P-04-272

Oskarshamn site investigation

Drill hole KAV04A:

Extensometer measurement of the coefficient of thermal expansion of rock

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October 2004

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Keywords: Rock mechanics, Coefficient of thermal expansion, Temperature change, Density, Porosity.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author and do not necessarily coincide with those of the client.

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Abstract

The coefficient of thermal expansion and the wet density has been determined on specimens from drill hole KAV04A. The specimens were sampled at one level in the drill hole at a depth of approximately 500 m. The rock types are mapped as Ävrö granite and Quartz monzodiorite. The coefficient of thermal expansion has been determined in the temperature interval 20–80°C. The results indicated that the thermal expansion was almost linear, and the coefficient of thermal expansion for the investigated specimens ranged between 4.6 and 9.5×10^{-6} mm/mm°C.

Sammanfattning

Längdutvidgningskoefficienten och våtdensiteten har bestämts på prover från borrhål KAV04A. Proverna kommer från en nivå i borrhålet, på ett ungefärligt djup av 500 m. De undersökta proverna är karterad som Ävrö granit och Kvartsmonzodiorit. Längdutvidgnin gskoefficienten bestämdes inom temperaturintervallet 20–80°C. Resultaten indikerade att längdutvidgningen var nästan linjär och längdutvidgningskoefficienten för de undersökta proverna varierade mellan 4.6 and 9.5×10^{-6} mm/mm°C.

Contents

1 Introduction

This document reports the data collected at the Laxemar site, which is one of the activities performed as part of the site investigation at Oskarshamn. The work was carried out in accordance with the activity plan AP PS 400–04-074 (SKB internal controlling document).

The purpose of the measurement is to determine the coefficient of thermal expansion at different temperatures.

The cores are sampled from borehole KAV04A at the Laxemar area (Figure 1-1). They were sampled 14 June 2004 by Thomas Janson, Tyréns AB. The specimens were taken from one level at a depth of approximately 500 m. The rock cores were transported by SKB and arrived to SP in August 2004. The testing was performed in September and October 2004 (see Appendix 1).

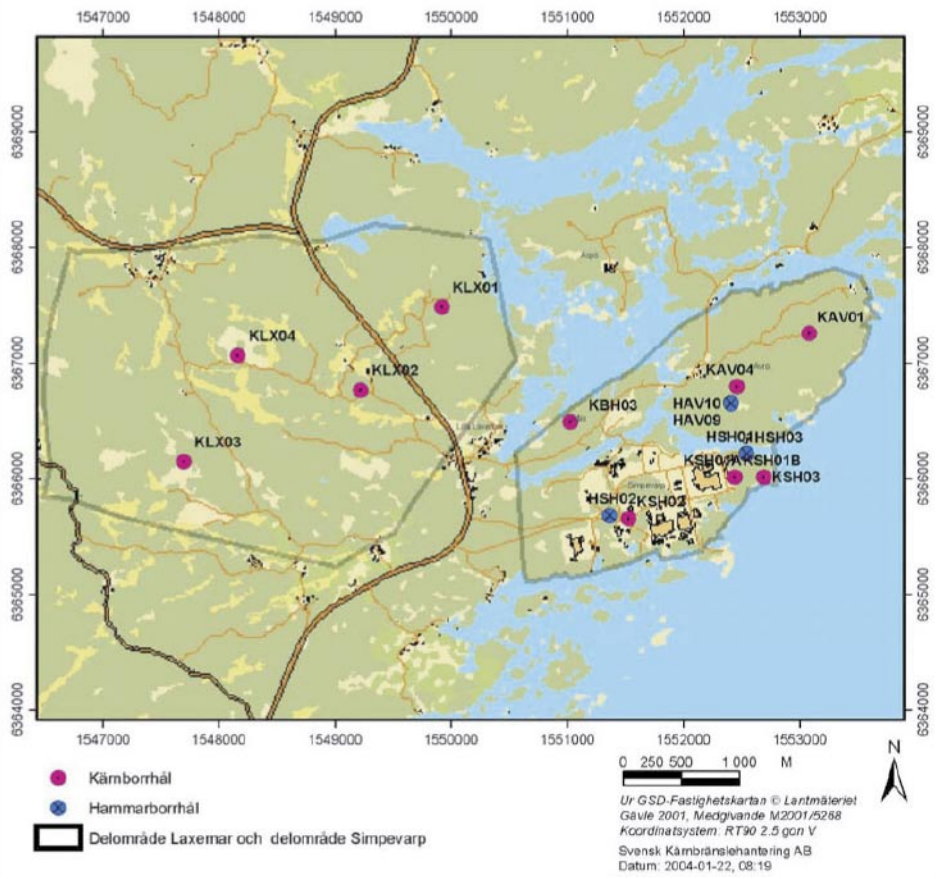


Figure 1-1. *The Oskarshamn site investigation area.*

2 Objective and scope

The purpose is to determine the linear coefficient of thermal expansion for rock cores in water-saturated condition in the interval +20–80°C.

These parameters will be used in a rock mechanical model for the Oskarshamn site area, performed by SKB. The specimens and the results will be presented in tables, diagrams and spreadsheets.

