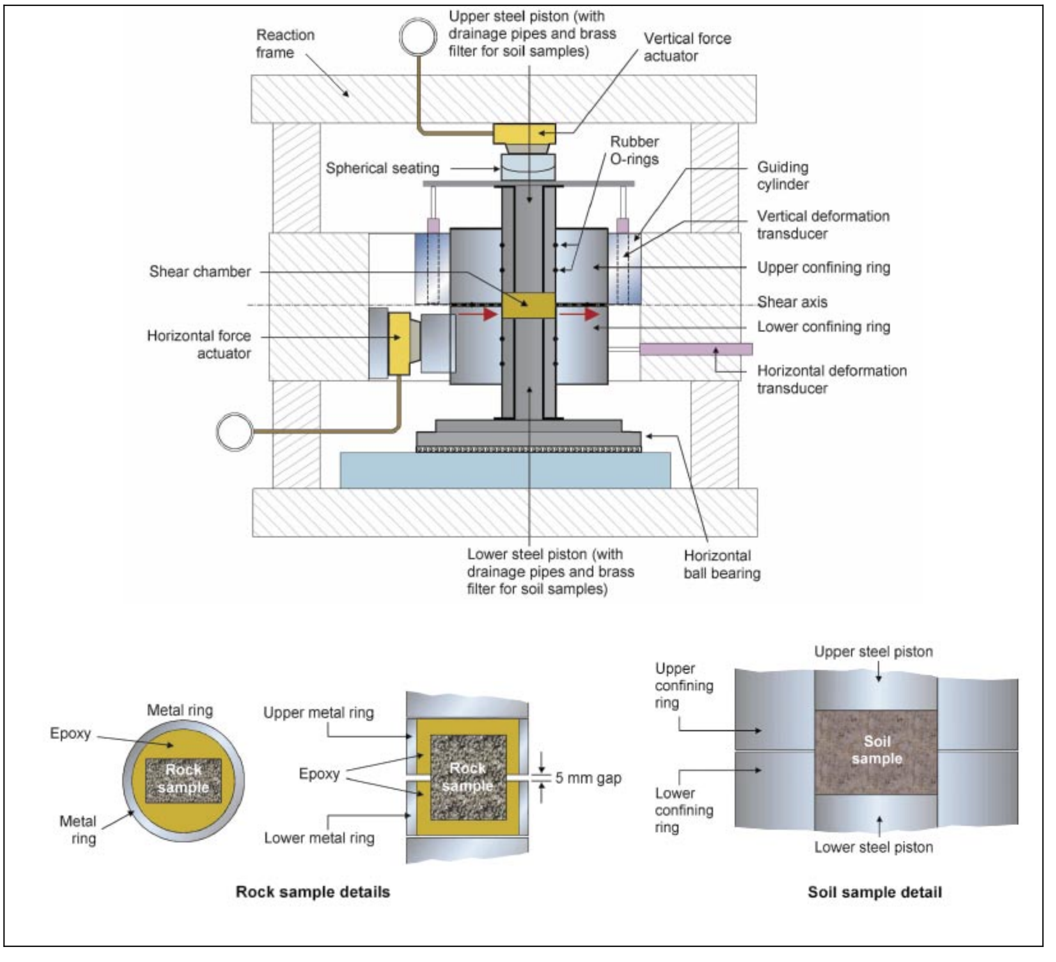


Figure 3-1. *Principle sketch showing a vertical cross-section through the NGI direct shear test apparatures (DST) for high stresses. Rock sample details shows how the rock sample is mounted in epoxy and metal rings before it is placed in the shear chamber. The diameter of the chamber is 80 mm. Maximum vertical and horizontal loads that can be applied to the rock sample are 275 and 184 kN respectively. Maximum shear displacement is about 9-10 mm.*

The maximum travels (strokes) of the vertical and the horizontal actuators are 16 and 11 mm, respectively. The filter disk at the top and the bottom are fixed to an upper and a lower piston, respectively. These pistons slide inside an upper and a lower confining ring. The two confining rings meet each other at middle height of the specimen and shearing takes place by moving (by the horizontal actuator) the lower confining ring horizontally while the upper confining ring is held back by a guiding cylinder fixed to the reaction frame (see Figure 3-1). Thus shearing takes place in the plane between the upper and the lower confining rings. The lower piston, which follows the lower confining ring during shearing, rests against a horizontal ball bearing which allows the horizontal movement of the lower piston during the shearing. The limitation of the vertical load (275 kN) is the maximum vertical load that can be applied to this bearing. Vertical and horizontal deformations (i.e. shear deformations) of the specimen are measured by electronic sensors (LVDT s). The vertical deformation sensors are mounted to a bracket, which is fixed to the lower steel piston (this bracket is not shown in Figure 3-1). The horizontal deformation sensor is fixed to the reaction frame.

4 Execution

The work was carried out in accordance with activity plan AP PF 400-04-05 (SKB`s internal controlling document) and method description MD 1900.005e version 1.9 (SKB`s internal controlling document).

Rock specimens are normally tested as follows:

1) The rock specimen is cast in epoxy inside two metal rings with the same outer diameter as the inner diameter of the confining rings (see Figure 4-1). For square specimens, the side length is limited to about 50 mm. At the middle height of the specimen there is a gap in the epoxy typically about 5 mm high where shearing of the specimen can take place. The epoxy covers both top and bottom of the specimen so that drainage from the specimen only can take place through the mid-height gap. The SKB tests were tested in dry condition and no drainage was needed. The whole set-up (including metal rings, epoxy and rock specimen) is placed in the compartment where the soil specimen is placed for soil testing.

2) If very large horizontal deformations are imposed, a Teflon ring of the same thickness as the height of the gap around the rock specimen may be placed between the upper and the lower confining rings to secure that the confining rings do not get stuck in the rock specimens at large deformations. To achieve this, the inner diameter of the Teflon ring must be larger than the inner diameter of the confining rings (see Figure 3-1). (The Teflon ring was not needed for the SKB tests).

The deformation sensors were set to zero deformation at a vertical stress level of 0.5 MPa.

The specimens were first subject to two normal loading cycles from 0.5 to 10.0 MPa. For each cycle, the normal stress was increased from 0.5 MPa up to 10.0 MPa and the decreased back to 0.5 MPa. Shearing was done at 3 different levels of normal stress. After the shearing displacement had taken place (at each normal stress level), it was suggested that the joints should be repositioned in their original positions before the new normal stress level was applied and the new shearing displacement began. After communication between NGI and SKB it was agreed upon not to reposition the joints after each normal stress level but to continue the shearing displacement for about 3 mm at each stress level. The maximum shearing length in the NGI apparatus is 9 mm. However in practice it proved to be difficult to determine residual shear strengths for each of the three shearing stages over only 9 mm. The final shearing lengths were therefore as follows:

~ 3 mm for loading cycle B,

~ 5.7 mm for loading cycle C

~ 9 mm, reposition of specimen to original position, for loading cycle D.

The specimens were finally tested according to Table 4-1

Table 4-1. Overview over the loading program for the DST tests.

Loading cycle	Normal stress during shearing	Comments	Plots
A		Normal loading of the joint from 0.5 to 10.0 MPa, 2 load cycles	Vertical stress vs. vertical displacement
B	σ_n = 0.5 MPa	Shearing until peak shear stress occurs and residual shear stress is clearly defined. Total shearing of about 3 mm Unloading of shear stress	Shear stress vs. shear displacement and vertical displacement vs. shear displacement
C	σ_n = 5.0 MPa	Shearing until peak shear stress occur and residual shear stress is clearly defined. Total shearing of about 5.7 mm (continuation from the 3 mm above) Unloading of shear stress	Same as B
D	σ_n = 20.0 MPa	Joint placed in original position, thereafter is sheared for about 9 mm. Final unloading	Same as B

The LVDTs, both for vertical deformation and for shear displacement were zeroed after the specimens had been loaded to 0.5 MPa vertical stress. A correction factor is added in the calculations for the effective joint area that is continuously changing while shearing. After the first shearing length is completed, the joint is placed again (pulled back) in its original position without blowing away the shear particles, "dust" that have been produced.

4.1 Description of the samples

The tested specimens were of Fine-grained diorite and Quartz monozodiorite, see Table 4-2. They were cut and specially prepared in a hard epoxy mix in order to fit the direct shear apparatus at NGI. All specimens were tested in natural dry conditions (i.e. no attempt was made to wet or dry the specimens, except that water coming in contact with the specimens during the cutting process and wiped away). No attempt was made to prevent evaporation from the specimens. In other words, the specimens were tested natural dry conditions at room temperature (i.e at about 19° C and roughly 25% relative humidity).

The test specimens from KSH01A are listed in the table below. A more detailed geological description of the joints is given in SKB mapping (Boremap) and database Sicada (FN 96).

Table 4-2. Overview over the tested specimens.

Borehole	Depth (m)	ID number	NGI test No.	Rock type	Joint set No *	Mineralsation	Joint Roughness
KSH01A	483.54	S01-117-13	DST205	Fine-grained diorite	Joint set 1	Chlorite calcite	Planar
KSH01A	485.93	S01-117-15	DST206	Fine-grained diorite	Joint set 2	Chlorite calcite	Planar
KSH01A	488.87	S01-117-17	DST207	Fine-grained diorite	Joint set 1	Chlorite calcite	Planar, slightly stepped
KSH01A	492.83	S01-117-19	DST208	Fine-grained diorite	Joint set 1	Chlorite calcite	Planar, slightly rough
KSH01A	495.27	S01-117-21	DST209	Fine-grained diorite	Joint set 2	Chlorite calcite	Planar
KSH01A	497.87	S01-117-23	DST210	Fine-grained diorite	Joint set 3	Chlorite calcite	Planar
KSH01A	709.61	S01-117-28	DST217	Quartz monozo-diorite	Joint set 1	Chlorite calcite	Planar

* The joint set number depends on the angle of intersection between the joint plane and the borehole axis and is given in Table 4-3 below.

Table 4-3. Correlation of the joint set number and the intersection angle between the joint plane and the borehole axis.

Joint set number	Angle of intersection in degrees
Set 1 (steep joints)	0-30°
Set 2 (ca 45 degrees joints)	30-60°
Set 3 (sub-horizontal joints)	60-90°

4.2 Testing

Several calibration tests were carried out by the end of February and until the beginning of March 2004. These tests were run in order to be able to correct the test results for false deformations. A steel specimen with the same shape and dimensions as a test specimen with a joint at an angle of about 30 degrees w.r.t the borehole axis (which is approximately the average angle of the tested specimens) was used for calibration purposes (see Figure 4-1). The epoxy mix used to fix the steel specimen to the metal ring was a mixture of dolomite powder and epoxy. The compressive strength of the epoxy mix is according to the manufacturer, 90 MPa. After consulting the manufacturer and in order to be able to increase the strength, more dolomite powder was added to the epoxy mix. However if too much dolomite is added, the epoxy mixture will be too stiff for the casting process to be successful. Different epoxy mixtures were tried. The same loading path as the one followed during the tests on rock was applied to the specimen. The results of the final test on the steel specimen are shown in Figures 4-2 and 4-3 below.

