P-06-34

Oskarshamn site investigation

Borehole KLX10

Tilt testing

Panayiotis Chryssanthakis
Norwegian Geotechnical Institute, Oslo

October 2006

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Keywords: AP-PS 400-05-109, Rock mechanics, Joint properties, JRC100, JCS100, Angles of joint friction and tilt test.

Summary

The Norwegian Geotechnical Institute (NGI) has carried out tilt testing on joint surfaces of drill cores from borehole KLX10 at Oskarshamn, during the period January 10th–13th, 2006. From a total drill core length of about 900 m, 9 tilt tests from the depth range 300 to 500 m were performed on three sets of joints.

The main results from the tilt tests are rather uniform throughout the joint surfaces and they do not show strong variations. The mean value of the joint roughness coefficient (JRC_o) obtained from tilt testing of all the joint samples is 7.1 The mean value of the joint wall compressive strength (JCS_o) from Schmidt hammer testing of all the joint samples is 93.9 MPa. The mean values of the basic (Φ_b) and residual (Φ_r) friction angles of all the tested samples are 31.2 and 26.4 degrees respectively.

Sammanfattning

Norges Geotekniska Institut (NGI) har gjort s k tilttester på öppna sprickor i borrkärneprover från borrhål KLX10 i Oskarshamn. Utifrån en sammanlagd borrkärnelängd på ca 900 m utvaldes 9 prover för tilttester på tre sprickgrupper i djupintervallet 300–500 m.

Resultaten är relativt enhetliga för samtliga sprickor och uppvisar inga stora variationer. Medelvärdet för råhetskoefficienten, JRC_o, för alla sprickor är 7,1. För sprickväggens tryckhållfasthet, JCS_0, som uppmättes med Schmidthammarprovning, uppgår medelvärdet till 93,9 MPa. Medelvärdet för basfriktionsvinkeln, Φ_b, och residualfriktionsvinkeln Φ_r, beräknat utifrån alla testade prover, är 31,2 respektive 26,4 grader.

Contents

1 Introduction

The Norwegian Geotechnical Institute (NGI) has carried out 9 tilt testing on joint surfaces of drill cores from borehole KLX10 at Oskarshamn in Sweden according to SKB Activity Plan AP PS 400-05-109, January 2006, Version 1.0 (SKB internal controlling document). The work has been carried out by Panayiotis Chryssanthakis and Pawel Jankowski during the period January 10th–13th, 2006, in accordance with SKB's method description MD 190.006, Version 1.0 (SKB internal controlling document).

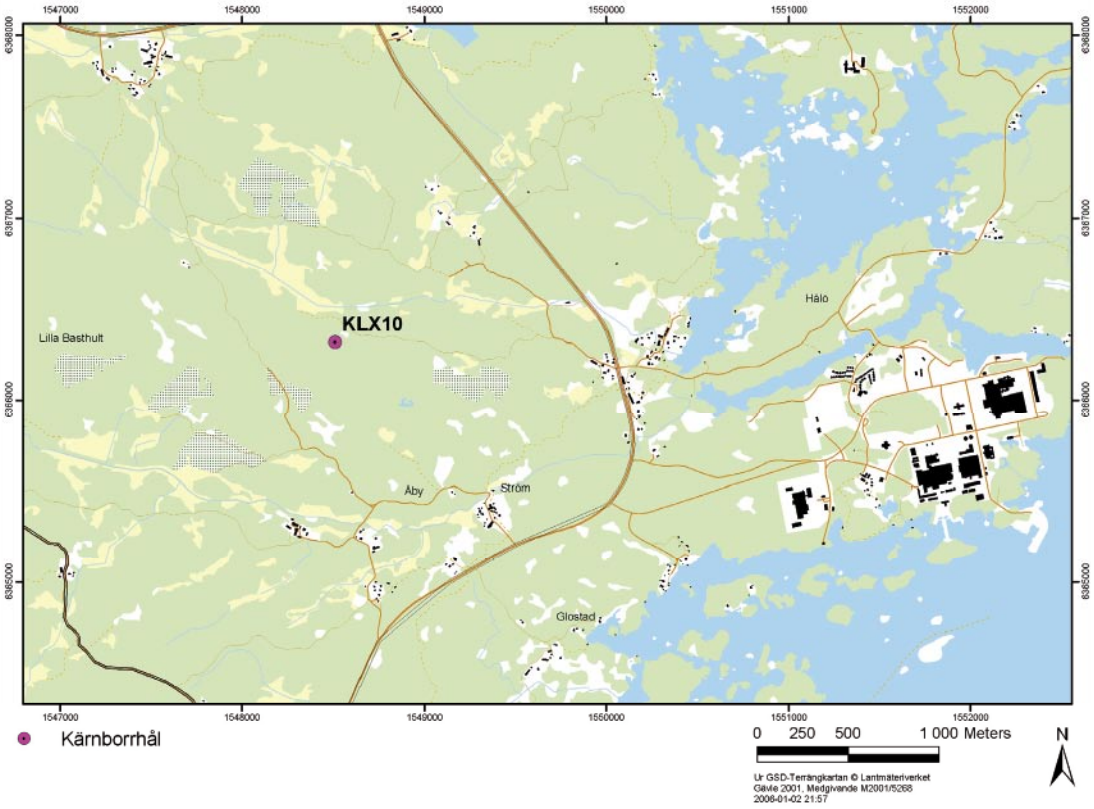

Figure 1-1. *Oskarshamns site investigation area with borehole KLX10.*

2 Objective and scope

The purpose of the testing is to determine the joint properties JRC and JCS as well as the basic and residual friction angles. The joint properties are parameters used in the rock mechanical model which will be established for the candidate area selected for site investigations at Oskarshamn.