3 Equipment

Following equipment have been used for the analyses:

- Extensometer (DEMEC inv no 102266) for measurement of the thermal expansion. Calibration of the instrument was done for each temperature interval(see Appendix 1). The uncertainty of the extensometer is $\pm 3.97\times10^{-6}$ mm/mm (strain), which equals an uncertainty of a single measurement of the coefficient of thermal expansion of $\pm 0.2\times10^{-6}$ mm/mm^{o}C for a temperature difference of 20 degrees C.
- Reference bar in invar steel for calibrate the extensometer.
- Heating chamber (inv no 102284) with an accuracy of ± 0.7°C at 80°C for heating up the specimens.
- A covered plastic box filled with water for keeping the specimens water saturated.

4 Execution

Determination of the coefficient of thermal expansion was made in accordance with SKB's method description SKB MD 191.002, Version 2.0 (SKB internal controlling document). The Department of Building Technology and Mechanics (BM) at SP performed the test.

4.1 Description of the samples

From the Laxemar area specimens were sampled from one level at a depth of approximately 500 m, in drill hole KAV04A. The sampled rock type is mapped as Quartz monzodiorite. Table 4-1 show the rock type and identification marks of the specimens.

Table 4-1. Rock type and identification marks (Rock-type classification according to Boremap).

Rock type	Identification	Sampling depth, according to bore map (Sec low)
Quartz monzodiorite	KAV04A-90L-1	492.90
Quartz monzodiorite	KAV04A-90L-2	494.24
Quartz monzodiorite	KAV04A-90L-3	494.49
Ävrö granite	KAV04A-90L-4	519.82
Ävrö granite	KAV04A-90L-5	520.07
Ävrö granite	KAV04A-90L-6	522.14

4.2 Testing

The execution procedure followed the prescription in SKB MD 191.002, Version 2.0 and SKB MD 160.002, Version 2.0 (SKB internal controlling document) and the following steps were performed:

Item	Activity
1	The specimens were cut according to the marks on the rock cores.
2	Two measuring points with a distance of 200 mm were glued on the specimens.
3	The specimens were photographed in JPEG-format.
4	The specimens were water saturated for seven days.
5	The wet density was determined (See Appendix 2)
6	The coefficient of thermal expansion was determined. The thermal expansion was measured at 20, 40, 60 and 80°C. On each temperature level was three to five measurements done with 24 h intervals in order to know that the expansion was completed for each temperature level (See Appendix 1). The coefficient of thermal expansion was determined between 20–80°C.

5 Results

The main results of the site investigation of KAV04A could be found in the SICADA database, FN 428.

5.1 Description of the specimens and presentation of the results

The temperature of water for water saturation was 20.0°C and the density of the water was 999 kg/m^3. The coefficient of thermal expansion was determined between +20–80°C. Figures 5-1 to 5-5 shows pictures and diagrams of the tested specimens for the thermal expansion in the intervals 20, 40, 60 and 80°C.

KAV04A-90L-1 (492.90 m)

Figure 5-1. *Diagram showing the thermal expansion of specimen KAV04A-90L-1 between 20 and 80°C, median values plotted.*

The Figure 5-1 shows a picture of the specimen and a diagram for the thermal expansion in the interval 20, 40, 60, 80°C. The coefficient of thermal expansion for specimen KAV04A-90L-1 was measured to be 8.6×10^{-6} mm/mm°C and the specimen had a wet density to 2,903 kg/m^3.

KAV04A-90L-2 (494.24 m)

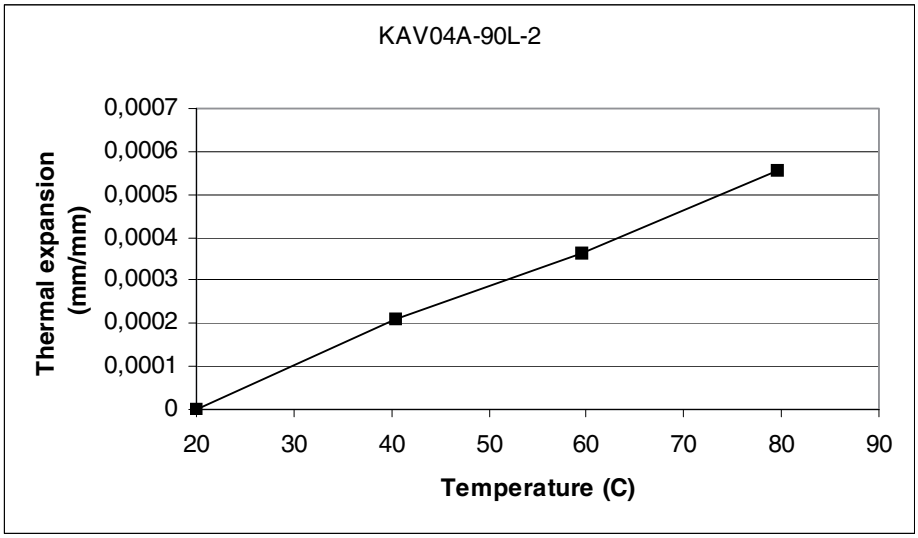


Figure 5-2. *Diagram showing the thermal expansion of specimen KAV04A-90L-2 between 20 and 80°C, median values plotted.*

The Figure 5-2 shows a picture of the specimen and a diagram for the thermal expansion in the interval 20, 40, 60, 80°C. The coefficient of thermal expansion for specimen KAV04A-90L-2 was measured to be 9.3×10^{-6} mm/mm°C and the specimen had a wet density of 2,896 kg/m^3.

