P-04-205

Forsmark site investigation

Borehole: KFM05A
Tilt testing

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August 2004

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Keywords: AP PF 400-04-67, Field note no Forsmark 371, 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 KFM05A, Forsmark, during the period June 7th–10th, 2004. From a total drill core length of about 900 m, 9 tilt tests were performed on three sets of joints.

The main results from the tilt tests are rather uniform regarding all 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 6.5. The mean value of the joint wall compressive strength (JCS_o) from Schmidt hammer testing of all the joint samples is 85.4 MPa. The mean values of the basic (Φ_b) and residual (Φ_r) friction angles of all the tested samples are 31.0 and 27.5 degrees respectively.

Sammanfattning

Norges Geotekniska Institut (NGI) har utfört s k tilttester på öppna sprickor i borrkärne-prover från borrhål KFM05A i Forsmark. Utifrån en sammanlagd borrkärnelängd på ca 900 m utvaldes 9 prover för tilttester på tre sprickgrupper.

Resultaten är relativt enhetliga för samtliga sprickor och uppvisar inga stora variationer. Medelvärdet för råhetskoefficienten, JRC_o, för alla sprickor är 6.5. För sprickväggens tryckhållfasthet, JCS_0, som uppmättes med Schmidthammarprovning, uppgår medelvärdet till 85,4 MPa. Medelvärdet för basfriktionsvinkeln, Φ_b, och residualfriktionsvinkeln, Φ_r, beräknat utifrån alla testade prover, är 31,0 respektive 27,5 grader.

Contents

1 Introduction

The Norwegian Geotechnical Institute (NGI) has carried out 9 tilt tests on joint surfaces of drill cores from borehole KFM05A at Forsmark in Sweden according to SKB Activity Plan AP PF 400-04-67, Version 1.0 (SKB internal controlling document).

The work has been performed by Panayiotis Chryssanthakis and Pawel Jankowski during the period June 7th–10th, 2004, in accordance with SKB's method description MD 190.006, Version 1.0 (SKB internal controlling document).

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 Forsmark.

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 (field note no Forsmark 371).

Table 2-1. Total number of tilt tests.

Borehole	Tilt tests	No of joint sets
KFM05A	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 the 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.

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.