The number of tests performed and the number of joint sets are given in Table 2-1.

The results from the tilt tests are presented in this report by means of tables, figures and spreadsheets. The results are also reported to SICADA.

Table 2-1. Total number of tilt tests.

Borehole	Tilt tests	No. of joint sets
KLX10	9	3

3 Equipment and methods

The tilt angles (α and Φ_b) are measured by a simple tilt apparatus, see Figure 3-1.

The tilt test apparatus is a self-weight tilt testing machine used for predicting the peak shear strength of a joint. Usually such joints, that are well preserved and considered representative of a joint set to which they belong, are selected for testing. The test consists of forcing the upper half of a jointed specimen to slide under its own weight.

The tilt test table consists of a hand driven rotating apparatus attached to an aluminium frame which is able to rotate 90 degrees in both directions (see Figure 3-1). The specimen is attached to a simple workshop clamp fastened upon the tilt test table. The joint area is then levelled to zero degrees before the tilt testing can start, (see Figure 3-1) The angle of tilting (α) can be read from a protractor attached to the rotating apparatus. The mass of the upper joint half and the fracture surface area are measured before tilt testing.

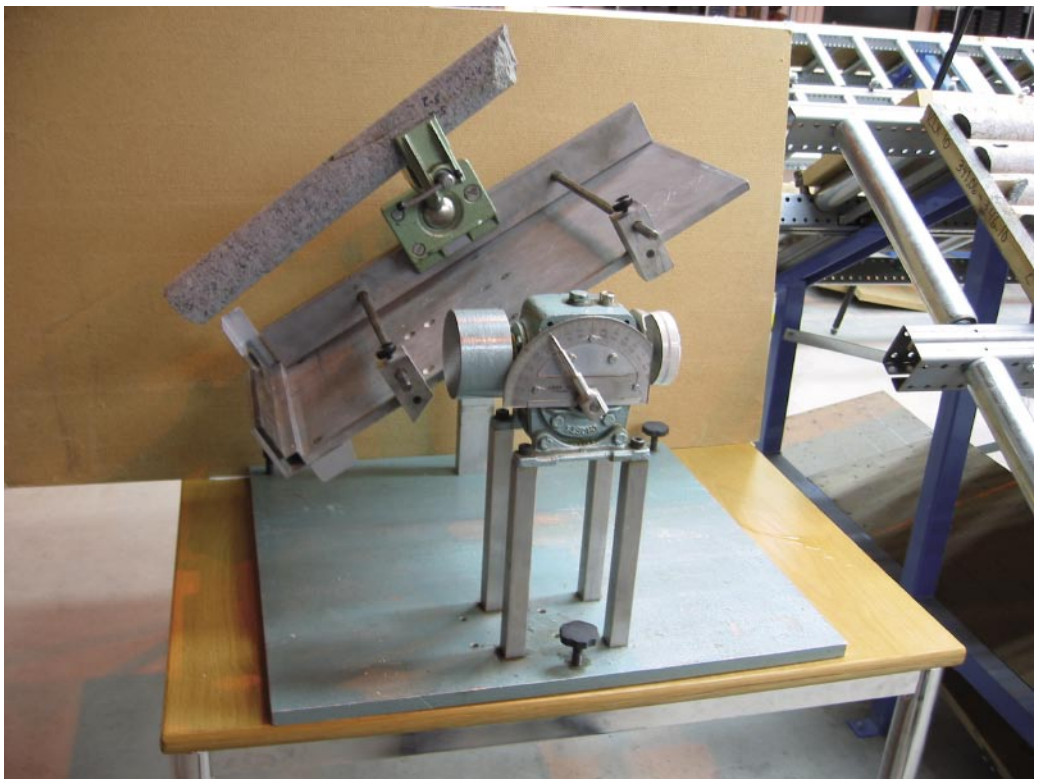

Figure 3-1. *NGI's Tilt test apparatus.*

For measurements of JCS, r and R, a Schmidt hammer with a clamp to fasten the samples is used see Figure 3-2.

The profiling is carried out by means of a profilometer, see Figure 3-3. In addition, a planimeter is necessary to measure the area of the fracture face.

Figure 3-2. *Clamp for the Schmidt hammer tests.*

Figure 3-3. *Profilometer applied on a joint surface.*

4 Execution

4.1 The sampling

The samples were taken from drill cores with a diameter of approximately 50 mm in such a way that each sample contained both faces of a joint, see Figure 4-1. To prepare the sample, sawing was usually necessary.

The frequency of the tilt test samples was determined by choosing one specimen for approximately 30 to 35 m in the depth range between 300 m and 500 m. A total of 9 tilt samples were chosen in co-operation with SKB. The depths quoted in the tables can be directly correlated with the SKB database SICADA. During the tilt tests, the real orientation of joints was not known, and therefore the various joints, were classified according to their angle of intersection with the core in the way it is displayed in Table 4-1.