KAV04A-90L-3 (494.49 m)

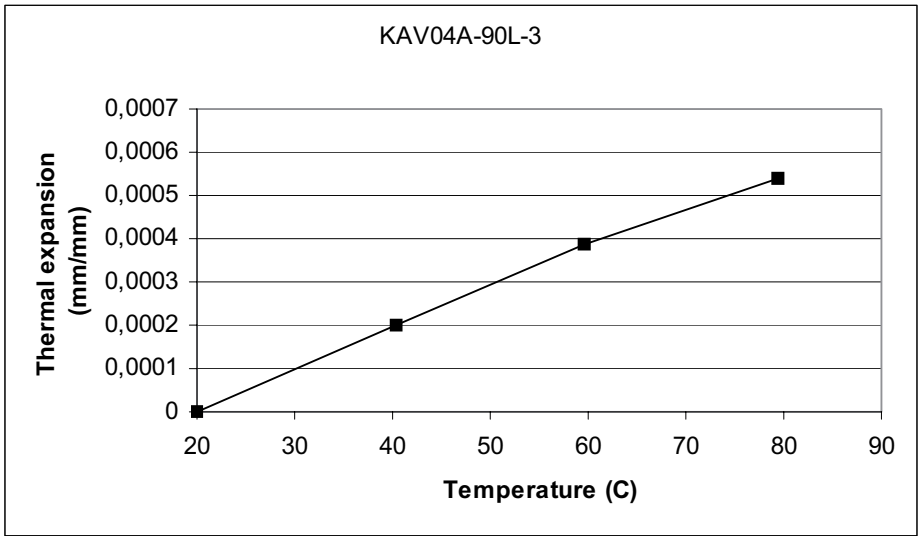


Figure 5-3. *Diagram showing the thermal expansion of specimen KAV04A-90L-3 between 20 and 80°C, median values plotted.*

The Figure 5-3 shows a picture of the specimen and a diagram for the thermal expansion in the interval 20, 40, 60, 80°C. The coefficient of thermal expansion for specimen KAV04A-90L-3 was measured to be 9.0×10^{-6} mm/mm°C and the specimen had a wet density of 2,896 kg/m^3.

KAV04A-90L-4 (519.82 m)

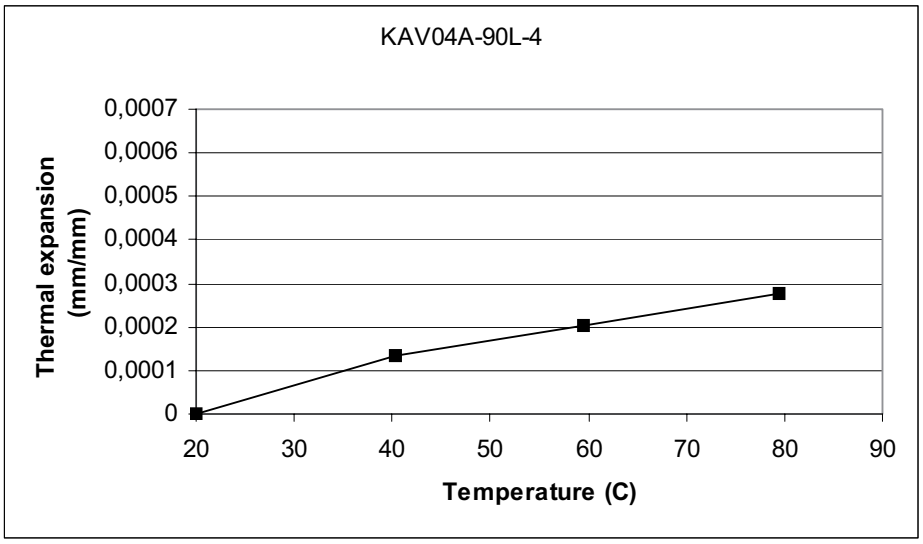
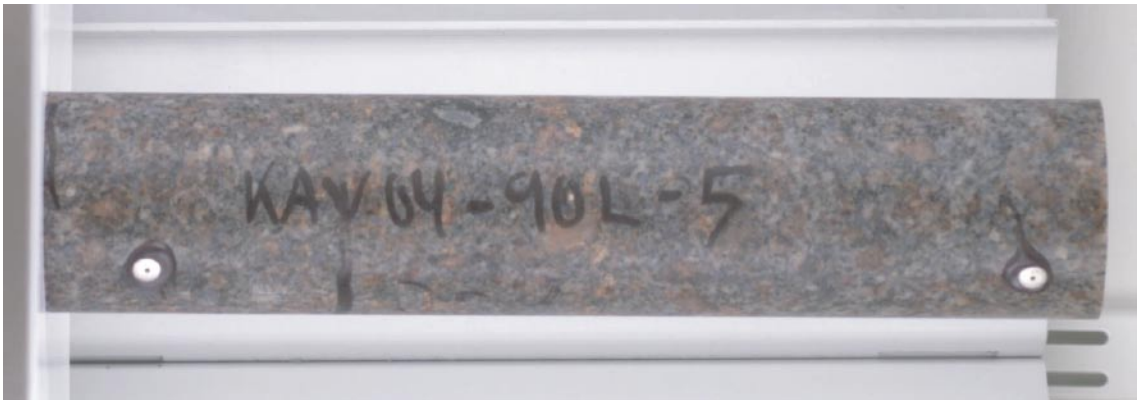


Figure 5-4. *Diagram showing the thermal expansion of specimen KAV04A-90L-4 between 20 and 80°C, median values plotted.*

The Figure 5-4 shows a picture of the specimen and a diagram for the thermal expansion in the interval 20, 40, 60, 80°C. The coefficient of thermal expansion for specimen KAV04A-90L-4 was measured to be 4.6×10^{-6} mm/mm°C and the specimen had a wet density of 2,703 kg/m^3.