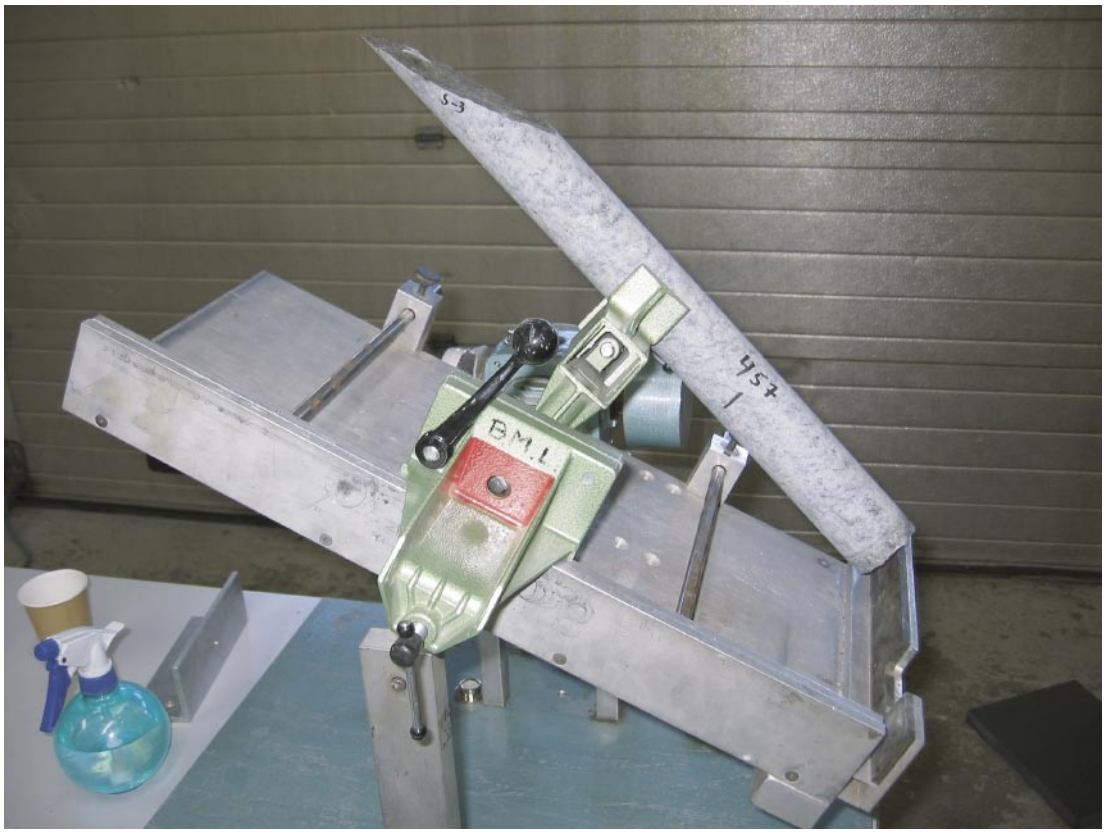

Figure 3-1. *NGI's tilt test apparatus.*

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

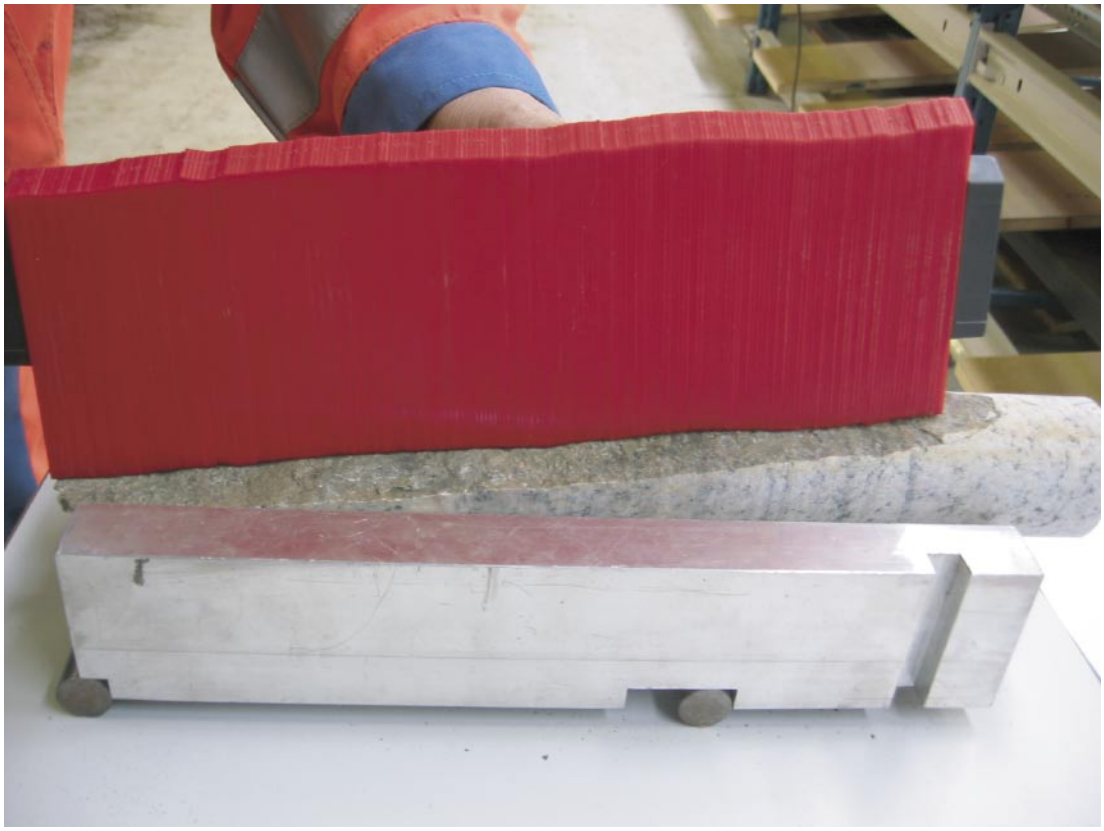

Figure 3-3. *Profilometer applied on a joint surface.*

4 Execution

4.1 Sampling

The samples were collected 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 per approximately 16 to 22 metres in the depth range between 370 m and 610 m borehole length (borehole KFM05A is inclined 60° to the horizontal plane). A selection of 9 tilt samples were collected 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.

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

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

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.