Table 4-1. Joint set numbers and orientations.

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

Figure 4-1. *Upper and lower joint surfaces used in the tilt test apparatus.*

Three profiles on each tilt joint surface have also been carried out. The rocks can be classified as Ävrö granite and in some areas fine grained granite, fine grained diorite-gabbro, fine grained dioritoid with some veins of amphibolite and pegmatite, were found over most of the length of the borehole. However, since core logging has been carried out by SKB, no detailed geological description has been attempted by NGI. Most common minerals on the joint surfaces are chlorite, calcite, pyrite, epidotite and laumontite. All 9 tilt joint surfaces from borehole KLX10 can be directly identified within the database SICADA at SKB. At the time of sampling, the core had been exposed to the atmosphere at room temperature for an extended period of time and may be presumed to be air-dried, though no measurements of the moisture content were made.

4.2 Testing

The tilt test consists of the tilting, Schmidt hammer measurements and profiling of the joint faces.

The measuring of the tilt angle α is performed on wet (humid) joint surfaces. The sample is then fixed to the tilt apparatus and tilted. At least three tilts are carried out on each sample, and the tilt angle should not vary more than 3^{o} in these tests. However, in some cases the characteristics of the sample change during testing. For example fracture coating may be removed, and therefore variation of more than 3^{o} may (in some cases) be accepted.

The same procedure is used for determining Φ_b which is the tilt angle core to core, but here the cores shall be dry.

The Schmidt hammer measurements for JCS were performed on wet (humid) joint surfaces (r value) with 10 blows on each test. The lower five blow values were then eliminated.

For measuring of R-value, Schmidt hammer readings on fresh, dry cores near the joint for tilting were performed on dry cores with 10 blows. The lower five blow values were again eliminated. The core surface in the borehole wall could be considered as uniform (straight).

The weight of the tilting block and the rock density are measured, and the fracture surface area is measured with a planimeter.

Profiling of the tilt tested fractures is carried out by means of a profilometer, and the profiles are drawn on a paper by pulling a pencil along the edge of the profilometer. For each fracture, three parallel profiles are drawn; one along the centre of the sample, one to the left and one to the right of the centre line. From the profile the roughness amplitude (a) and the profile length (L) are measured.

Several density measurements of the rock were carried out during tilt testing. The samples were taken directly from the racks in the core shed, and consequently the measurements were done on air-dried samples. The unit weight specimens are chosen at approximately 100 m intervals. The specimens are cut as perfect cylinders from which the volumes are calculated. The balance used for weighing the specimens has an accuracy of 0.01g. The accuracy of the calliper used for measuring the size (height and diameter) of the specimens is of 0.01 mm.

The results were in the range 2,679–2,742 g/cm^3. In the calculations the densities listed in Table 4-2 have been used.

Table 4-2. Depth ranges in borehole KLX10 with the relevant unit weight used.

Depth Interval m	m	Unit weight kN/m³
100.00	349.95	26.79
349.95	446.83	27.42
446.83	500.00	27.27

4.3 Nonconformities

None.

5 Results from the tilt testing

5.1 General

The results from the different measurements were placed in Excel spreadsheet (Input data). Excel then calculated the different parameters which are exposed in another sheet (Output data).

Tables showing all the input and output data are given in Appendix A. Separate tables are presented for each of the three joint sets. A table displaying all the joint sets is also presented in Appendix A.

Complete input and output data from the tilt tests, such as JRC, JCS, Schmidt hammer readings, and roughness amplitudes are shown in the tables in Appendix A.

The 9 tilt test specimens have been selected from the total of about 900 m of core material of borehole KLX10 (101.13–1,001.20 m) in the depth range between 300 m and 500 m. As mentioned earlier, the fractures were classified in three sets according to the angle of intersection with the core. Each set may, however, consist of fractures with different dip, dip directions and different mineralization.

5.2 Results from Borehole KLX10

In the depth range 300–500 m from borehole KLX10, 9 tilt tests and 9×3 profilings on joints were performed. Complete input data and output data from tilt tests and profiling are found in Appendix A. Figures 5-1, 5-2 and 5-3 show the variation of the parameters JCS_o, JRC_o, Φ_r and Φ_b versus depth for each of the three joint sets respectively. All the results from borehole KLX10 are presented together in the plots. Table 5-1 shows the arithmetic mean values of these parameters. A summary of the tilt tests and profiling is also given in Table 5-1.

Table 5-1. Arithmetic mean JCS_o, JRC_o, Φ_r and Φ_b -values, borehole KLX10.