KAV04A-90L-5 (520.07 m)



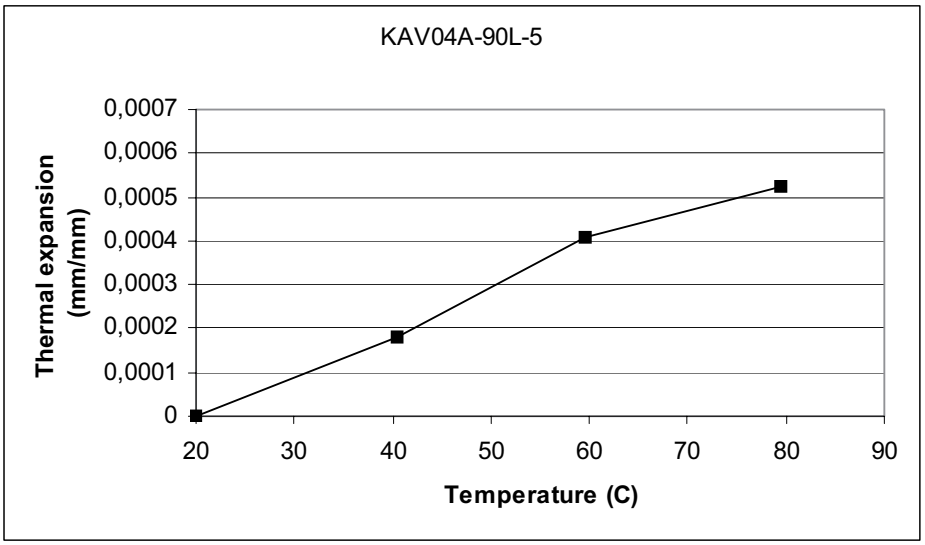


Figure 5-5. *Diagram showing the thermal expansion of specimen KAV04A-90L-5 between 20 and 80°C, median values plotted.*

The Figure 5-5 shows a picture of the specimen and a diagram for the thermal expansion in the interval 20, 40, 60, 80°C. The coefficient of thermal expansion for specimen KAV04A-90L-5 was measured to be 8.7×10^{-6} mm/mm°C and the specimen had a wet density of 2,690 kg/m^3.

KAV04A-90L-6 (522.14 m)

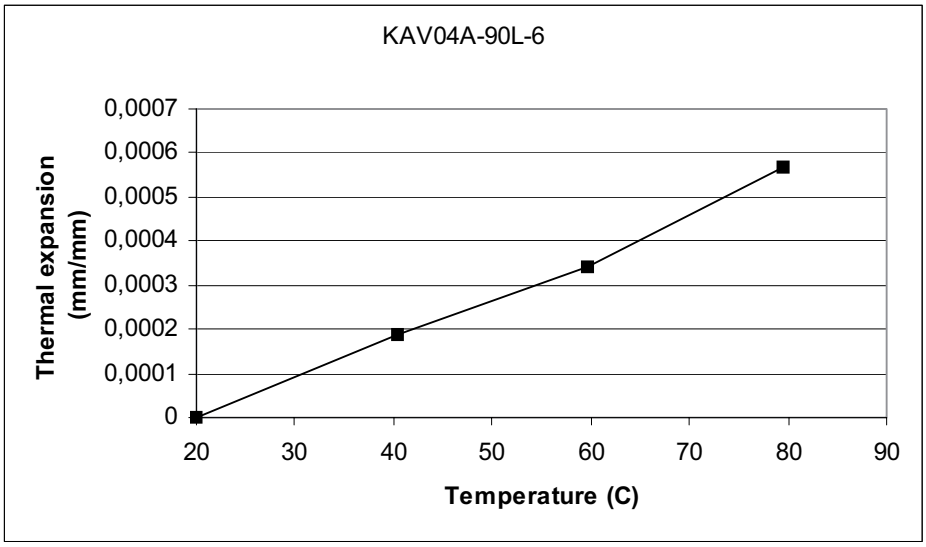


Figure 5-6. *Diagram showing the thermal expansion of specimen KAV04A-90L-6 between 20 and 80°C, median values plotted.*

The Figure 5-6 shows a picture of the specimen and a diagram for the thermal expansion in the interval 20, 40, 60, 80°C. The coefficient of thermal expansion for specimen KAV04A-90L-6 was measured to be 9.5×10^{-6} mm/mm°C and the specimen had a wet density of 2,680 kg/m^3.

5.2 Results for the entire test series

A summary of the test results are shown in Table 5-1.

Table 5-1. Summary of the results for the coefficient of thermal expansion (median values) and wet density of the tested specimens.

Specimen	Coefficient of thermal expansion between 20 and 80°C (mm/mm°C)	Wet density (kg/m^3)
KAV04A-90L-1	8.6×10^{-6}	2,671
KAV04A-90L-2	9.3×10^{-6}	2,675
KAV04A-90L-3	9.0×10^{-6}	2,677
KAV04A-90L-4	4.6×10^{-6}	2,664
KAV04A-90L-5	8.7×10^{-6}	2,669
KAV04A-90L-6	9.5×10^{-6}	2,670
Median	8.9×10^{-6}	
Maximum value	9.5×10^{-6}	
Minimum value	4.6×10^{-6}	

5.3 Discussion

The variation between the specimens is approximately 4.9×10^{-6} mm/mm°C, which is approximately 24 times the uncertainty of the measurement (0.2×10^{-6} mm/mm°C). It has not been observed any lost of demec studs, and the diagrams show that the thermal expansion have been rather linear for all specimens. It is therefore suggested that the variation of the results are related to the difference in geological properties of the specimens.