Three profilings on each tilt joint surface have also been carried out. The rocks can be classified as mainly metamorphic, including granite, granodiorite, tonalite with some veins of amphibolite, and pegmatite. 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 KFM05A 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° in these tests. However, in some cases the characteristics of the sample change during testing. For example fracture coating may be removed, and therefore a variation of more than 3° 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 the R-value, Schmidt hammer readings on fresh, dry cores near the joint for tilting were performed with 10 blows. The lower five blow values were again eliminated.

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

Profiling of the tilt tested fractures was carried out by means of a profilometer, and the profiles were drawn on a paper by pulling a pencil along the edge of the profilometer. For each fracture, three parallel profiles were 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) were measured.

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

The results were in the range 2,657–2,663 g/cm^3. The densities listed in Table 4-2 have been used for the calculations.

Table 4-2. Depth ranges in borehole KFM05A with the relevant unit weight used.

Depth m	Interval m	Unit weight kN/m^3
150.00	413.45	26.63
413.45	500.70	26.57
500.70	742.00	26.61

4.3 Nonconformities

None.

5 Results from the tilt testing

5.1 General

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

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. Separate tables are presented for each of the three joint sets. A table displaying all the joint sets is also presented in Appendix.

5.2 Results from borehole KFM05A

9 tilt tests and 9×3 profilings on joints were performed on core samples from section 370–610 m (borehole length) in borehole KFM05A. Complete input and output data from tilt tests and profiling are found in Appendix. 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 results from borehole KFM05A 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 KFM05A.

Fracture set	JRC_o (tilt)	JCS_o MPa	Φ_b (°)	Φ_r (°)	Number (tilt)	Number (profiles)
Set 1	7.45	98.24	30.5	28.00	3	3
Set 2	5.56	89.94	32.4	29.39	3	3
Set 3	6.53	68.18	30.1	25.08	3	3
Mean/Total	**6.51**	**85.45**	**31.0**	**27.49**	**9**	**9**