The corrections for false deformations used to calculate vertical and horizontal deformations are based on simplified versions of the observed curves shown in Figures 4-2 and 4-3.

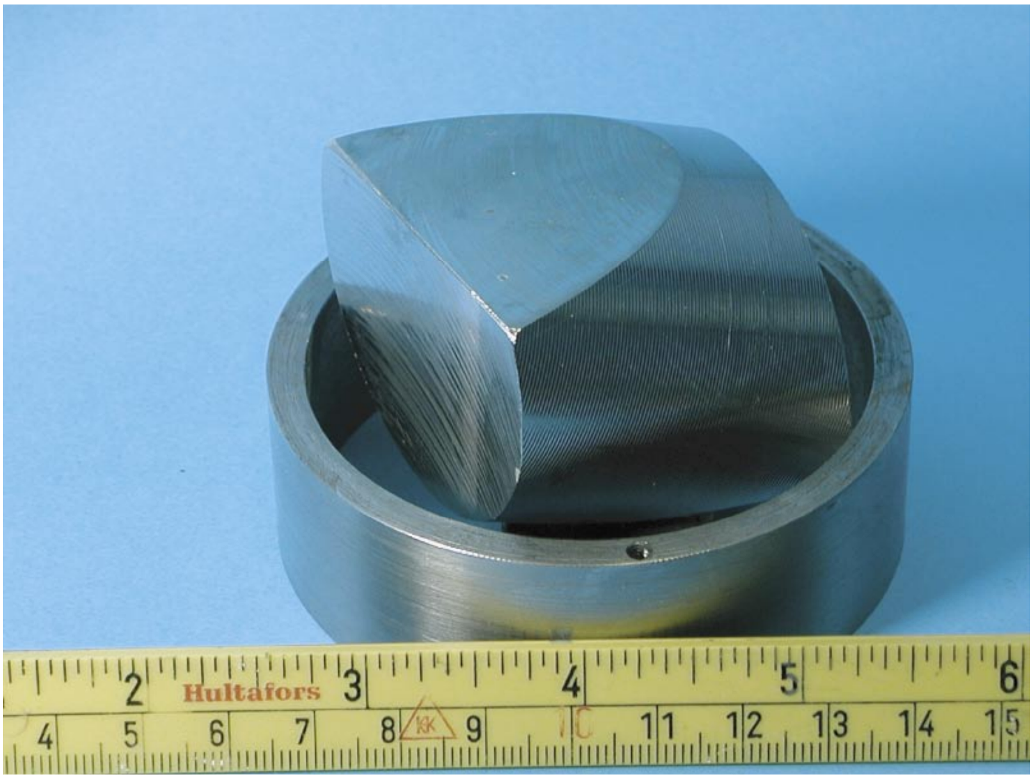


Figure 4-1. *Photogragh of the specially shaped steel specimen just before epoxy is poured around it.*

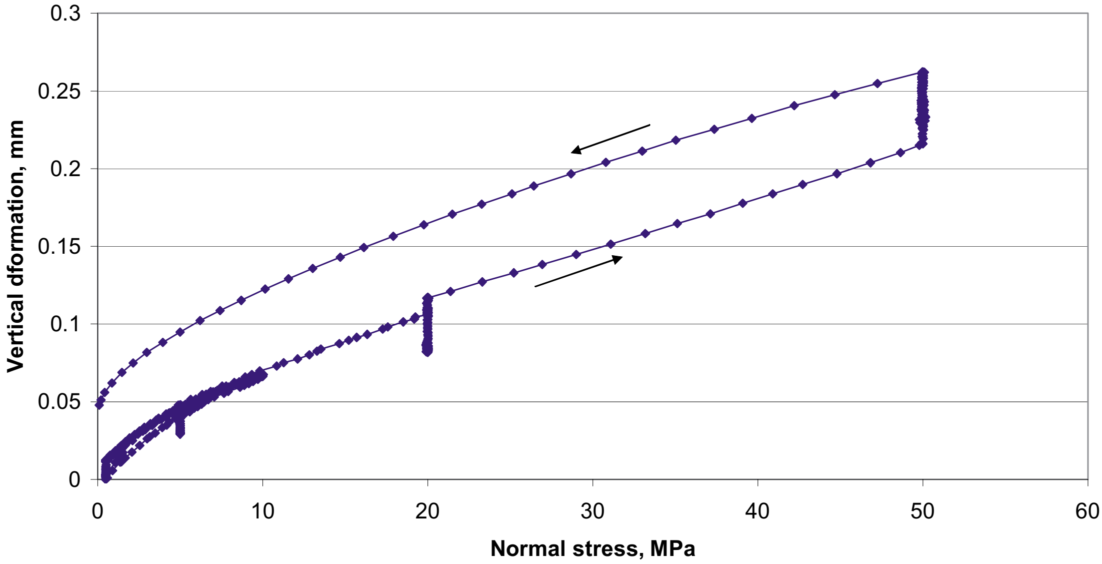


Figure 4-2. *Vertical false deformations of the DST apparatus when loading the steel specimen with improved epoxy mix.*

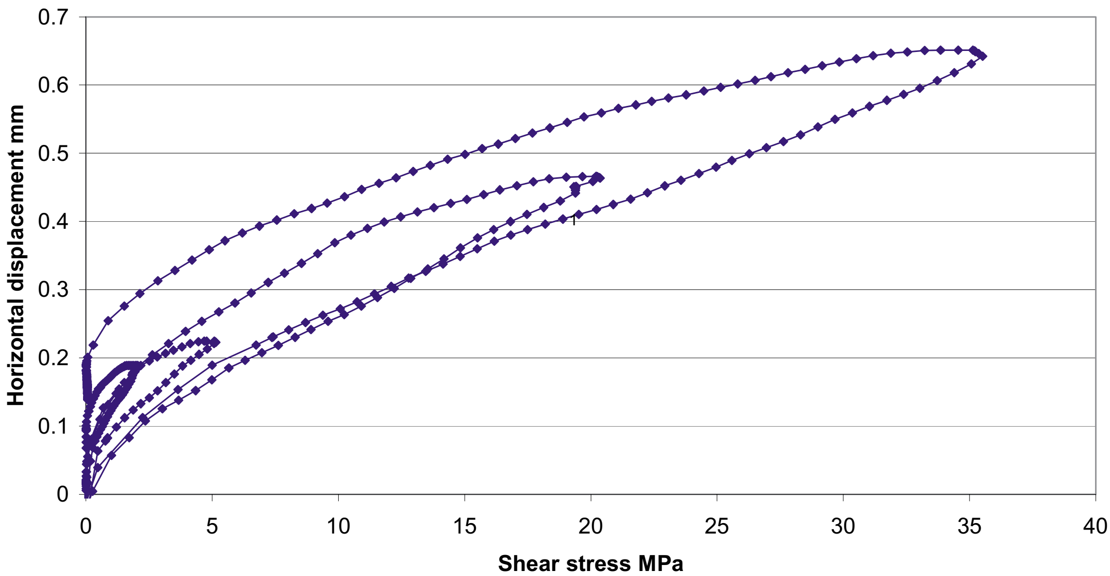


Figure 4-3. *Horizontal false deformations of the DST apparatus when loading the steel specimen with improved epoxy mix.*

The maximum stresses applied to the specimens during this testing programme resulted in false deformations of the order of 0.11 mm for a normal stress of 20.0 MPa and of about 0.46 mm for a shear stress of 20 MPa. The system was also tried for a normal stress up to 50 MPa, and a shear stress of 35 MPa. The false deformations are taken into account in the formulas used for calculation of horizontal and vertical displacements for the DST tests on the rock specimens.

5 Results

For the KSH01A borehole at Simpevarp seven DST tests were performed. The detailed results for each test plus photographs of the specimen before and after the tests are presented in Figures A.1 to A.35 in Appendix A.

The reported figures in the appendix show:

- the vertical (normal) stress versus vertical displacement for loading cycle A (see Table 4-1 for loading program for the DST tests).
- the shear stress versus shear displacement for loading cycles B, C and D
- vertical displacement versus shear displacement for loading cycles B, C and D
- photographs of the specimen before and after testing

5.1 Description and presentation of the specimens

Summaries of the obtained results are listed in Table 5-1. The results in Table 5-1 could also be found in the database SICADA FN96.

Table 5-1. Result list for all direct shear tests for borehole KSH01A.

Borehole number	Specimen depth	ID number	NGI's test number	Specimen area cm^2	Normal stress at 0.5 MPa		Normal stress at 5.0 MPa		Normal stress at 20.0 MPa	
					Peak shear stress at 0.5 Mpa	Residual shear stress MPa	Peak shear stress at 5.0 MPa	Residual shear stress MPa	Peak shear stress at 20.0 MPa	Residual shear stress MPa
KSH01A	483.54	K01-117-13	DST205	24.80	1.87	0.85	4.43	3.95	14.64	13.25
KSH01A	485.93	K01-117-15	DST206	23.10	1.16	0.78	3.82	3.65	12.50	12.30
KSH01A	488.87	K01-117-17	DST207	22.90	1.43	0.93	5.10	4.30	16.33	15.92
KSH01A	492.83	K01-117-19	DST208	24.70	1.70	0.87	4.02	3.50	13.14	12.57
KSH01A	495.27	K01-117-21	DST209	22.90	1.96	0.97	4.58	4.20	16.11	14.25
KSH01A	497.87	K01-117-23	DST210	21.90	1.38	0.75	5.06	4.95	17.87	15.35
KSH01A	709.61	K01-117-28	DST217	24.25	1.43	0.89	4.91	4.19	16.85	15.90
		maximum value MPa		24.80	1.96	0.97	5.10	4.95	17.87	15.92
		average value MPa		23.51	1.56	0.86	4.56	4.11	15.35	14.22
		minimum value MPa		21.90	1.16	0.75	3.82	3.50	12.50	12.30

The following points may be noted in connection with Table 5-1:

- The peak shear stress for a given normal stress level is the highest value recorded at this level. The residual shear stress for a given normal stress level is the average shear stress of the last part of shearing at this level.
- Due to problems with the regulating pump tests DST 209 and DST 217 had higher normal stress (1.1 MPa and 0.9 MPa respectively) than specified during a short period of time during loading cycle B.

5.2 Results for the entire test series

The summary of the results in tabular form according to the various joint set numbers is presented in the tables 5-2, 5-3 and 5-4. Table 5-5 shows the corresponding tilt test results (arithmetic mean values of joint properties) for the various joint sets in borehole KSH01A /Chryssanthakis, 2003/.

Table 5-2. Summary of the DST tests for joint set 1.