Fracture set	JRC_o (tilt)	JCS_o MPa	Φ_b (°)	Φ_r (°)	Number (tilt)	Number (profiles)
Set 1	7.01	107.35	31.3	27.29	3	3
Set 2	6.87	87.28	30.9	25.31	3	3
Set 3	7.47	87.04	31.5	26.71	3	3
Mean/total	7.12	93.89	31.2	26.43	9	9

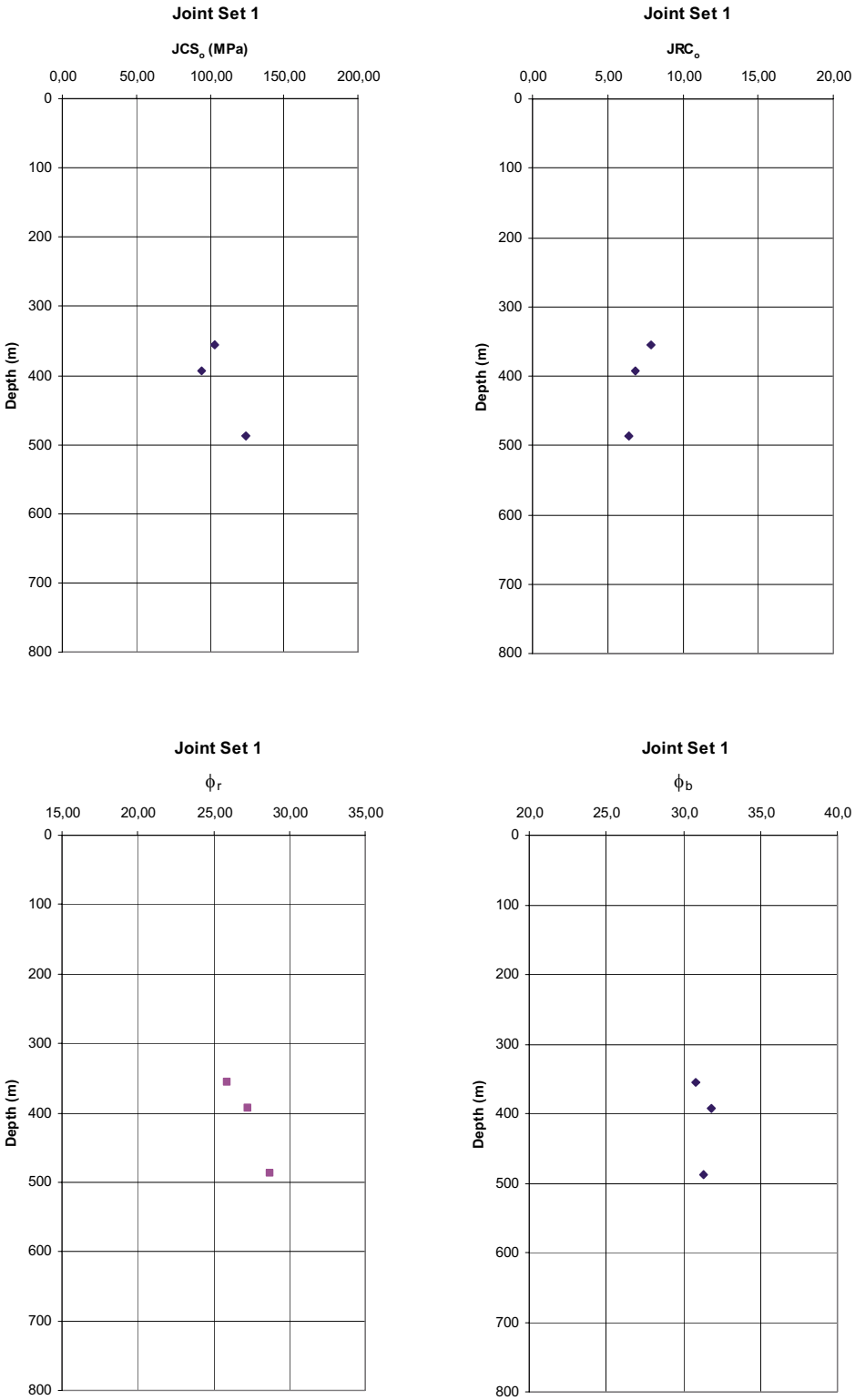

Figure 5-1. *Variation of joint parameters with depth for Set 1.*

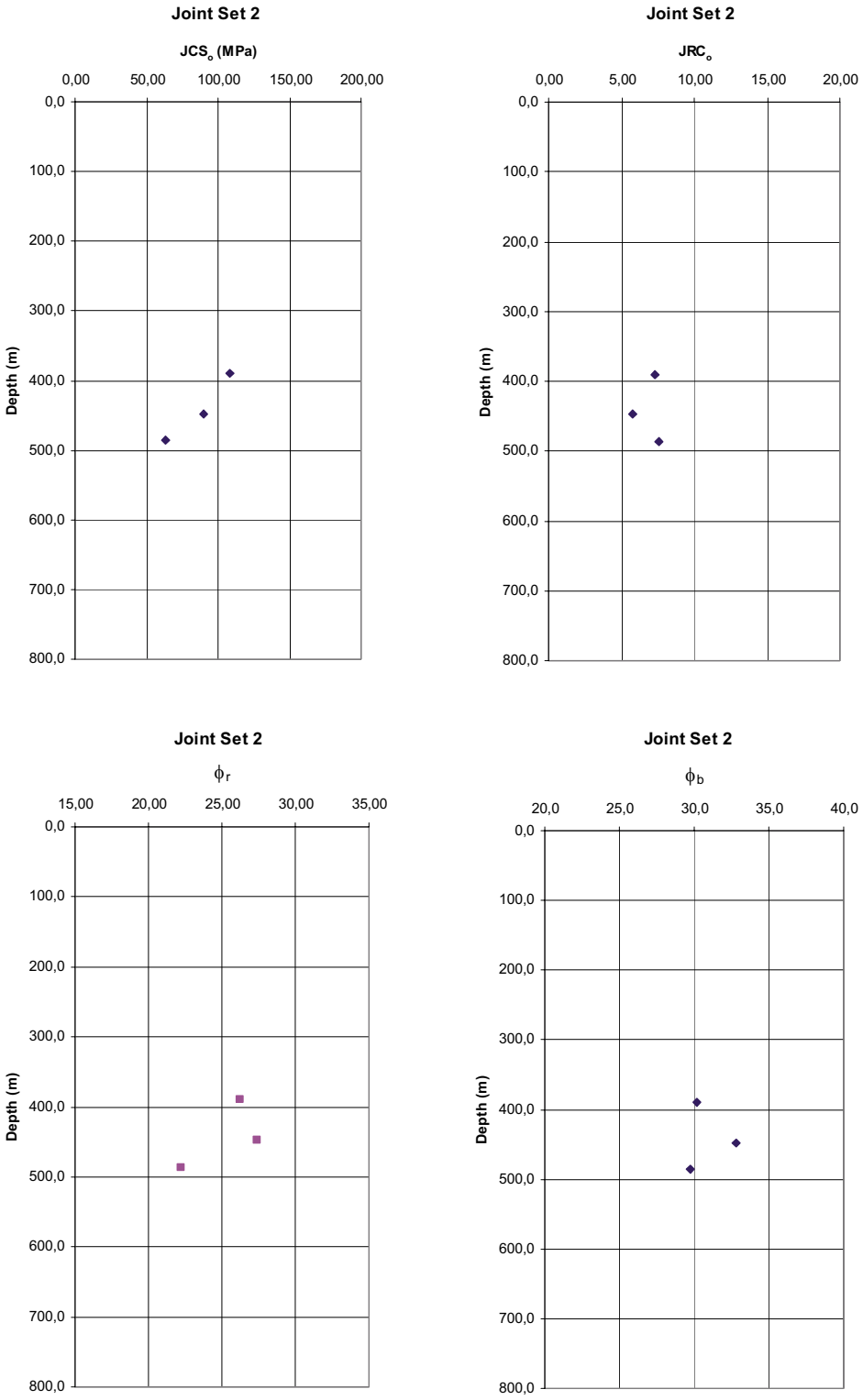

Figure 5-2. *Variation of joint parameters with depth for Set 2.*

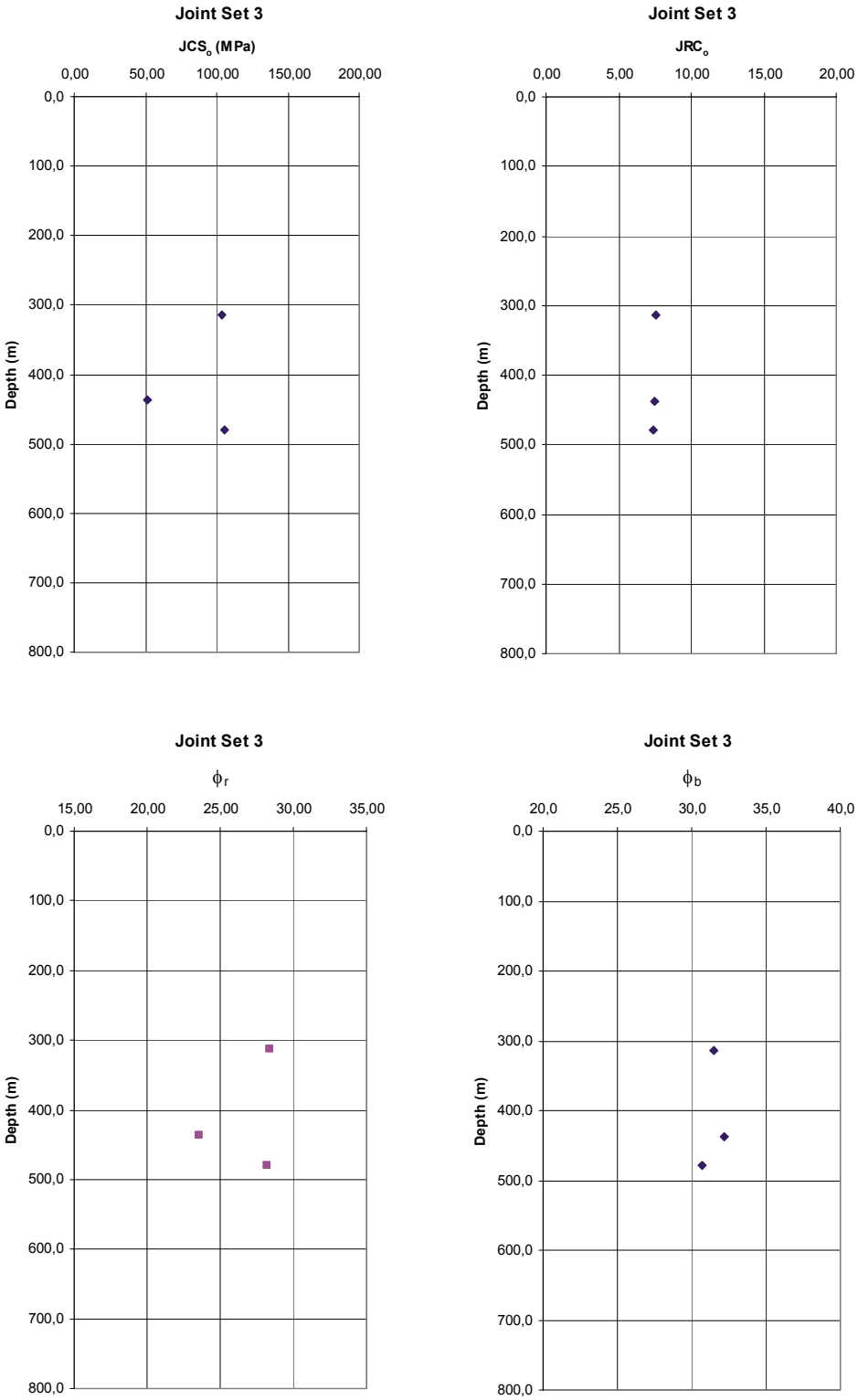

Figure 5-3. *Variation of joint parameters with depth for Set 3.*

5.3 Evaluation of the results

The joint faces are rather similar concerning mineralization, and the tilt tests show rather uniform JRC-values. Because of the small core diameter, the results are associated with some uncertainty, since the standard length for such tests is 100 mm, i.e. L_{100}. In terms of uncertainty level, the small number of tests for this borehole must be also taken into account. Tilting of samples with relatively high JRC-values is sometimes impossible, because toppling takes place before sliding. However, the selection of the tilt test