References

NT BUILD 479. Natural Building stones: Coefficient of thermal expansion.

Appendix 1

Determination of the linear coefficient of thermal expansion

Uppdragsnummer:	**P402276**	
Borrhål:	KAVO4	
Metod:		
Provkroppar som provas se nästa blad		
Provberedning	**Datum**	**Sign**
Sågning:	9/1/04	Lej
Foto:	10/13/04	uå
Vattenmättnad start datum:	9/8/04	Lej
Vägning vattenmättat yttorrt tillstånd:		Lej
Provning start:	9/15/04	Lej
Vägning torrt tillstånd:		
Utrustning	**Inventarienummer**	**Kalibrerad datum**
Extensometer:	102266	5/5/03
Våg	102291	3/10/04
Torkskåp	102284	8/31/04
Termometer	102080	6/14/04
Övrigt		
Eventuella avvikelser under provning:		
	Datum	**Sign**
Proverna åter i kärnlådan:		

Provningsprotokoll längdutvidgningskoefficient

Uppdrags nummer:		**P402276**				
Borrhål:		**KAVO4**				
						Median
Mättempe-ratur	**19,4**	**C**	**C**	**C**	**19,4**	**C**	**19,4**

Prov ID	**Skalvärde/datum**	**Skalvärde/datum**	**Skalvärde/datum**	**Skalvärde/datum**	**Median**
1	–15	04/09/15	04/09/17	–15	–15,00
2	42			42	42,00
3	45			45	45,00
4	82			82	82,00
5	29			29	29,00
6	254			254	254,00
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					

Provningsprotokoll längdutvidgningskoefficient

Uppdrags nummer:	**P402276**								
Borrhål:	**KAVO4**								
									Median
Mättempe-ratur	**40**	**C**	**40,4**	**C**	**40,4**	**C**	**40,5**	**C**	**40,4**

Prov ID	**Skalvärde/datum**		**Skalvärde/datum**		**Skalvärde/datum**		**Skalvärde/datum**		**Median**
1	23	04/09/16	24	04/09/17	29	04/09/20	30	04/09/21	26,5
2	86		91		99		99		95
3	85		91		100		101		95,5
4	105		109		122		123		115,5
5	67		71		78		79		74,5
6	296		300		302		302		301

Provningsprotokoll längdutvidgningskoefficient

Uppdrags nummer:		**P402276**							
Borrhål:	**KAVO4**								
									Median
Mättempe-ratur	**59,3**	**C**	**59,9**	**C**	**60,1**	**C**	**59,3**	**C**	**59,6**

Prov ID	**Skalvärde/datum**		**Skalvärde/datum**		**Skalvärde/datum**		**Skalvärde/datum**		**Median**
1	62	04/09/23	69	04/09/24	69	04/09/27	68	04/09/28	68,5
2	132		135		134		133		133,5
3	139		133		146		146		142,5
4	146		134		133		130		133,5
5	128		128		136		136		132
6	341		340		341		340		340,5
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									

Provningsprotokoll längdutvidgningskoefficient

Uppdrags nummer:	**P402276**								
Borrhål:	**KAVO4**								
									Median
Mättempe-ratur	**79,6**	**C**	**79,4**	**C**	**80,4**	**C**	**79,4**	**C**	**79,5**

Prov ID	**Skalvärde/datum**		**Skalvärde/datum**		**Skalvärde/datum**		**Skalvärde/datum**		**Median**
1	108	04/10/01	115	04/10/05	114	04/10/06	115	04/09/28	114,5
2	180		178		185		186		182,5
3	180		175		183		182		181
4	143		151		152		156		151,5
5	171		160		161		161		161
6	389		397		398		397		397

Längdutvidgningskoefficient

Provningsmetod: NT BUILD 479 Tempdifferens 21

1 skaldel motsvarar 3,97 mikrostrain = $3{,}97 \times 10^{-6}$ strain

Borrhål/nivå: KAVO4 Delta l = längdförändringen i mm = strain x l

Prov id	Skalvärde start	Skalvärde vid mätning Datum temperatur	Differens skaldelar	Strain (mm/mm)	Delta l	l	Längdutvidgningskoeff mm/mm per grader C	Längdutv mm/mm
1	–15	26,5	41,5	0,000164755	0,032951	200,0	0,00000785	0,000165
2	42	95	53	0,00021041	0,042082	200,0	0,00001002	0,000210
3	45	95,5	50,5	0,000200485	0,040097	200,0	0,00000955	0,000200
4	82	115,5	33,5	0,000132995	0,026599	200,0	0,00000633	0,000133
5	29	74,5	45,5	0,000180635	0,036127	200,0	0,00000860	0,000181
6	254	301	47	0,00018659	0,037318	200,0	0,00000889	0,000187