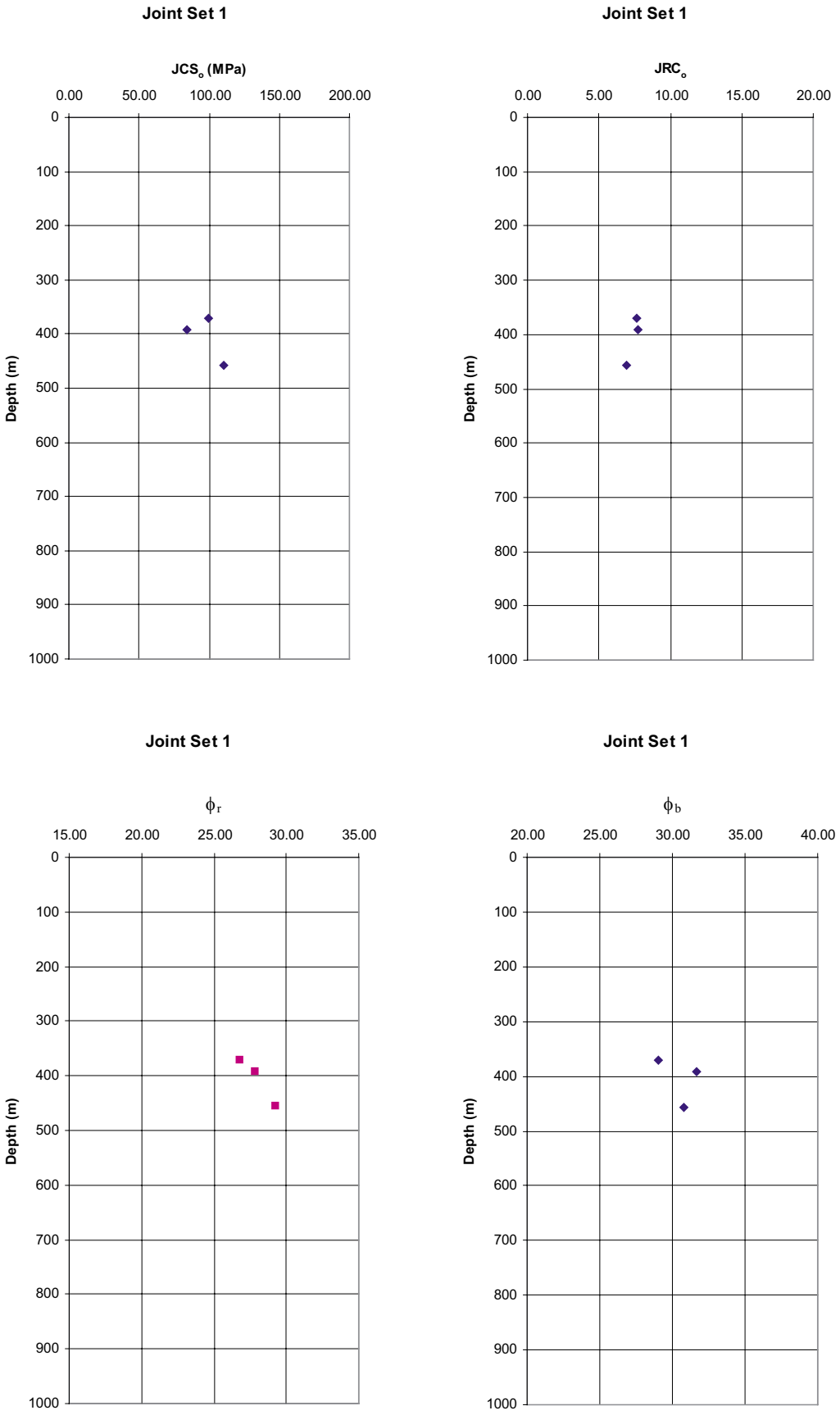

Figure 5-1. *Variation of joint parameters with depth for Set 1.*

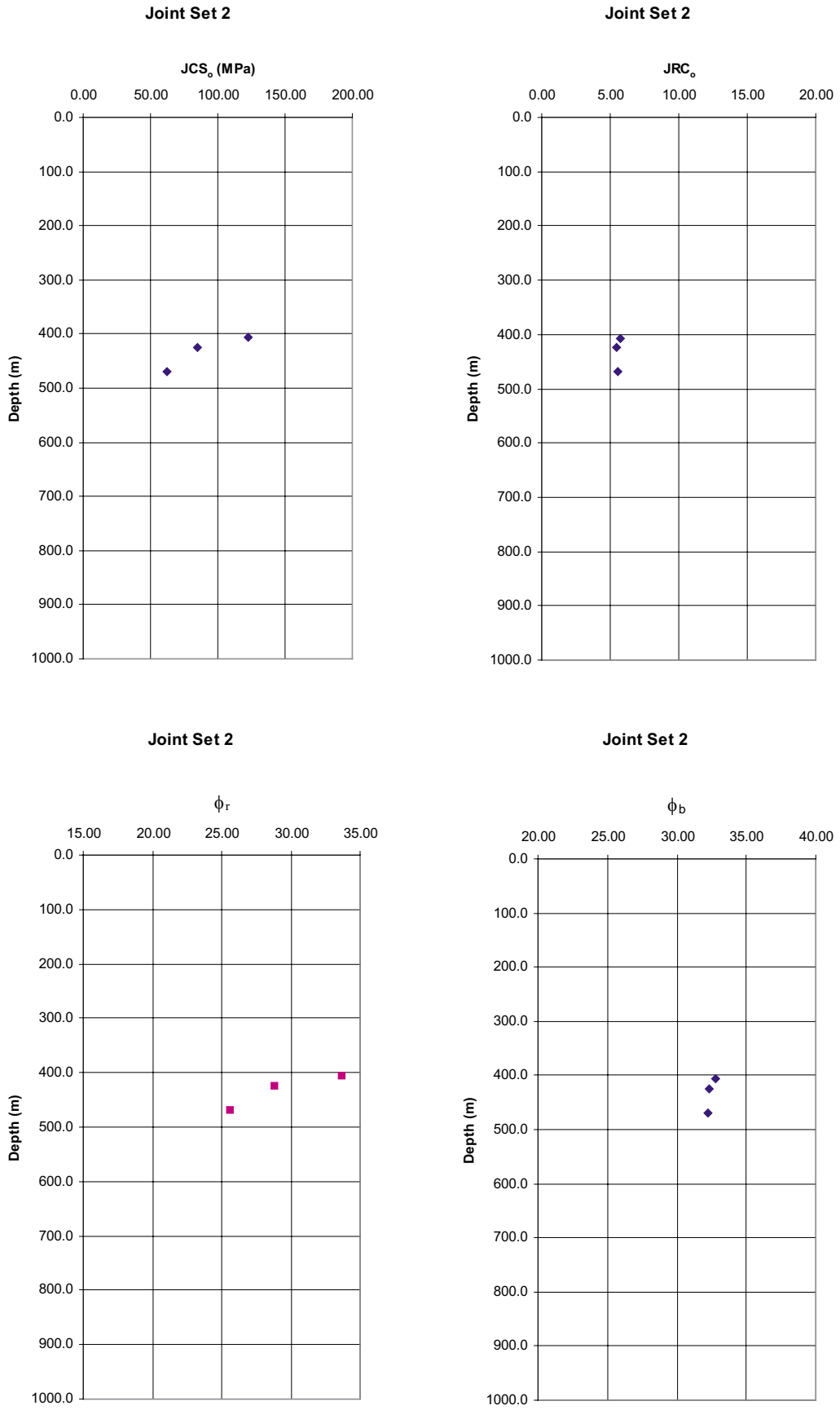

Figure 5-2. *Variation of joint parameters with depth for Set 2.*

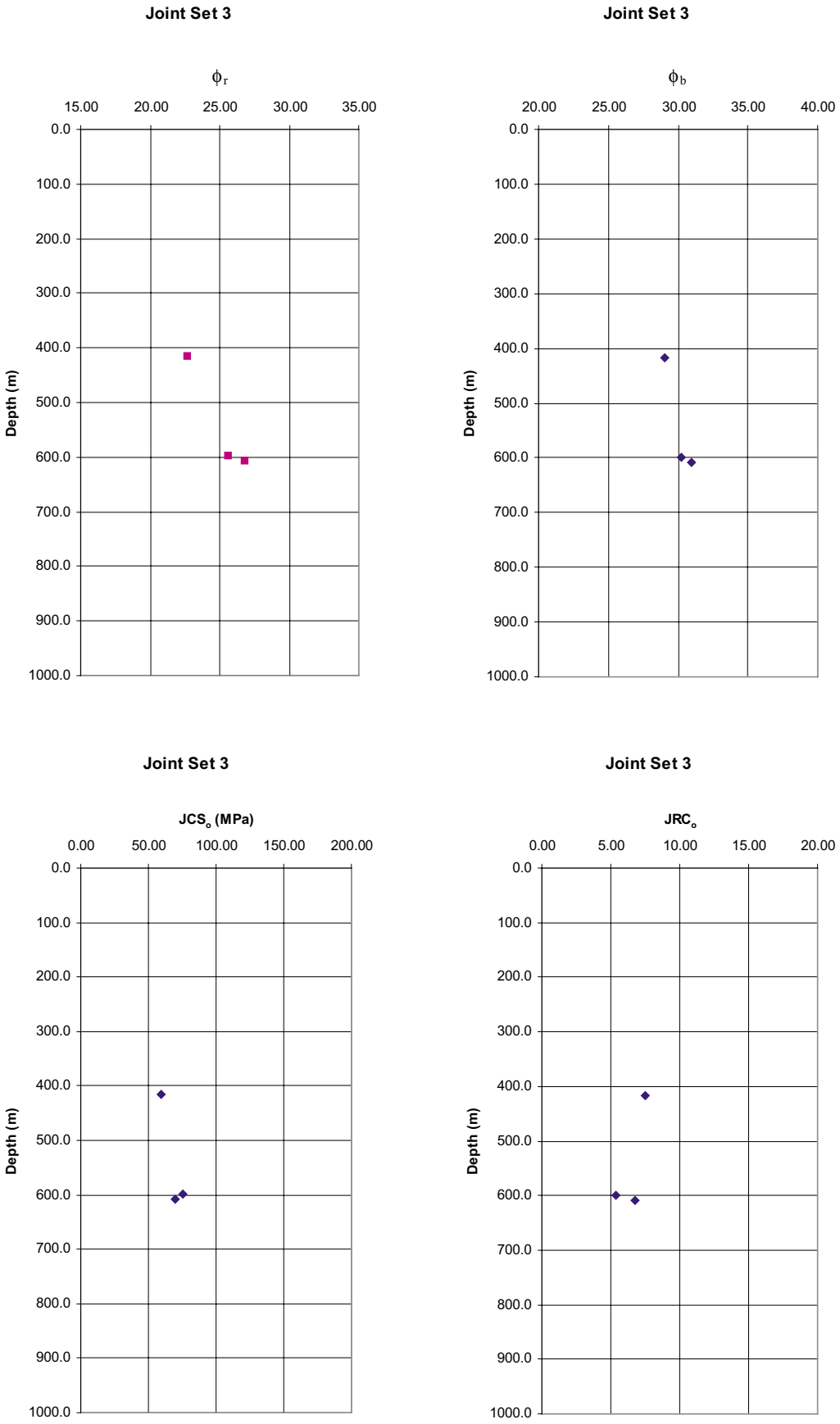

Figure 5-3. *Variation of joint parameters with depth for Set 3.*

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 5.4 and 7.8. This means that the sample selection for tilt testing is representative for borehole KFM05A.

The main results from tilt testing

ROCK JOINT CHARACTERISATION
CLIENT: SKB- Tilt tests

	PAGE 1
Operator:	PC
Date:	2004-06-07
Borehole:	KFM05A

INPUT DATA Depth zone: 100.3–1002.7m

#Saknas!

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 REBOUN NUMBE (r)	ROCK REBOUND NUMBER (R)	BASIC FRICTION ANGLE (°)	ROCK UNIT WEIGHT (kN/m^3)