samples did not take into account the possible toppling before sliding. In case of toppling, only profiling would have been carried out, but it did not prove to be necessary. All profiling is therefore taken in order to compare them with the tilt test results. If joints are too rough to reach shear failure by tilting, “pull test” should be performed using a calibrated equipment attached to the tilt table. The pull test is performed on a horizontally-placed joint sample.

In general, the joint roughness on all three joint sets varied between 5.8 and 7.9. This means that the sample selection for tilt testing is representative for the KLX10 borehole.

6 References

Janson T, 2002. Metodbeskrivning för: Bestämning av sprickegenskaperna: Råhetskoefficient, ytans tryckhållfasthet och den residuala friktionsvinkeln. SKB report MD 190.006 ver 1.0. Svensk Kärnbränslehantering AB.

Appendix A

The main results from tilt testing

ROCK JOINT CHARACTERISATION
CLIENT: SKB- Tilt tests

PAGE 1
Operator: PC
Date: 16/1/2006
Borehole: KLX10A

INPUT DATA Depth zone: 101,1-1001,2 m

F:\p\2003\10\20031089\Reports\Rap KLX10A\[alljoints KLX10A.xls]INPUT DATA 1

SAMPLE No	JOINT SET No	DEPTH (m)	ORIENT. DIP/ DIP DIR. (°)	MEAN JOINT AMP. a (mm)	MEAN JOINT LENG. L (mm)	MASS m (g)	AREA A (cm^2)	MEAN TILT ANGLE (°)	JOINT REBOUND NUMBER (r)	ROCK REBOUND NUMBER (R)	BASIC FRICTION ANGLE (°)	ROCK UNIT WEIGHT (kN/m^3)
1	set 1	355,397	Sicada	3,6	132,0	245,00	63,6	84,3	41,6	55,2	30,8	27,42
2	set 2	390,462	Sicada	3,3	57,0	111,00	26,9	74,0	42,5	53,0	30,2	27,42
3	set 3	313,747	Sicada	2,5	50,0	118,40	23,5	85,7	42,7	50,5	31,5	26,79
4	set 1	392,590	Sicada	3,7	187,3	318,10	78,9	70,3	40,0	51,8	31,8	27,42
5	set 2	447,395	Sicada	2,6	56,0	152,70	26,5	61,0	39,3	53,7	32,8	27,27
6	set 3	437,017	Sicada	2,1	48,0	120,40	20,7	66,3	29,0	51,2	32,2	27,42
7	set 1	486,976	Sicada	4,0	115,0	115,60	48,2	71,7	45,2	51,8	31,3	27,27
8	set 2	486,375	Sicada	5,2	79,7	179,80	35,6	67,0	33,1	52,7	29,7	27,27
9	set 3	479,097	Sicada	2,9	47,7	101,00	21,1	77,7	42,3	48,4	30,7	27,27
			Arithmetic av	3,3	85,9	162,4	38,3	73,1	39,5	52,0	31,2	27,3
			minimum val	2,1	47,7	101,0	20,7	61,0	29,0	48,4	29,7	26,8
			maximum va	5,2	187,3	318,1	78,9	85,7	45,2	55,2	32,8	27,4