Borehole number	Specimen depth	ID number	NGI's test number	Normal stress at 0.5 MPa		Normal stress at 5.0 MPa		Normal stress at 20.0 MPa	
				Peak shear stress at 0.5 MPa	Residual shear stress MPa	Peak shear stress at 5.0 MPa	Residual shear stress MPa	Peak shear stress at 20.0 MPa	Residual shear stress MPa
KSH01A	483.54	K01-117-13	DST205	1.87	0.85	4.43	3.95	14.64	13.25
KSH01A	488.87	K01-117-17	DST207	1.43	0.93	5.10	4.30	16.33	15.92
KSH01A	492.83	K01-117-19	DST208	1.70	0.87	4.02	3.50	13.14	12.57
KSH01A	709.61	K01-117-28	DST217	1.43	0.89	4.91	4.19	16.85	15.90
		maximum value MPa		1.87	0.93	5.10	4.30	16.85	15.92
		average value MPa		1.61	0.89	4.62	3.99	15.24	14.41
		minimum value MPa		1.43	0.85	4.02	3.50	13.14	12.57

Table 5-3. Summary of the DST tests for joint set 2.

Borehole number	Specimen depth	ID number	NGI's test number	Normal stress at 0.5 MPa		Normal stress at 5.0 MPa		Normal stress at 20.0 MPa	
				Peak shear stress at 0.5 MPa	Residual shear stress MPa	Peak shear stress at 5.0 MPa	Residual shear stress MPa	Peak shear stress at 20.0 MPa	Residual shear stress MPa
KSH01A	485.93	K01-117-15	DST206	1.16	0.78	3.82	3.65	12.50	12.30
KSH01A	495.27	K01-117-21	DST209	1.96	0.97	4.58	4.20	16.11	14.25
		maximum value MPa		1.96	0.97	4.58	4.20	16.11	14.25
		average value MPa		1.56	0.88	4.20	3.93	14.31	13.28
		minimum value MPa		1.16	0.78	3.82	3.65	12.50	12.30

Table 5-4. Results from the only one DST test for joint set 3.

Borehole number	Specimen depth	ID number	NGI's test number	Normal stress at 0.5 MPa		Normal stress at 5.0 MPa		Normal stress at 20.0 MPa	
				Peak shear stress at 0.5 MPa	Residual shear stress MPa	Peak shear stress at 5.0 MPa	Residual shear stress MPa	Peak shear stress at 20.0 MPa	Residual shear stress MPa
KSH01A	497.87	K01-117-23	DST210	1.38	0.75	5.06	4.70	17.87	15.35

Table 5-5. Arithmetic mean of JCS_o, JRC_o, Φ_r and Φ_b -values, Borehole KSH 01A /Chryssanthakis, 2003/.

Fracture set	JRC_o (tilt)	JCS_o MPa	Φ_b (°)	Φ_r (°)	Number (tilt)	Number (profiles)
Set 1	6,4	77,3	30,8	25,6	18	18
Set 2	6,1	95,4	31,7	28,2	17	17
Set 3	6,4	81,8	31,4	26,6	16	16
Mean/Total	6,3	84,7	31,3	26,8	51	51

5.3 Discussion

The DST tests performed at NGI can be described as routine rock mechanical tests for determining the shear characteristics of rock joints. The technical staff, mentioned in Section 1 performed all DST tests, calibrations of the LVDTs and transducers and dummy tests (i.e tests for determination of false deformations). Emphasis was placed to the design of the epoxy mix used to fix the specimens in the DST apparatus in order to achieve a mixture that was stiff enough for the applied stresses. The logging frequency has been 10 sec during loading step A. The shearing velocity has been approximately 6 mm/hour for loading step B and 12 mm/hour for loading step D respectively. The logging frequency for the three shearing stages has been 20 sec.

Some minor problems with one of the regulating pumps, for test number DST 209 and DST 217 caused higher normal stress values (1.1 MPa and 0.9 MPa respectively) than specified during a short period of time at loading cycle B. These irregularities are not considered to affect the final residual stress values significantly.

For some of the tests listed in the appendix, for example DST 207, the shear displacement values have a negative sign in the beginning of loading step D. This is because the specimen was not repositioned at exactly zero deformation position. These negative values do not have any effect on the test results.

The spreading of the results is larger during the first loading step B (normal stress 0.5 MPa) than during loading step C (normal stress 5 MPa) and D (normal stress 20 MPa). This may be expected since the shearing of the joint asperities takes place mainly during loading step B. The specimens have different joint roughness coefficients despite the fact that most of them are characterized as planar joints. The joint asperities are considered to be less important during loading steps C and D.

The residual shear stress values are considered to be rather high compared to the peak shear stress values. This is not surprising since the specimens have a relative high JCSo value and a high uniaxial compressive strength.

It was decided not to add any trend lines for the residual shear stress values since each test behaved in a different way. As a rule of thump, the residual value quoted in this report is the mean shear stress value for approximately the last 1 mm of shearing during loading step B. For loading steps C and D the residual shear stress value is the mean shear stress value for approximately the last 2 mm of shearing.

References

Kjeldstad, A. Chuhan, F. Høeg, K. and Bjørlykke, K, 2003. Cataclastic shearband formation in sands at high stress- An analogue experimental model and its relevance for faults in sedimentary basins. Accepted for publication in the Journal of Structural Geology.

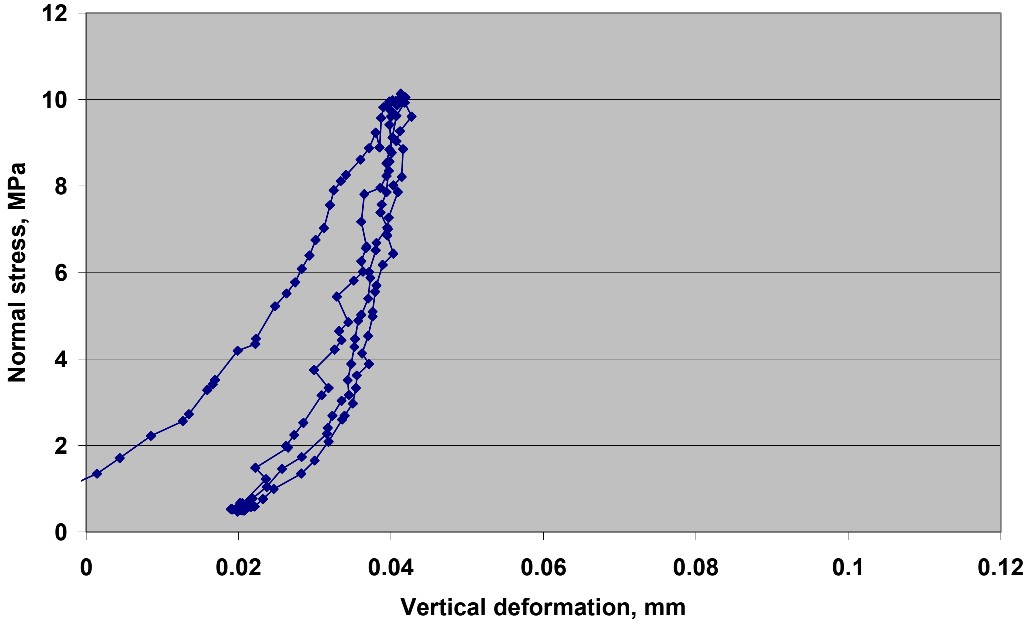
ISRM standards, 1981. Suggested methods for Direct Shear Stress testing. Editor E.T Brown, Published for the Commission on Testing Methods, Pergamon Press

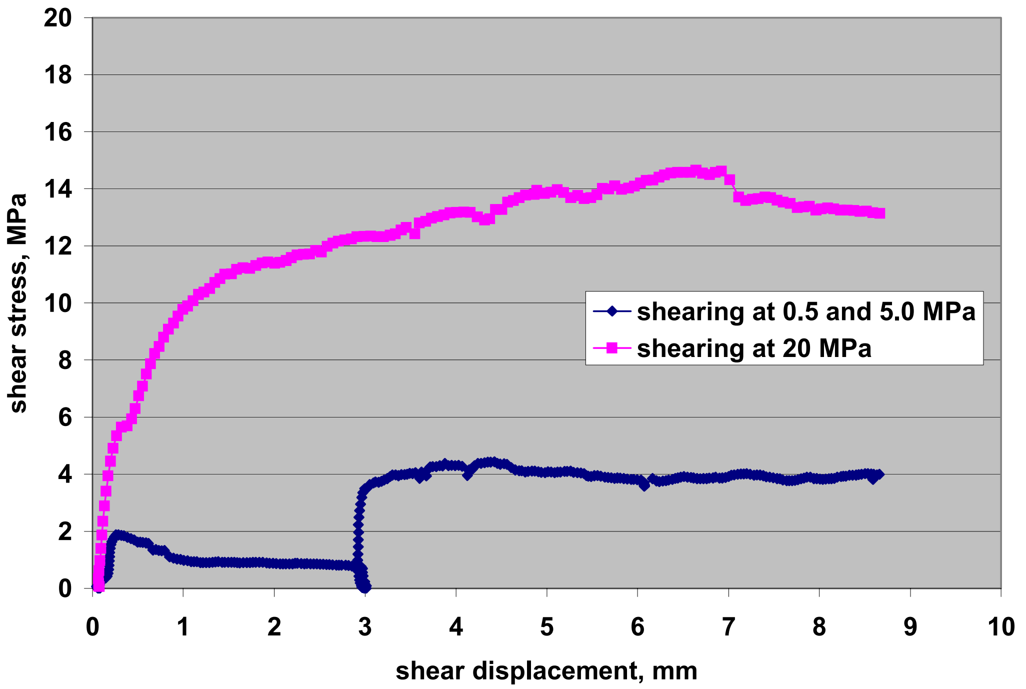
SKB, 2003. Borehole KSH01A Results of tilt testing. SKB report, P-03-107, November 2003.