använder sista mätvärdet på 20 grader

använder median på 40 graders-mätn

Längdutvidgningskoefficient

Provningsmetod: NT BUILD 479 Tempdifferens 40,2

1 skaldel motsvarar 3,97 mikrostrain = $3{,}97 \times 10^{-6}$ strain

Borrhål/nivå: KAVO4 Delta l = längdförändringen i mm = strain x l

Prov id	Skalvärde start	Skalvärde vid mätning Datum tem-peratur	Differens skaldelar	Strain (mm/mm)	Delta l	l	Längdutvidg-ningskoeff mm/mm per grader C	Längdutv mm/mm
1	–15	68,5	83,5	0,000331495	0,066299	200,0	0,00000825	0,000332
2	42	133,5	91,5	0,000363255	0,072651	200,0	0,00000904	0,000363
3	45	142,5	97,5	0,000387075	0,077415	200,0	0,00000963	0,000387
4	82	133,5	51,5	0,000204455	0,040891	200,0	0,00000509	0,000204
5	29	132	103	0,00040891	0,081782	200,0	0,00001017	0,000409
6	254	340,5	86,5	0,000343405	0,068681	200,0	0,00000854	0,000343

använder sista mät-värdet på 20 grader

använder median på 60 graders-mätn

Längdutvidgningskoefficient

Provningsmetod: NT BUILD 479 Tempdifferens 60,1

1 skaldel motsvarar 3,97 mikrostrain = $3{,}97 \times 10^{-6}$ strain

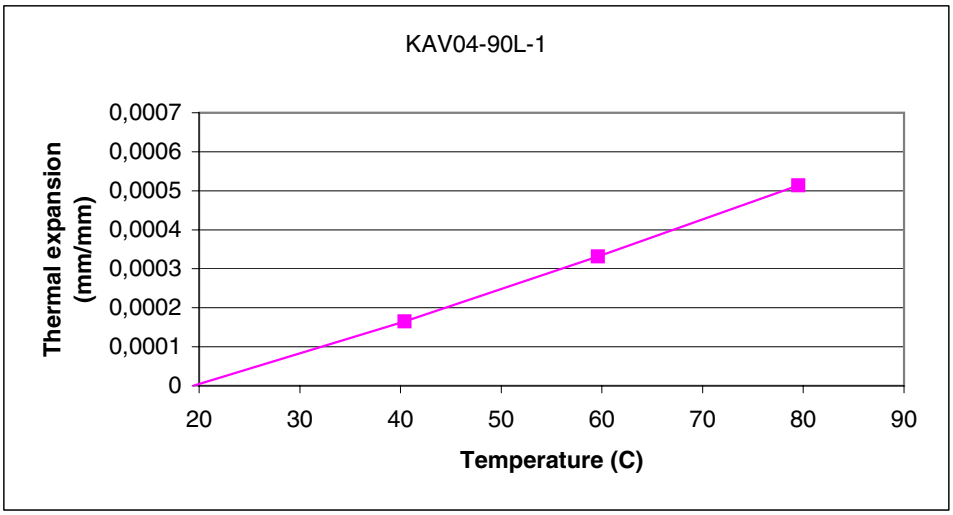
Borrhål/nivå: KAVO4 Delta l = längdförändringen i mm = strain x l

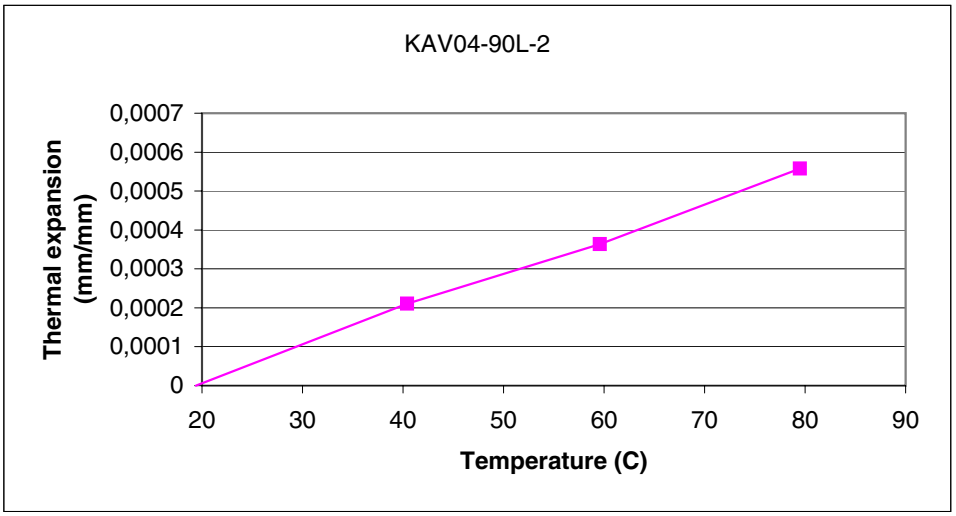
Prov id	Skalvärde start	Skalvärde vid mätning Datum temperatur	Differens skaldelar	Strain (mm/mm)	Delta l	l	Längdutvidgningskoeff mm/mm per grader C	Längdutv mm/mm
1	–15	114,5	129,5	0,000514115	0,102823	200,0	0,00000855	0,000514
2	42	182,5	140,5	0,000557785	0,111557	200,0	0,00000928	0,000558
3	45	181	136	0,00053992	0,107984	200,0	0,00000898	0,000540
4	82	151,5	69,5	0,000275915	0,055183	200,0	0,00000459	0,000276
5	29	161	132	0,00052404	0,104808	200,0	0,00000872	0,000524
6	254	397	143	0,00056771	0,113542	200,0	0,00000945	0,000568