ROCK JOINT CHARACTERISATION TESTED

CLIENT: SKB- Tilt tests

PAGE 3
Operator: PC
Date: 16/1/2006
Borehole: KLX10A

OUTPUT DATA Depth zone: 101,1-1001,2 m

F:\p\2003\10\20031089\Reports\Rap KLX10A\[alljoints KLX10A.xls]OUTPUT DATA

SAMPLE No	JOINT SET NO	DEPTH (m)	JCS_0 (MPa)	NORMAL STRESS (MPa)	RESIDUAL FRICTION ANGLE (°)	JRC_0 AT JOINT LENGTH	100mm DIVIDED BY JOINT LENGTH TESTED	EXTRPL`D JRC_{100}- VALUES 100 mm	EXTRPL`D JCS_{100}- VALUES 100 mm (MPa)
1	set 1	355,397	103,23	3,73E-06	25,9	7,85	0,76	8,20	110,20
2	set 2	390,462	108,52	3,07E-05	26,2	7,29	1,75	6,72	95,96
3	set 3	313,747	103,91	2,78E-06	28,4	7,56	2,00	6,81	88,79
4	set 1	392,590	94,45	4,49E-05	27,2	6,81	0,53	7,42	107,36
5	set 2	447,395	89,76	1,33E-04	27,4	5,76	1,79	5,39	81,21
6	set 3	437,017	51,26	9,22E-05	23,5	7,44	2,08	6,67	43,51
7	set 1	486,976	124,36	2,32E-05	28,8	6,38	0,87	6,50	127,74
8	set 2	486,375	63,55	7,56E-05	22,2	7,55	1,25	7,30	60,37
9	set 3	479,097	105,95	2,13E-05	28,2	7,39	2,10	6,63	89,90
		Arithmetic av.	93,89	4,75E-05	26,43	7,12	1,46	6,85	89,45
		maximum val.	124,36	1,33E-04	28,75	7,85	2,10	8,20	127,74
		minimum val.	51,26	2,78E-06	22,24	5,76	0,53	5,39	43,51

ROCK JOINT CHARACTERISATION

CLIENT: SKB- Tilt tests

	PAGE 1	
	Operator:	PC
	Date:	16/1/2006
	Borehole:	KLX10A

INPUT DATA

Depth zone: 101,1-1001,2 m

F:\p\2003\10\20031089\Reports\Rap KLX10A\[set 1 KLX10A.xls]INPUT DATA 1

SAMPLE No	JOINT SET No	DEPTH (m)	ORIENT. DIP/ DIP DIR. (°)	MEAN JOINT AMP. a (mm)	MEAN JOINT LENG. L (mm)	MASS m (g)	AREA A (cm^2)	MEAN TILT ANGLE (°)	JOINT REBOUND NUMBER (r)	ROCK REBOUND NUMBER (R)	BASIC FRICTION ANGLE (°)	ROCK UNIT WEIGHT (kN/m^3)
1	set 1	355,397	Sicada	3,6	132,0	245,00	63,6	84,3	41,6	55,2	30,8	27,42
2	set 1	392,590	Sicada	3,7	187,3	318,10	78,9	70,3	40,0	51,8	31,8	27,42
3	set 1	486,976	Sicada	4,0	115,0	115,60	48,2	71,7	45,2	51,8	31,3	27,27
			Arithmetic av	3,8	144,8	226,2	63,6	75,4	42,3	52,9	31,3	27,4
			minimum val	3,6	115,0	115,6	48,2	70,3	40,0	51,8	30,8	27,3
			maximum va	4,0	187,3	318,1	78,9	84,3	45,2	55,2	31,8	27,4

ROCK JOINT CHARACTERISATION

TESTED

CLIENT: SKB- Tilt tests

	PAGE 3	
	Operator:	PC
	Date:	16/1/2006
	Borehole:	KLX10A

OUTPUT DATA

Depth zone: 101,1-1001,2 m

F:\p\2003\10\20031089\Reports\Rap KLX10A\[set 1 KLX10A.xls]OUTPUT DATA

SAMPLE No	JOINT SET NO	DEPTH (m)	JCS_0 (MPa)	NORMAL STRESS (MPa)	RESIDUAL FRICTION ANGLE (°)	JRC_0 AT JOINT LENGTH	100mm DIVIDED BY JOINT LENGTH TESTED	EXTRPL`D JRC_{100}- VALUES 100 mm	EXTRPL`D JCS_{100}- VALUES 100 mm (MPa)
1	set 1	355,397	103,23	3,73E-06	25,9	7,85	0,76	8,20	110,20
2	set 1	392,590	94,45	4,49E-05	27,2	6,81	0,53	7,42	107,36
3	set 1	486,976	124,36	2,32E-05	28,8	6,38	0,87	6,50	127,74
		Arithmetic av.	107,35	2,39E-05	27,29	7,01	0,72	7,37	115,10
		maximum val.	124,36	4,49E-05	28,75	7,85	0,87	8,20	127,74
		minimum val.	94,45	3,73E-06	25,87	6,38	0,53	6,50	107,36