Appendix A

The main results from direct shear testing

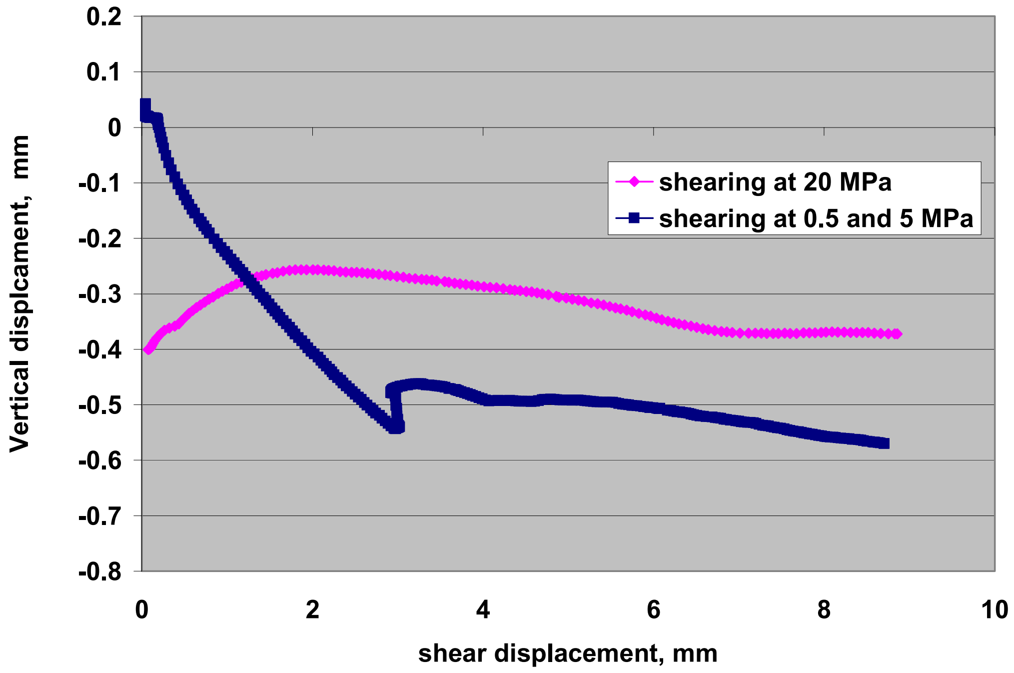
Note: The identification numbers written on the photographs differ from those given in the tables. The numbers on the photographs are those that were written on the specimens when received from SKB.





Test DST 205

Borehole KSH01A, ID K01-117-13, depth 483.54 m
Figure A.1 (top) vertical stress versus vertical displacement for loading cycle A
Figure A.2 (bottom): shear stress versus shear displacement for loading cycle B, C, and D

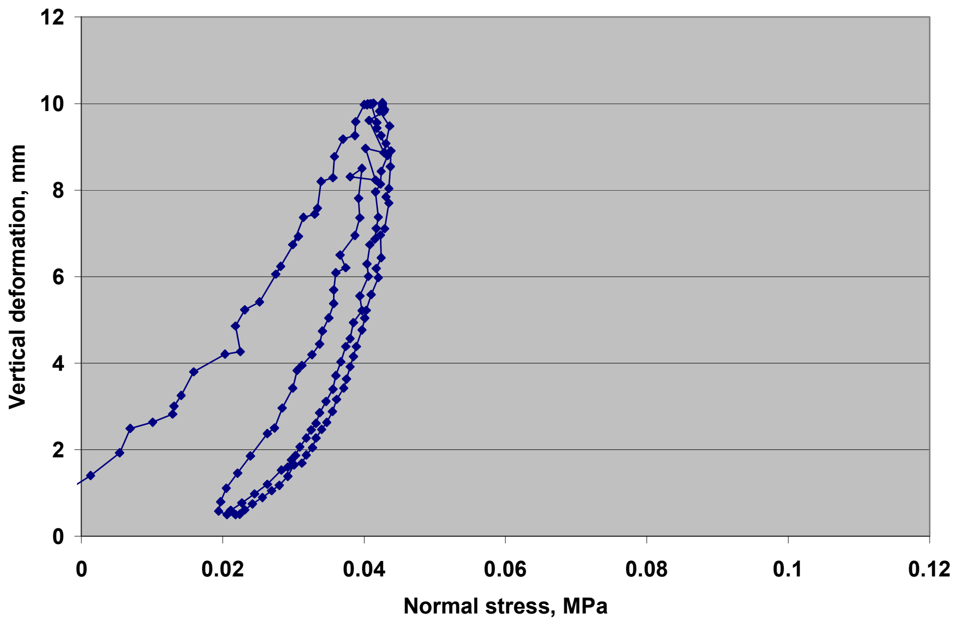


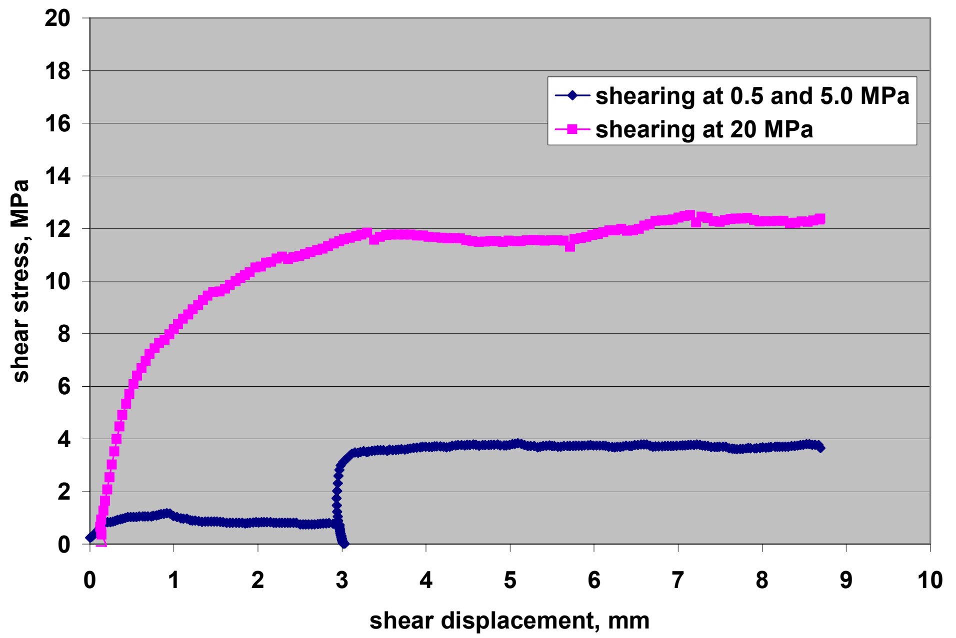
Test DST 205

Borehole KSH01A, ID K01-117-13, depth 483.54 m
Figure A.3 Normal displacement versus shear displacement loading cycle B, C, and D (dilation)

Test DST 205

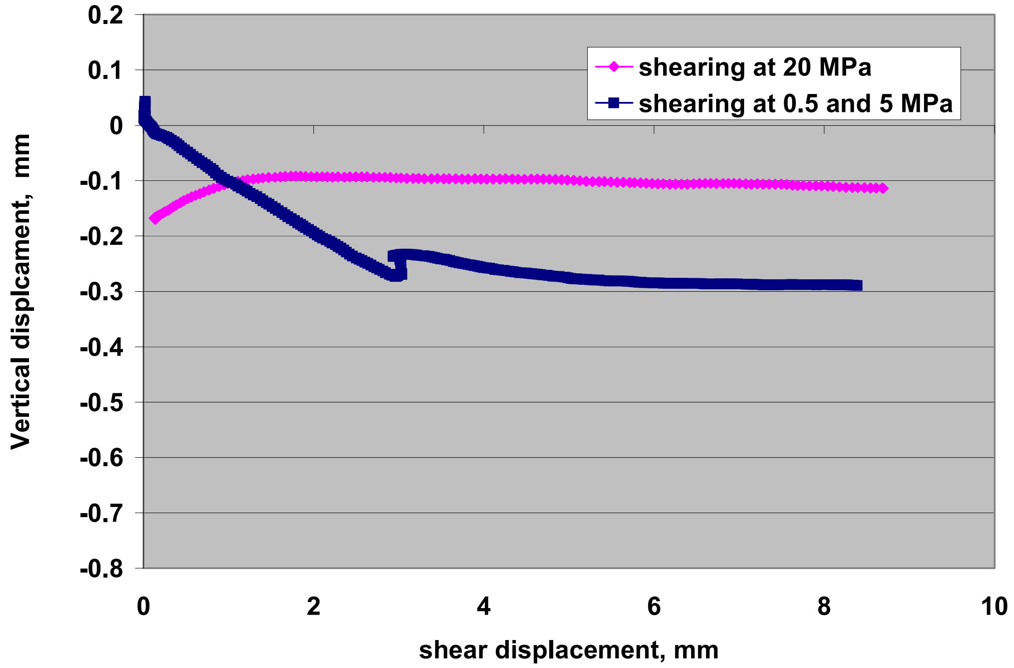
Borehole KSH01A, Id K01-117-13, depth 483.54 m
Figure A.4 (top) : before testing
Figure A.5 (bottom): after testing





Test DST 206

Borehole KSH01A, ID K01-117-15, depth 485.93 m
Figure A.6 (top) vertical stress versus vertical displacement for loading cycle A
Figure A.7 (bottom): shear stress versus shear displacement for loading cycle B, C, and D