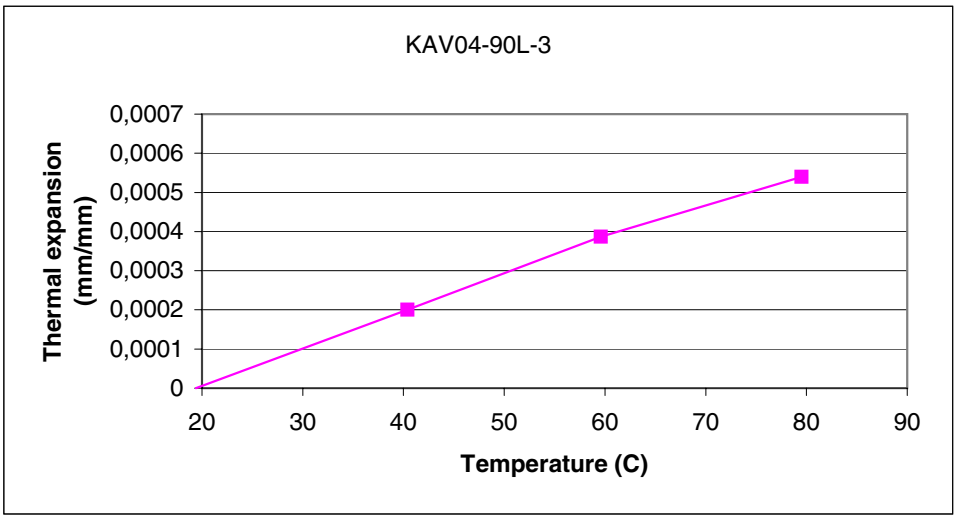
använder sista mätvärdet på 20 grader

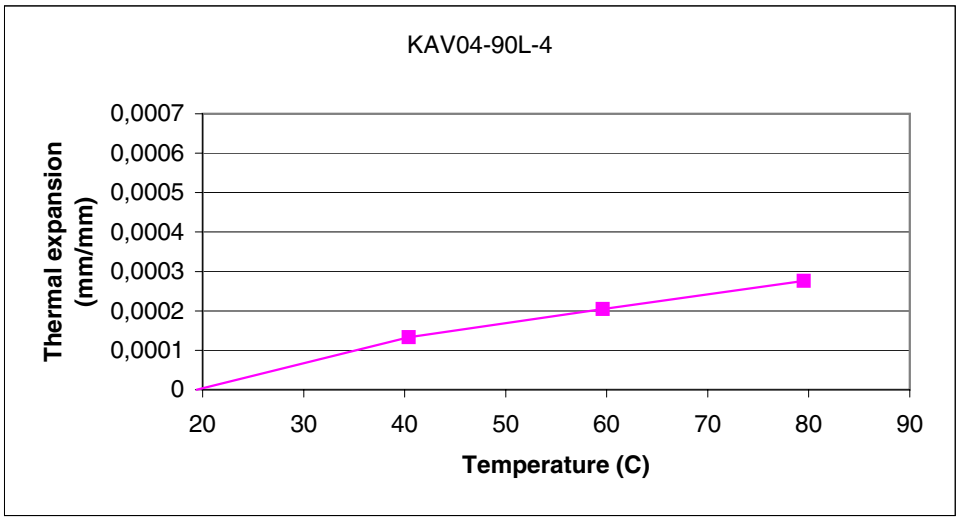
använder median på 80 graders-mätn

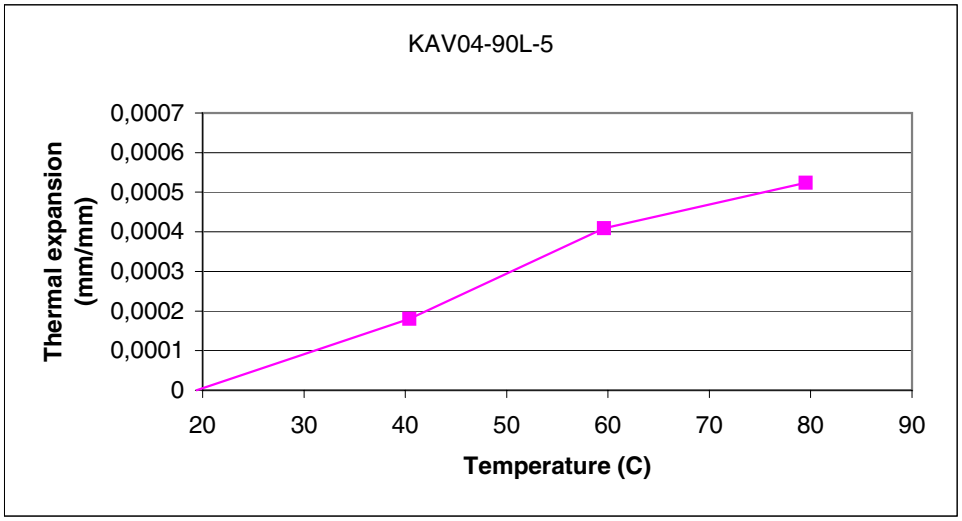
Längdutvidgningskoeff	Borrhål:	KAVO4			Längdutvidgning				
Temperatur/ mm/mm per grader C	19,4	40,4	59,6	79,5	Temperatur / mm/mm	19,4	40,4	59,6	79,5
KAV04-90L-1	0	0,0000078455	0,0000082461	0,0000085543	1	0	0,000164755	0,000331495	0,000514115
KAV04-90L-2	0	0,0000100195	0,0000090362	0,0000092809	2	0	0,00021041	0,000363255	0,000557785
KAV04-90L-3	0	0,0000095469	0,0000096287	0,0000089837	3	0	0,000200485	0,000387075	0,00053992
KAV04-90L-4	0	0,0000063331	0,0000050859	0,0000045909	4	0	0,000132995	0,000204455	0,000275915
KAV04-90L-5	0	0,0000086017	0,0000101719	0,0000087195	5	0	0,000180635	0,00040891	0,00052404
KAV04-90L-6	0	0,0000088852	0,0000085424	0,0000094461	6	0	0,00018659	0,000343405	0,00056771