1	set 1	370,363	SICADA	1,5	89,0	150,50	41,7	86,0	42,2	47,4	29,0	26,63
2	set 1	392,033	SICADA	3,0	110,7	256,70	53,4	82,5	39,2	48,4	31,7	26,57
3	set 1	456,728	SICADA	3,6	124,0	306,40	57,1	74,0	44,2	47,8	30,8	26,57
			Arithmetic av.	2,7	107,9	237,9	50,7	80,8	41,9	47,9	30,5	26,6
			minimum val.	1,5	89,0	150,5	41,7	74,0	39,2	47,4	29,0	26,6
			maximum val.	3,6	124,0	306,4	57,1	86,0	44,2	48,4	31,7	26,6

ROCK JOINT CHARACTERISATION TESTED

CLIENT: SKB- Tilt tests

	PAGE 3
Operator:	PC
Date:	07.06.2004
Borehole:	KFM05A

OUTPUT DATA Depth zone: 100.3–1,002.7m

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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 1	370.363	99.75	1.72E-06	26.8	7.63	1.12	7.49	97.13
2	set 1	392.033	84.44	8.03E-06	27.9	7.78	0.90	7.90	86.47
3	set 1	456.728	110.53	4.00E-05	29.3	6.94	0.81	7.15	115.59
		Arithmetic av.	98.24	1.66E-05	28.00	7.45	0.94	7.51	99.73