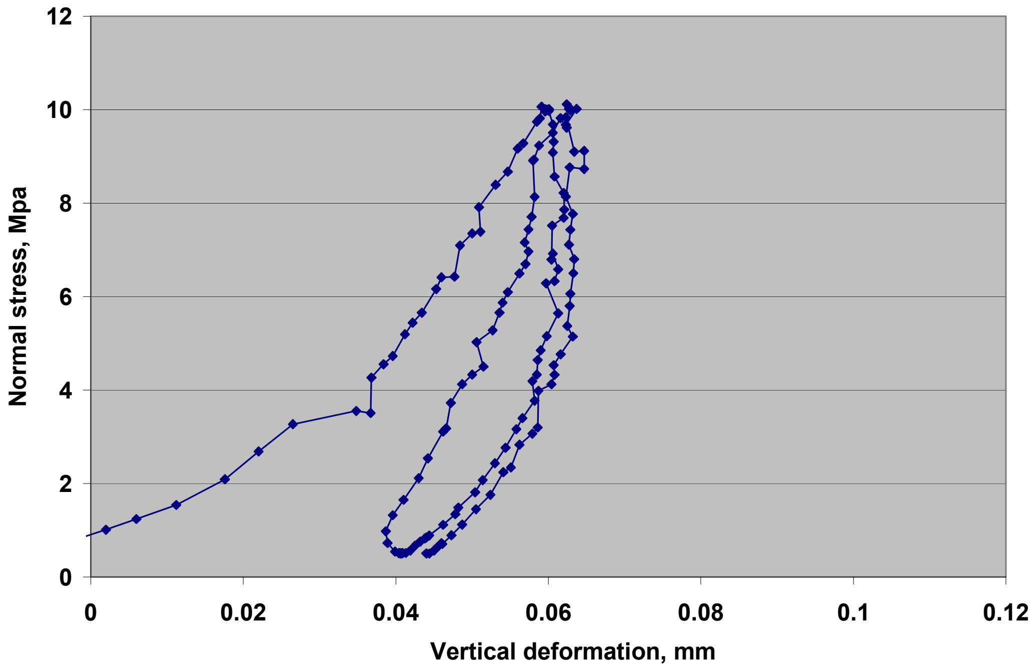


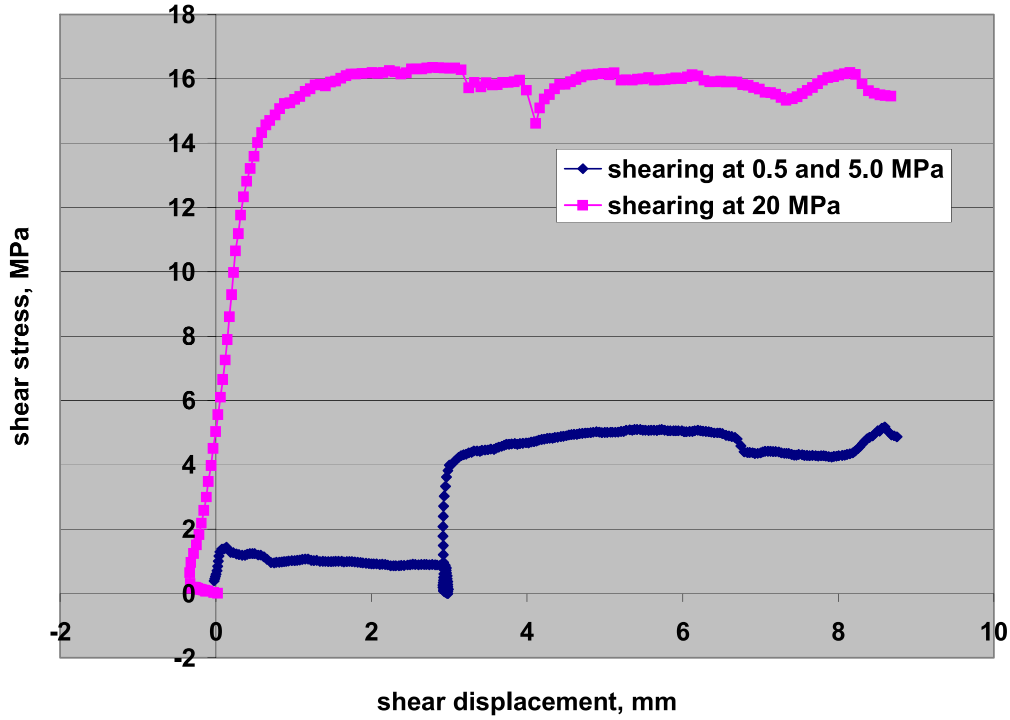
Test DST 206

Borehole KSH01A, ID K01-117-15, depth 485.93 m
Figure A.8 Normal displacement versus shear displacement loading cycle B, C, and D (dilation)

Test DST 206

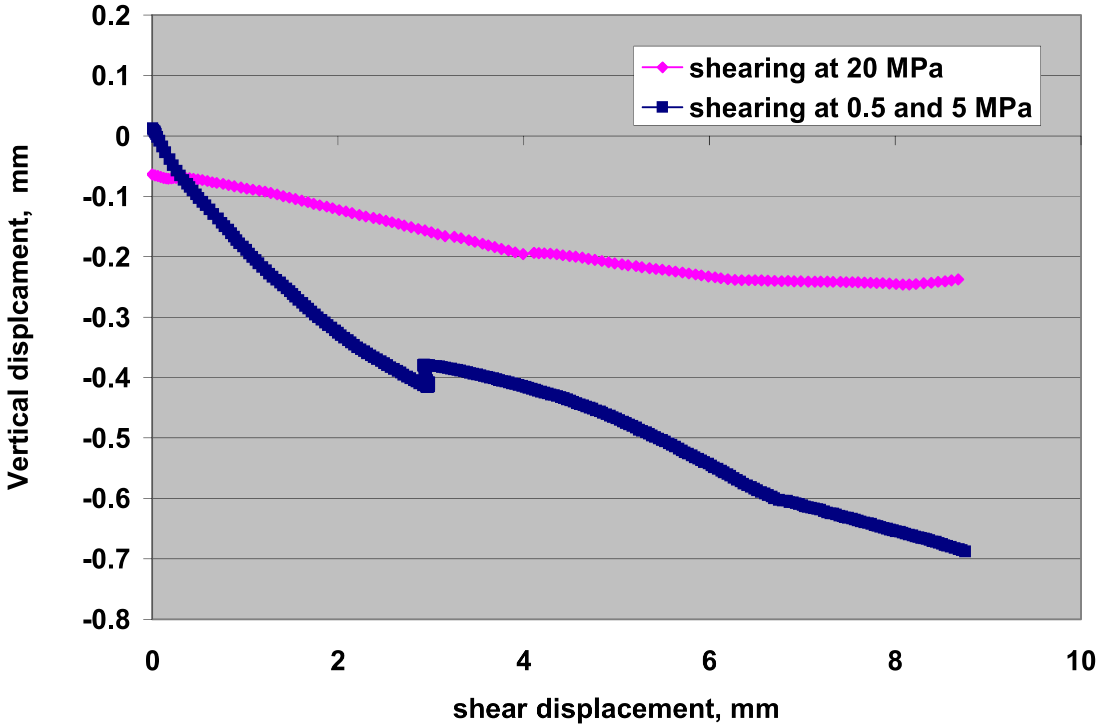
Borehole KSH01A, Id K01-117-15, depth 485.93 m
Figure A.9 (top) : before testing
Figure A.10 (bottom): after testing





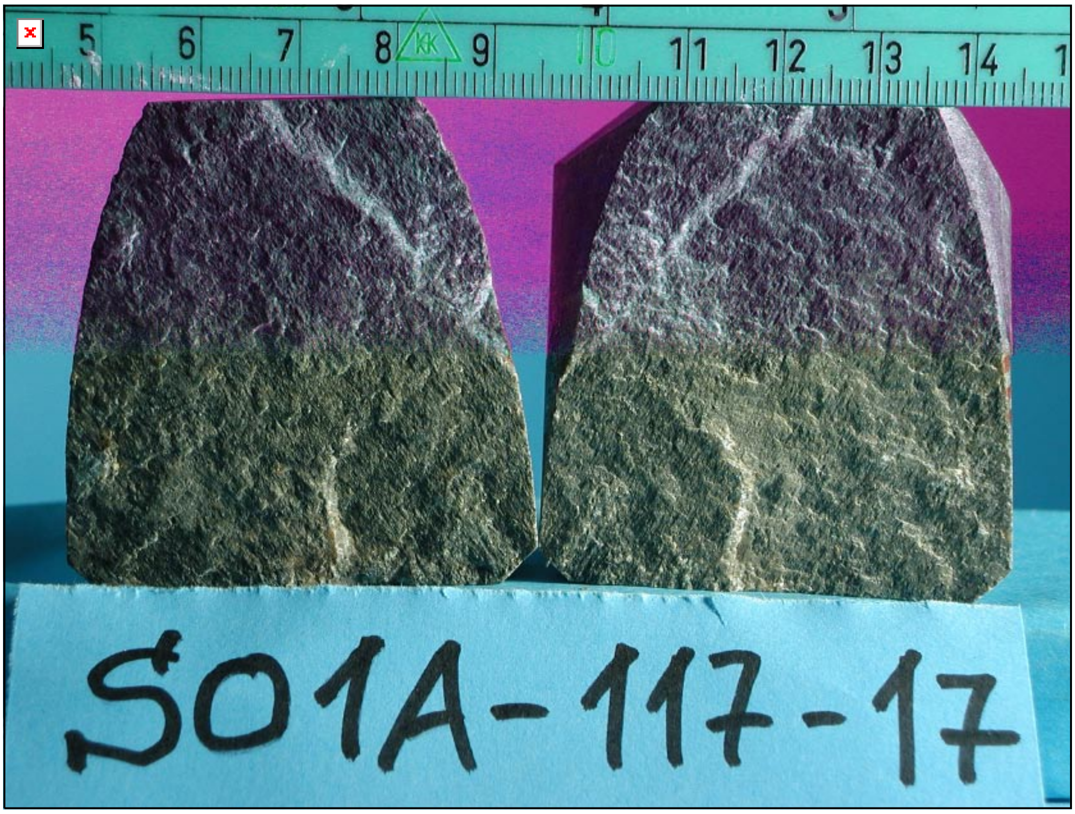
Test DST 207

Borehole KSH01A, ID K01-117-17, depth 488.87m
Figure A.11 (top) vertical stress versus vertical displacement for loading cycle A
Figure A.12 (bottom): shear stress versus shear displacement for loading cycle B, C, and D