ROCK JOINT CHARACTERISATION

CLIENT: SKB- Tilt tests

	PAGE 1	
	Operator:	PC
	Date:	16/1/2006
	Borehole:	KLX10A

INPUT DATA

Depth zone: 101,1-1001,2 m

F:\p\2003\10\20031089\Reports\Rap KLX10A\[set 2 KLX10A.xls]INPUT DATA 1

SAMPLE No	JOINT SET No	DEPTH (m)	ORIENT. DIP/ DIP DIR. (°)	MEAN JOINT AMP. a (mm)	MEAN JOINT LENG. L (mm)	MASS m (g)	AREA A (cm^2)	MEAN TILT ANGLE (°)	JOINT REBOUND NUMBER (r)	ROCK REBOUND NUMBER (R)	BASIC FRICTION ANGLE (°)	ROCK UNIT WEIGHT (kN/m^3)
1	set 2	390,462	Sicada	3,3	57,0	111,00	26,9	74,0	42,5	53,0	30,2	27,42
2	set 2	447,395	Sicada	2,6	56,0	152,70	26,5	61,0	39,3	53,7	32,8	27,27
3	set 2	486,375	Sicada	5,2	79,7	179,80	35,6	67,0	33,1	52,7	29,7	27,27
			Arithmetic av	3,7	64,2	147,8	29,7	67,3	38,3	53,1	30,9	27,3
			minimum val	2,6	56,0	111,0	26,5	61,0	33,1	52,7	29,7	27,3
			maximum va	5,2	79,7	179,8	35,6	74,0	42,5	53,7	32,8	27,4

ROCK JOINT CHARACTERISATION

TESTED

CLIENT: SKB- Tilt tests

	PAGE 3	
	Operator:	PC
	Date:	16/1/2006
	Borehole:	KLX10A

OUTPUT DATA

Depth zone: 101,1-1001,2 m

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SAMPLE No	JOINT SET NO	DEPTH (m)	JCS_0 (MPa)	NORMAL STRESS (MPa)	RESIDUAL FRICTION ANGLE (°)	JRC_0 AT JOINT LENGTH	100mm DIVIDED BY JOINT LENGTH TESTED	EXTRPL`D JRC_{100}- VALUES 100 mm	EXTRPL`D JCS_{100}- VALUES 100 mm (MPa)
1	set 2	390,462	108,52	3,07E-05	26,2	7,29	1,75	6,72	95,96
2	set 2	447,395	89,76	1,33E-04	27,4	5,76	1,79	5,39	81,21
3	set 2	486,375	63,55	7,56E-05	22,2	7,55	1,25	7,30	60,37
		Arithmetic av.	87,28	7,97E-05	25,31	6,87	1,60	6,47	79,18
		maximum val.	108,52	1,33E-04	27,44	7,55	1,79	7,30	95,96
		minimum val.	63,55	3,07E-05	22,24	5,76	1,25	5,39	60,37

ROCK JOINT CHARACTERISATION

CLIENT: SKB- Tilt tests

	PAGE 1	
	Operator:	PC
	Date:	16/1/2006
	Borehole:	KLX10A

INPUT DATA

Depth zone: 101,1-1001,2 m

F:\p\2003\10\20031089\Reports\Rap KLX10A\[set 3 KLX10A.xls]INPUT DATA 1

SAMPLE No	JOINT SET No	DEPTH (m)	ORIENT. DIP/ DIP DIR. (°)	MEAN JOINT AMP. a (mm)	MEAN JOINT LENG. L (mm)	MASS m (g)	AREA A (cm^2)	MEAN TILT ANGLE (°)	JOINT REBOUND NUMBER (r)	ROCK REBOUND NUMBER (R)	BASIC FRICTION ANGLE (°)	ROCK UNIT WEIGHT (kN/m^3)
1	set 3	313,747	Sicada	2,5	50,0	118,40	23,5	85,7	42,7	50,5	31,5	26,79
2	set 3	437,017	Sicada	2,1	48,0	120,40	20,7	66,3	29,0	51,2	32,2	27,42
3	set 3	479,097	Sicada	2,9	47,7	101,00	21,1	77,7	42,3	48,4	30,7	27,27
			Arithmetic av	2,5	48,6	113,3	21,8	76,6	38,0	50,0	31,5	27,2
			minimum val	2,1	47,7	101,0	20,7	66,3	29,0	48,4	30,7	26,8
			maximum va	2,9	50,0	120,4	23,5	85,7	42,7	51,2	32,2	27,4

ROCK JOINT CHARACTERISATION

TESTED

CLIENT: SKB- Tilt tests

	PAGE 3	
	Operator:	PC
	Date:	16/1/2006
	Borehole:	KLX10A

OUTPUT DATA

Depth zone: 101,1-1001,2 m

F:\p\2003\10\20031089\Reports\Rap KLX10A\[set 3 KLX10A.xls]OUTPUT DATA

SAMPLE No	JOINT SET NO	DEPTH (m)	JCS_0 (MPa)	NORMAL STRESS (MPa)	RESIDUAL FRICTION ANGLE (°)	JRC_0 AT JOINT LENGTH	100mm DIVIDED BY JOINT LENGTH TESTED	EXTRPL`D JRC_{100}- VALUES 100 mm	EXTRPL`D JCS_{100}- VALUES 100 mm (MPa)
1	set 3	313,747	103,91	2,78E-06	28,4	7,56	2,00	6,81	88,79
2	set 3	437,017	51,26	9,22E-05	23,5	7,44	2,08	6,67	43,51
3	set 3	479,097	105,95	2,13E-05	28,2	7,39	2,10	6,63	89,90
		Arithmetic av.	87,04	3,87E-05	26,71	7,47	2,06	6,70	74,07
		maximum val.	105,95	9,22E-05	28,41	7,56	2,10	6,81	89,90
		minimum val.	51,26	2,78E-06	23,53	7,39	2,00	6,63	43,51