		minimum val.	84.44	1.72E-06	26.81	6.94	0.81	7.15	86.47
		maximum val.	110.53	4.00E-05	29.29	7.78	1.12	7.90	115.59

ROCK JOINT CHARACTERISATION

CLIENT: SKB- Tilt tests

	PAGE 1
Operator:	PC
Date:	2004-06-07
Borehole:	KFM05A

INPUT DATA

Depth zone: 100.3–1002.7m

#Saknas!

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 REBOUN NUMBE (r)	ROCK REBOUND NUMBER (R)	BASIC FRICTION ANGLE (°)	ROCK UNIT WEIGHT (kN/m^3)
1	set 1	370,363	SICADA	1,5	89,0	150,50	41,7	86,0	42,2	47,4	29,0	26,63
2	set 1	392,033	SICADA	3,0	110,7	256,70	53,4	82,5	39,2	48,4	31,7	26,57
3	set 1	456,728	SICADA	3,6	124,0	306,40	57,1	74,0	44,2	47,8	30,8	26,57
			Arithmetic av.	2,7	107,9	237,9	50,7	80,8	41,9	47,9	30,5	26,6
			minimum val.	1,5	89,0	150,5	41,7	74,0	39,2	47,4	29,0	26,6
			maximum val.	3,6	124,0	306,4	57,1	86,0	44,2	48,4	31,7	26,6