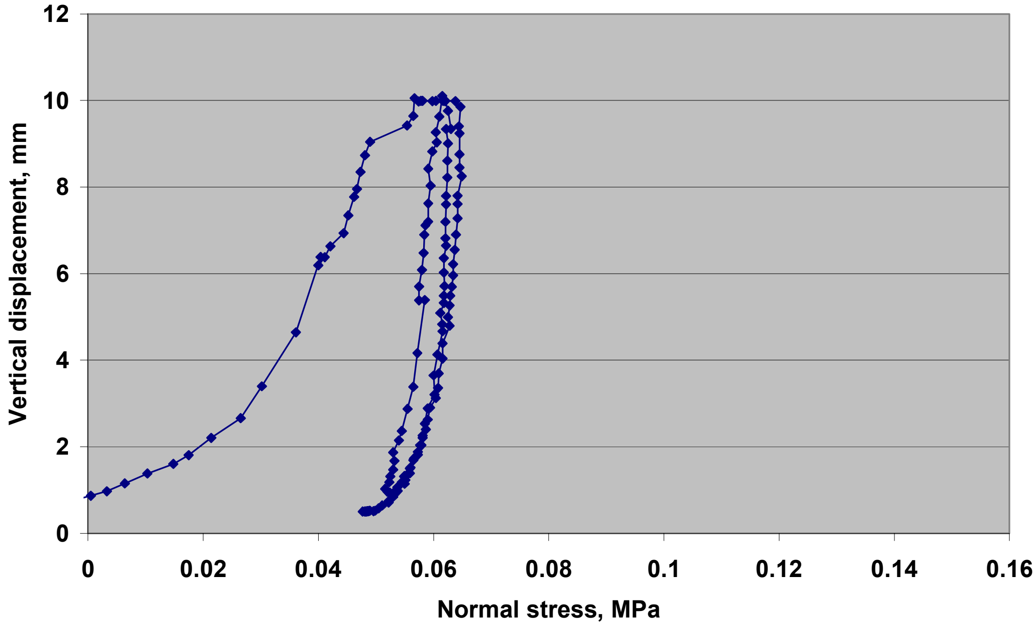
Test DST 207

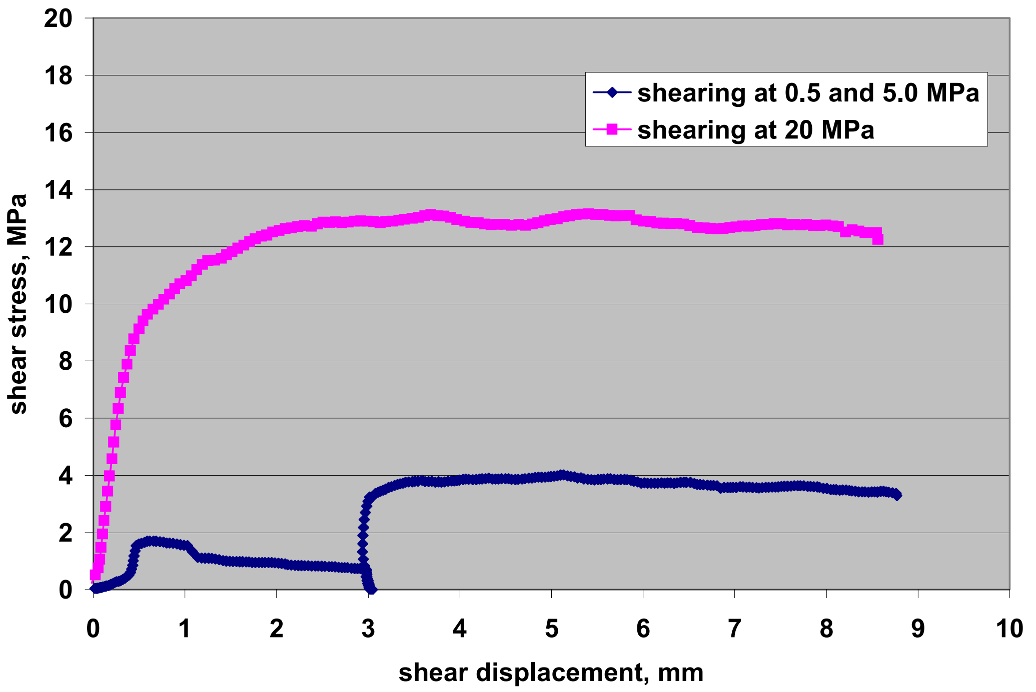
Borehole KSH01A, ID K01-117-17, depth 488.87m
Figure A.13 Normal displacement versus shear displacement loading cycle B, C, and D (dilation)



Test DST 207

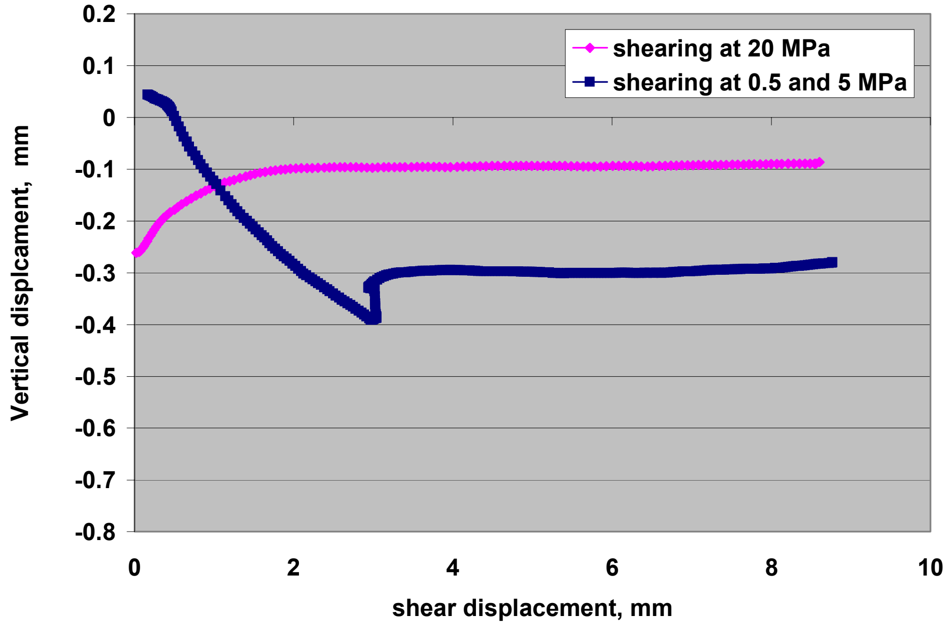
Borehole KSH01A, ID K01-117-17, depth 488.87m
Figure A.14 (top) : before testing
Figure A.15 (bottom): after testing





Test DST 208

Borehole KSH01A, ID K01-117-19, depth 492.83 m
Figure A.16 (top) vertical stress versus vertical displacement for loading cycle A
Figure A.17 (bottom): shear stress versus shear displacement for loading cycle B, C, and D

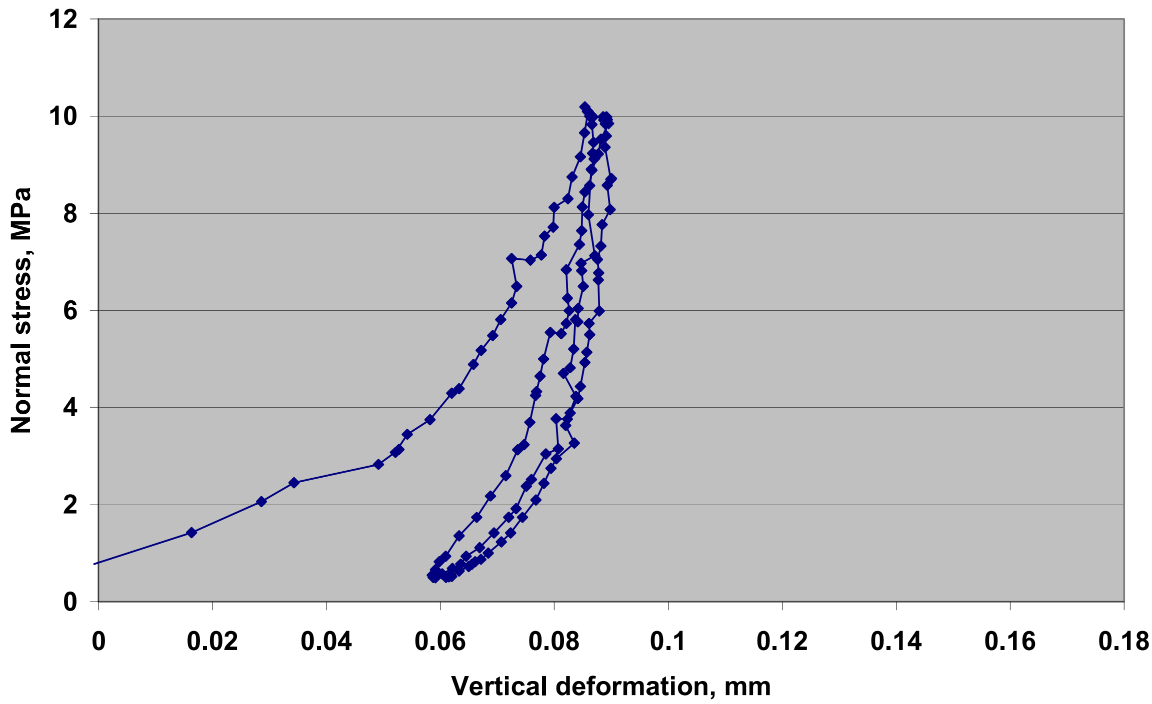


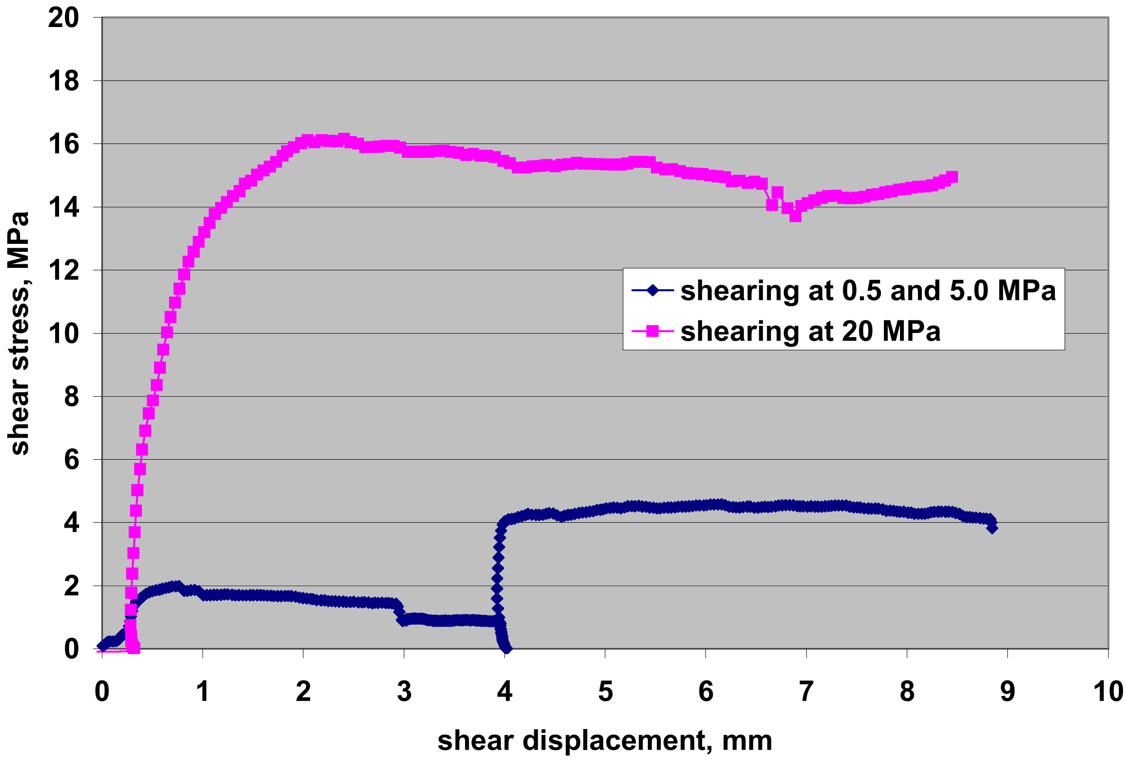
Test DST 208

Borehole KSH01A, ID K01-117-19, depth 492.83 m
Figure A.18 Normal displacement versus shear displacement loading cycle B, C, and D (dilation)