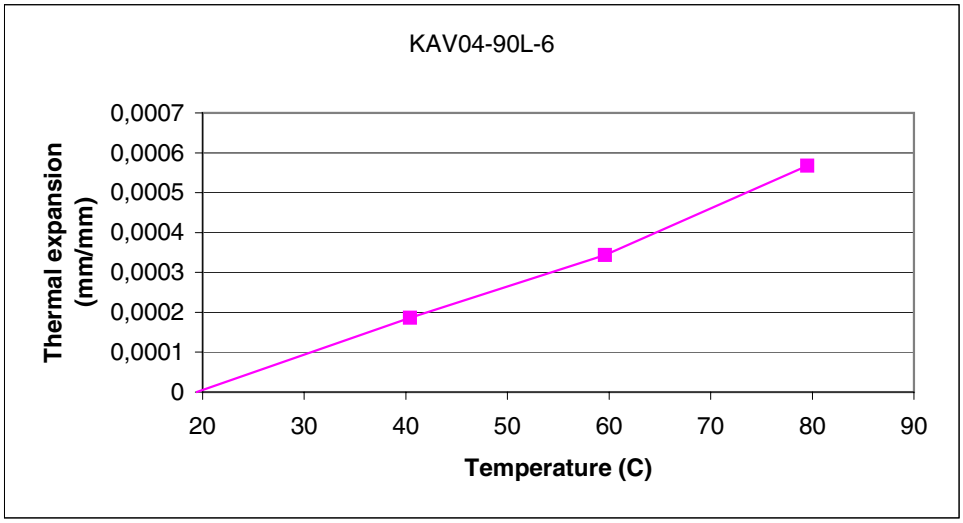

KAV04-90L-1
Thermal expansion (mm/mm)
0,0007
0,0006
0,0005
0,0004
0,0003
0,0002
0,0001
0
20
30
40
50
60
70
80
90
Temperature (C)


KAV04-90L-2
Thermal expansion (mm/mm)
0,0007
0,0006
0,0005
0,0004
0,0003
0,0002
0,0001
0
20
30
40
50
60
70
80
90
Temperature (C)


KAV04-90L-3
Thermal expansion (mm/mm)
0,0007
0,0006
0,0005
0,0004
0,0003
0,0002
0,0001
0
20
30
40
50
60
70
80
90
Temperature (C)


KAV04-90L-4
Thermal expansion (mm/mm)
0,0007
0,0006
0,0005
0,0004
0,0003
0,0002
0,0001
0
20
30
40
50
60
70
80
90
Temperature (C)


KAV04-90L-5
Thermal expansion (mm/mm)
0,0007
0,0006
0,0005
0,0004
0,0003
0,0002
0,0001
0
20
30
40
50
60
70
80
90
Temperature (C)


KAV04-90L-6
Thermal expansion (mm/mm)
0,0007
0,0006
0,0005
0,0004
0,0003
0,0002
0,0001
0
20
30
40
50
60
70
80
90
Temperature (C)

Appendix 2

Determination of wet density

Vattenmättnadsdensitet

KAV04 Uppdrags nr: P402276
Metod: EN 13755, ISRM (1973), avsnitt 3 samt SKB MD 160.002 version 1.0
Provad av: Lej
Datum: 10/19/04

	Prov-märkning:	Vikt i vatten, Msub (g)	Yttor vikt, Msat (g)	Yttorr vikt, Ms (g)	Bulk volume, V (cm^3)	Pore volume, Vv (cm^3)	Porosity, n (%)	Dry density, ρd (g/cm^3)	Wet density (g/cm^3)
1	KAVO4-1	906,54	1381,62		475,94	1384,11	290,82	0,000	2,903
2	2	903,00	1377,97		475,83	1380,45	290,12	0,000	2,896
3	3	902,79	1377,57		475,64	1380,05	290,15	0,000	2,896
4	4	811,74	1287,09		476,21	1289,41	270,77	0,000	2,703
5	5	805,06	1280,2		476,00	1282,51	269,44	0,000	2,690
6	6	801,36	1277,11		476,61	1279,41	268,44	0,000	2,680
7	7				0,00	0,00			
8	8				0,00	0,00			
9	9				0,00	0,00			
10	10				0,00	0,00			
11	11				0,00	0,00			
12	12				0,00	0,00			
13	13				0,00	0,00			
14	14				0,00	0,00			
15	15				0,00	0,00			
16	16				0,00	0,00			
17	17				0,00	0,00			
18	18				0,00	0,00			
19					0,00	0,00			
20					0,00	0,00			
21					0,00	0,00			

Vattnets temperatur ºC): 20 Våg, inv.nr: 102291
Vattnets desitet (ºC): 0,9982 Termometer, inv.nr: 102080