ROCK JOINT CHARACTERISATION

TESTED

CLIENT: SKB- Tilt tests

	PAGE 3
Operator:	PC
Date:	07.06.2004
Borehole:	KFM05A

OUTPUT DATA

Depth zone: 100.3–1,002.7m

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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 1	370.363	99.75	1.72E-06	26.8	7.63	1.12	7.49	97.13
2	set 1	392.033	84.44	8.03E-06	27.9	7.78	0.90	7.90	86.47
3	set 1	456.728	110.53	4.00E-05	29.3	6.94	0.81	7.15	115.59
		Arithmetic av.	98.24	1.66E-05	28.00	7.45	0.94	7.51	99.73
		minimum val.	84.44	1.72E-06	26.81	6.94	0.81	7.15	86.47
		maximum val.	110.53	4.00E-05	29.29	7.78	1.12	7.90	115.59

ROCK JOINT CHARACTERISATION

CLIENT: SKB- Tilt tests

PAGE 1	
Operator:	PC
Date:	07.06.2004
Borehole:	KFM05A

INPUT DATA

Depth zone: 100.3–1,002.7 m

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	406.909	SICADA	1.8	53.3	128.90	24.5	69.7	46.0	44.0	32.8	26.63
2	set 2	424.669	SICADA	1.9	61.3	154.90	27.2	60.3	39.3	47.6	32.3	26.57
3	set 2	468.596	SICADA	1.7	49.0	141.80	24.7	56.3	33.6	50.0	32.2	26.57
			Arithmetic a	1.8	54.5	141.9	25.5	62.1	39.6	47.2	32.4	26.6
			minimum va	1.7	49.0	128.9	24.5	56.3	33.6	44.0	32.2	26.6
			maximum va	1.9	61.3	154.9	27.2	69.7	46.0	50.0	32.8	26.6

ROCK JOINT CHARACTERISATION

TESTED

CLIENT: SKB- Tilt tests

PAGE 3	
Operator:	PC
Date:	07.06.2004
Borehole:	KFM05A

OUTPUT DATA

Depth zone: 100.3–1,002.7 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	406.909	122.46	6.21E-05	33.7	5.72	1.88	5.32	109.93
2	set 2	424.669	84.90	1.37E-04	28.8	5.44	1.63	5.15	78.38
3	set 2	468.596	62.46	1.73E-04	25.6	5.52	2.04	5.10	55.51
		Arithmetic av.	89.94	1.24E-04	29.39	5.56	1.85	5.19	81.27
		minimum val.	62.46	6.21E-05	25.64	5.44	1.63	5.10	55.51
		maximum val.	122.46	1.73E-04	33.71	5.72	2.04	5.32	109.93

ROCK JOINT CHARACTERISATION

CLIENT: SKB- Tilt tests

	PAGE 1	
	Operator:	PC
	Date:	2004-06-07
	Borehole:	KFM05A

INPUT DATA

Depth zone: 100.3–1,002.7 m

#Saknas!

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 REBOUN NUMBE (r)	ROCK REBOUND NUMBER (R)	BASIC FRICTION ANGLE (°)	ROCK UNIT WEIGHT (kN/m^3)
1	set 3	416,538	SICADA	1,2	44,0	133,20	21,4	65,7	32,7	47,6	29,0	26,57
2	set 3	598,963	SICADA	2,1	56,0	170,60	25,2	55,7	37,1	48,0	30,2	26,61
3	set 3	608,285	SICADA	2,2	62,0	166,90	28,3	66,3	35,5	44,8	31,0	26,61
			Arithmetic av.	1,8	54,0	156,9	25,0	62,6	35,1	46,8	30,1	26,6
			minimum val.	1,2	44,0	133,2	21,4	55,7	32,7	44,8	29,0	26,6
			maximum val.	2,2	62,0	170,6	28,3	66,3	37,1	48,0	31,0	26,6

ROCK JOINT CHARACTERISATION

TESTED

CLIENT: SKB- Tilt tests

	PAGE 3	
	Operator:	PC
	Date:	07.06.2004
	Borehole:	KFM05A

OUTPUT DATA

Depth zone: 100.3–1,002.7 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 3	416.538	59.51	1.03E-04	22.7	7.46	2.27	6.60	49.52
2	set 3	598.963	75.64	2.11E-04	25.7	5.41	1.79	5.08	68.85
3	set 3	608.285	69.39	9.34E-05	26.8	6.72	1.61	6.30	63.01
		Arithmetic av.	68.18	1.36E-04	25.08	6.53	1.89	5.99	60.46
		minimum val.	59.51	9.34E-05	22.74	5.41	1.61	5.08	49.52
		maximum val.	75.64	2.11E-04	26.85	7.46	2.27	6.60	68.85