Test DST 208

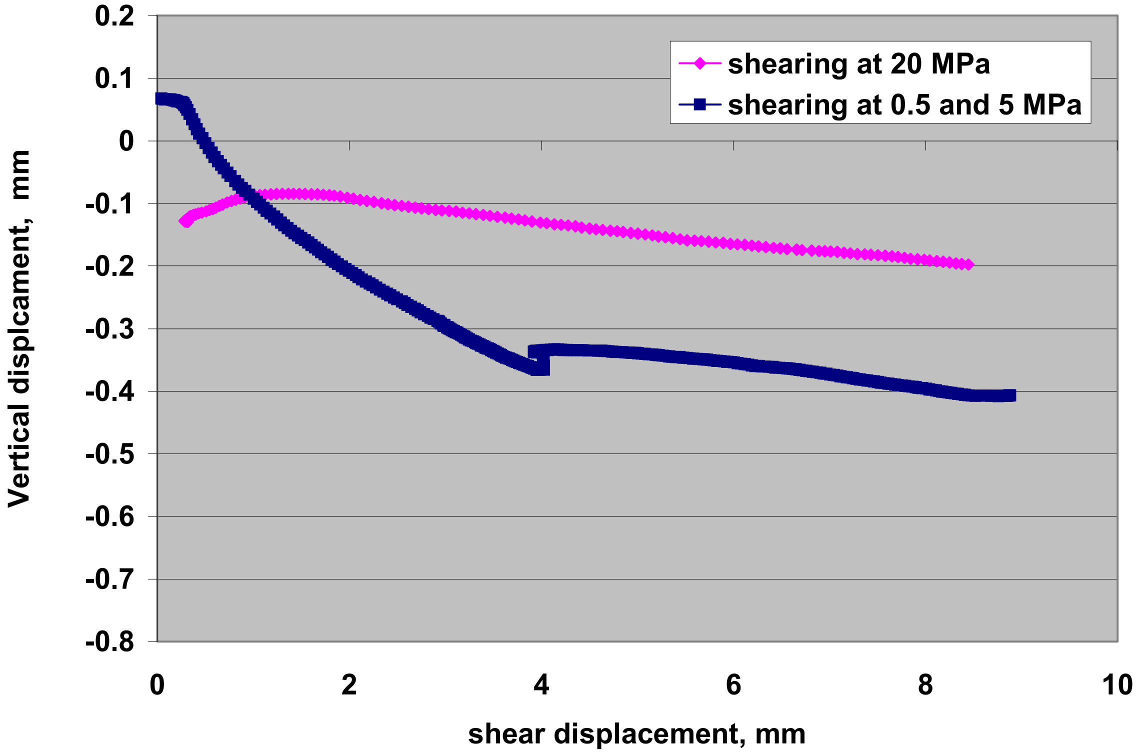
Borehole KSH01A, ID K01-117-19, depth 492.83 m
Figure A.19 (top) : before testing
Figure A.20 (bottom): after testing





Test DST 209

Borehole KSH01A, ID K01-117-21, depth 495.27 m
Figure A.21 (top) vertical stress versus vertical displacement for loading cycle A
Figure A.22 (bottom): shear stress versus shear displacement for loading cycle B, C, and D

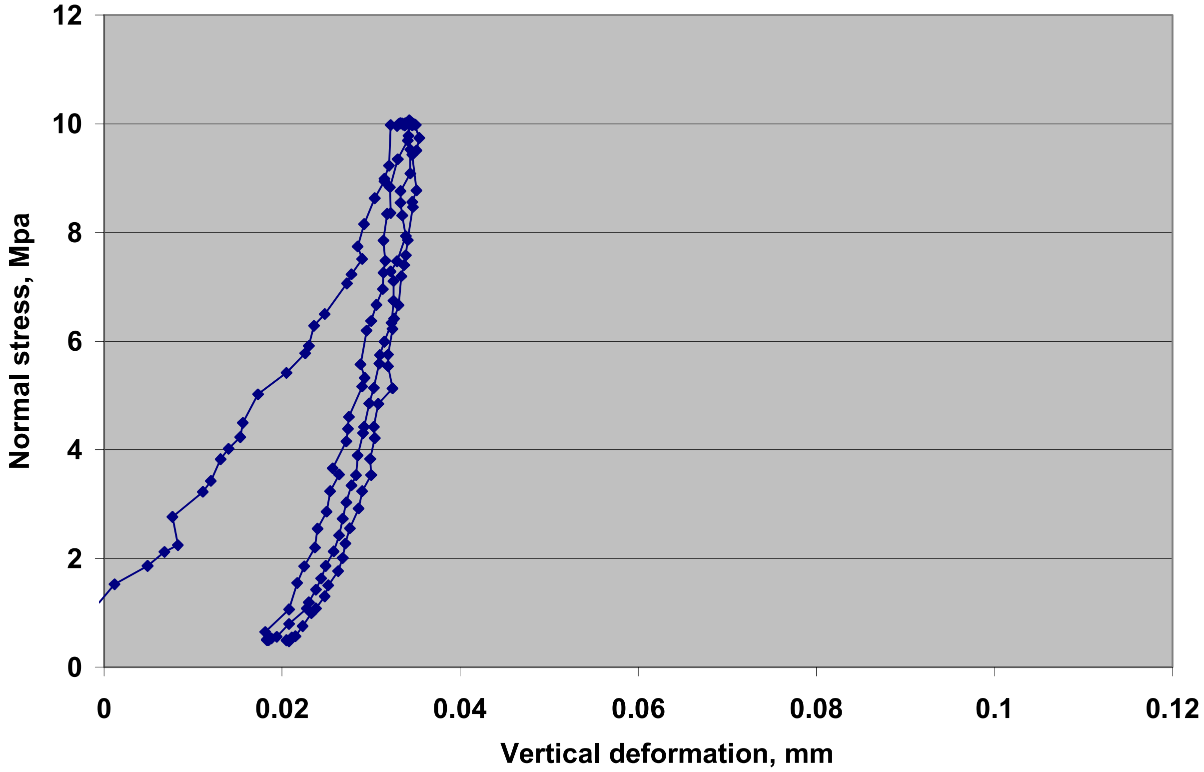


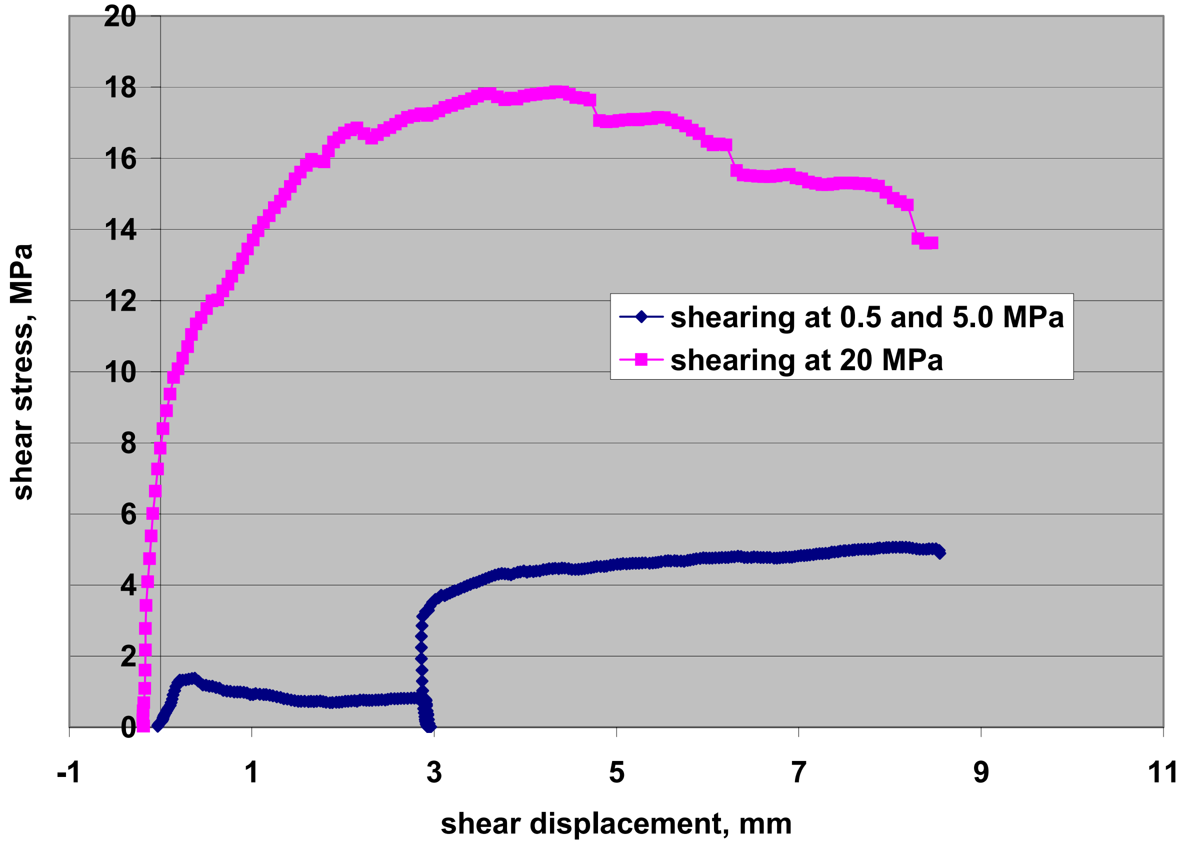
Test DST 209

Borehole KSH01A, ID K01-117-21, depth 495.27 m
Figure A.23 Normal displacement versus shear displacement loading cycle B, C, and D (dilation)

Test DST 209

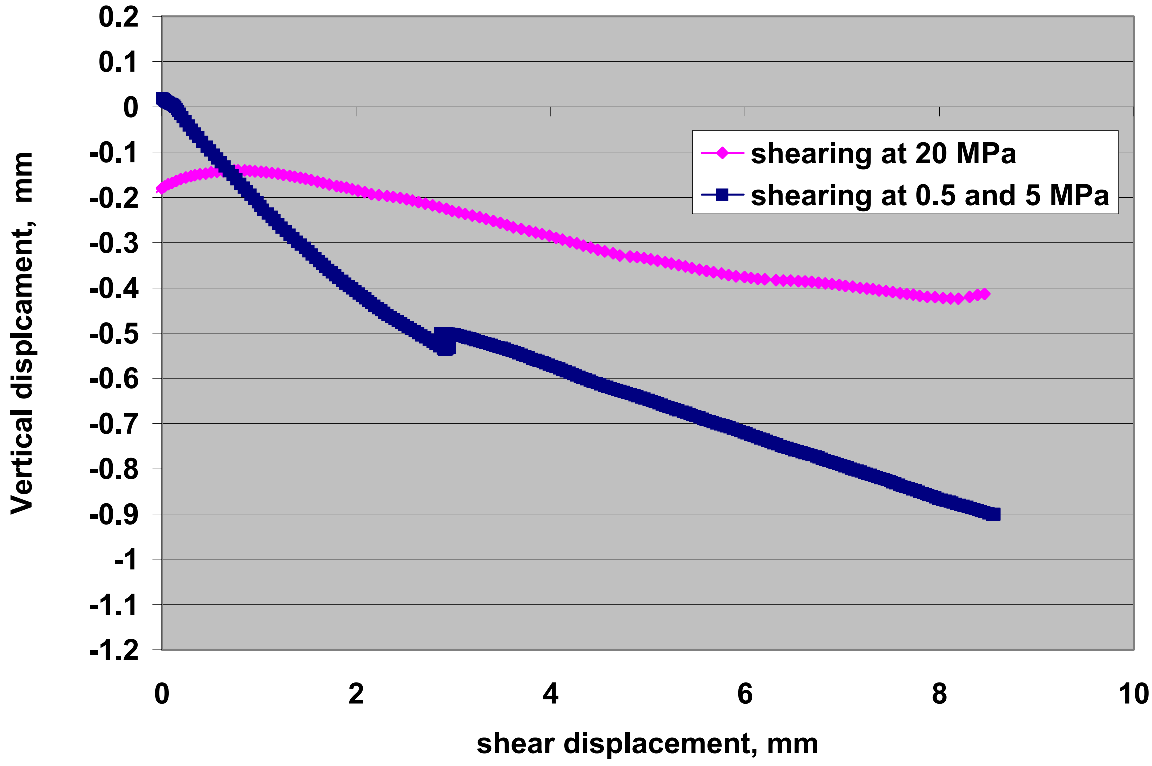
Borehole KSH01A, ID K01-117-21, depth 495.27 m
Figure A.24 (top) : before testing
Figure A.25 (bottom): after testing





Test DST 210

Borehole KSH01A, ID K01-117-23, depth 497.87 m
Figure A.26 (top) vertical stress versus vertical displacement for loading cycle A
Figure A.27 (bottom): shear stress versus shear displacement for loading cycle B, C, and D

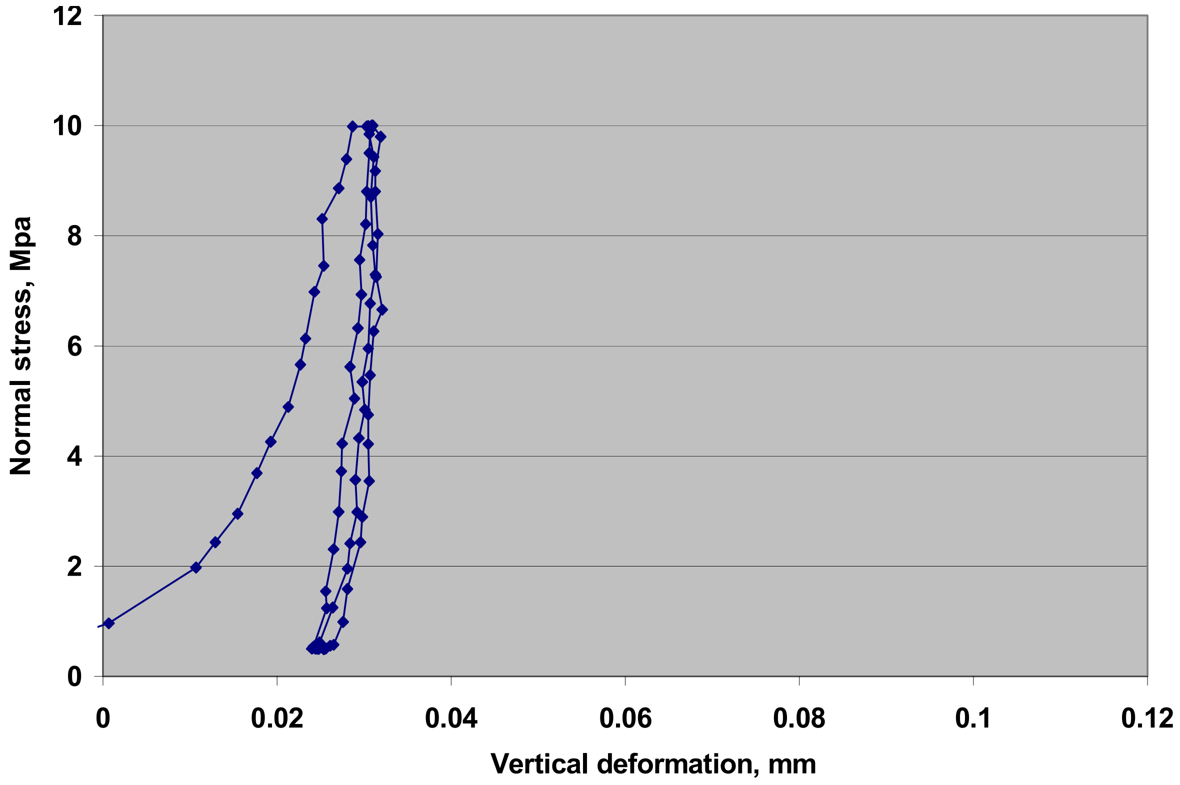


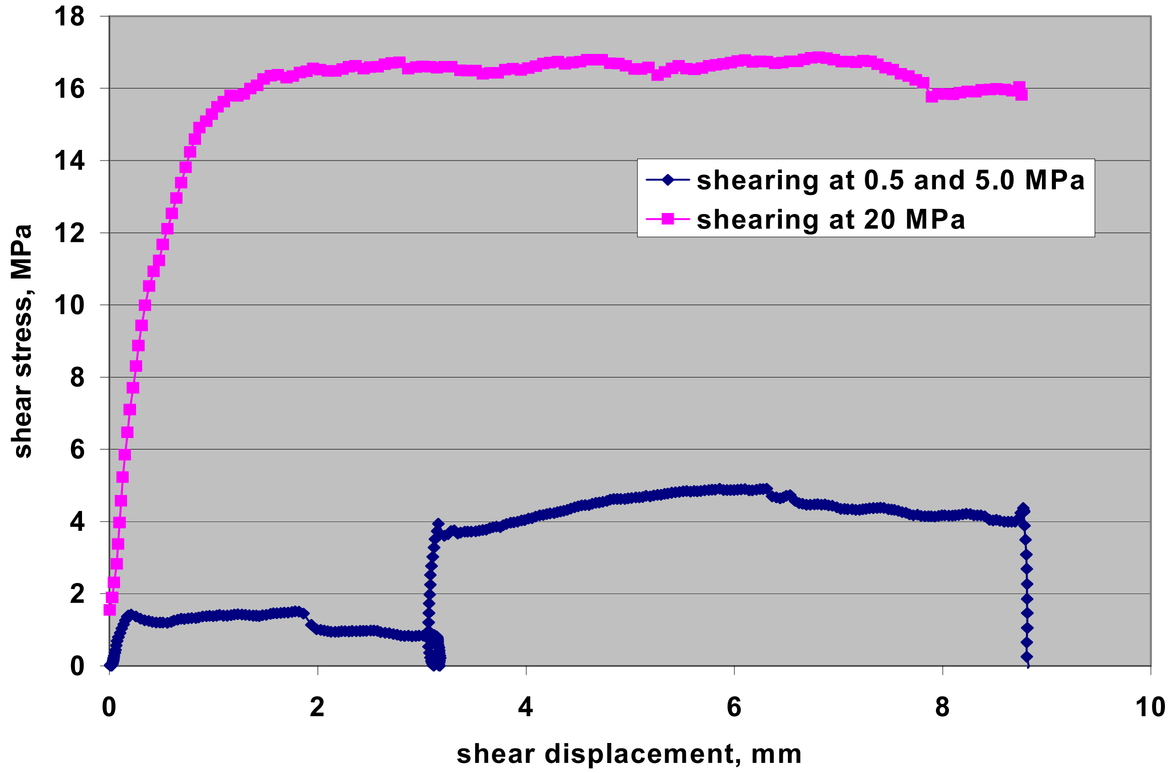
Test DST 210

Borehole KSH01A, ID K01-117-23, depth 497.87 m
Figure A.28 Normal displacement versus shear displacement loading cycle B, C, and D (dilation)

Test DST 210

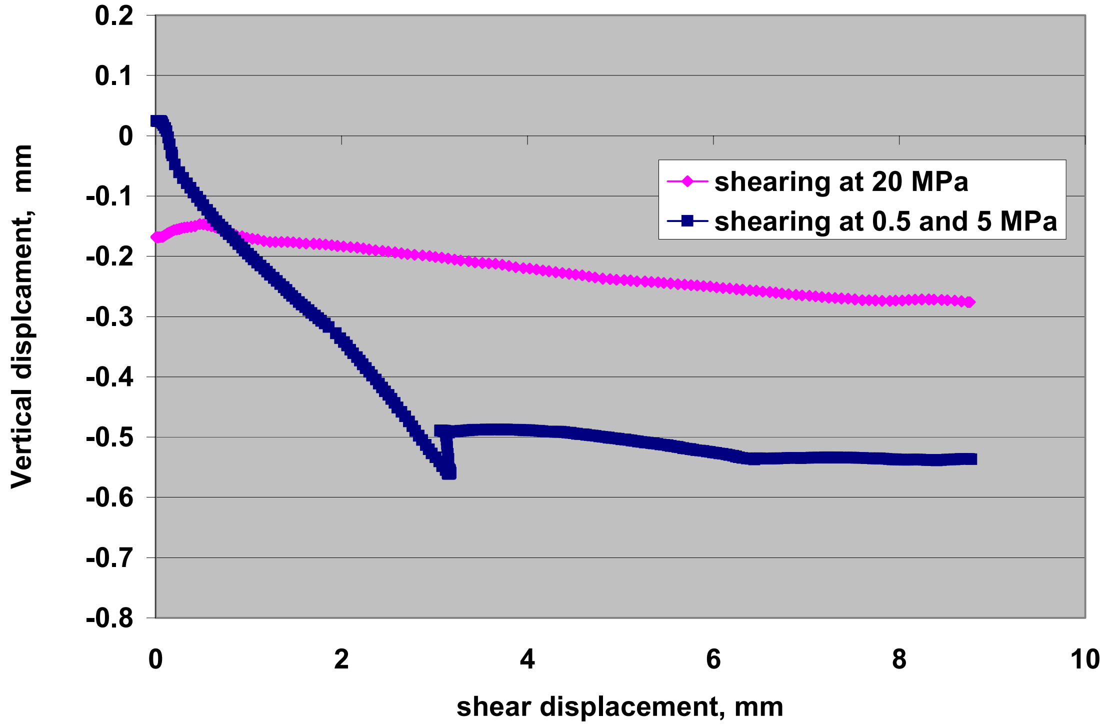
Borehole KSH01A, ID K01-117-23, depth 497.87 m
Figure A.29 (top) : before testing
Figure A.30 (bottom): after testing





Test DST 217

Borehole KSH01A, ID K01-117-28, depth 709.61 m
Figure A.31 (top) vertical stress versus vertical displacement for loading cycle A
Figure A.32 (bottom): shear stress versus shear displacement for loading cycle B, C, and D



Test DST 217

Borehole KSH01A, ID K01-117-28, depth 709.61 m
Figure A.33 Normal displacement versus shear displacement loading cycle B, C, and D (dilation)

Test DST 217

Borehole KSH01A, ID K01-117-28, depth 709.61 m
Figure A.34 (top): before testing
Figure A.35 (bottom): after testing