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Äspö Hard Rock Laboratory

Prototype Repository

Hydraulic tests and deformation measurements during operation phase, test campaign 2, single hole test

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SWECO VIAK

April 2004

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Abstract

The Prototype Repository project is focused on testing and demonstrating the function of the SKB deep repository system. Activities aimed at contributing to development and testing of the practical, engineering measures required to rationally perform the steps of a deposition sequence are also included in the project but are also part of other projects.

The objective of the single-hole tests is to estimate the transmissivity of the Hydro Mechanical (HM) test sections equipped with deformation sensors.

Single hole tests were done in 9 boreholes of the Prototype Repository tunnel. There is a tenth HM section in KA3550G01, which, however, could not be tested due to packer system failure. In the G-tunnel there is a hole with a HM-equipped section to be used as a reference hole. The results are shown in the table below.

Table 1 Results from the test campaign 2. (1) Indicates packer system failure, (2) indicates no tests were done this test campaign, "-" indicates it was not possible to evaluate any value with selected method.

Section	HM section	Specific capacity (m^2/s)	T_{MOYE} (m^2/s)	T_{eval} (m^2/s)	Skinfactor
KA3550G01:2	X	(1)	(1)	(1)	(1)
KA3552G01:2	X	$1.6 \cdot 10^{-9}$	$1.0 \cdot 10^{-9}$	$6.5 \cdot 10^{-10}$	-1.8
KA3554G01:2	X	$8.3 \cdot 10^{-8}$	$5.3 \cdot 10^{-8}$	$5.3 \cdot 10^{-7}$	34
KA3554G02:4	X	$1.2 \cdot 10^{-9}$	$7.9 \cdot 10^{-10}$	$2.5 \cdot 10^{-8}$	120
KA3548A01:3	X	$1.0 \cdot 10^{-7}$	$6.9 \cdot 10^{-8}$	$9.8 \cdot 10^{-8}$	-0.3
KA3542G01:3	X	$4.9 \cdot 10^{-8}$	$3.2 \cdot 10^{-8}$	$9.7 \cdot 10^{-8}$	6
KA3544G01:2	X	$5.9 \cdot 10^{-10}$	$3.6 \cdot 10^{-10}$	-	-
KA3542G02:2	X	$4.9 \cdot 10^{-10}$	$3.1 \cdot 10^{-10}$	$1.9 \cdot 10^{-10}$	-1.3
KA3563G:4	-	(2)	(2)	(2)	(2)
KA3546G01:2	X	$6.0 \cdot 10^{-10}$	$3.9 \cdot 10^{-10}$	-	-
KA3566G01:2	-	(2)	(2)	(2)	(2)
KA3572G01:2	-	(2)	(2)	(2)	(2)
KA3574G01:3	-	(2)	(2)	(2)	(2)
KA3539G:2	X	$3.0 \cdot 10^{-7}$	$2.0 \cdot 10^{-7}$	$8.6 \cdot 10^{-7}$	1.6

Sammanfattning

Huvudsyftet med prototypförvaret är att testa och demonstrera funktionen av en del av SKB: s djupförvars system. Aktiviteter som syftar till utveckling och försök av praktiska och ingenjörsmässiga lösningar, som krävs för att på ett rationellt sätt kunna stegvis utföra deponeringen av kapslar med kärnbränsle, är inkluderade i projektet för prototyp förvaret men även i andra projekt.

Målsättningen med enhålstesterna är att få en uppskattning av transmissiviteten hos de hydromekaniska testsektionerna, (HM), som är utrustade med sprickdeformationssensorer.

Enhålstester gjordes i totalt 9 stycken borrhål. Ett tionde borrhål är utrustad med HM sensorer men har ej kunnat testas på grund av läckageproblem med de hydrauliska manschetterna. I G-tunneln finns ytterligare ett borrhål med en HM sensorer installerade. Det hålet är tänkt att användas såsom referenshål. Resultaten från denna testomgång presenteras i tabellen nedan.

Tabell 1 Resultat från testomgång 2. (1) indikerar läckageproblem med manschetterna, (2) indikerar att inga tester gjordes i dessa sektioner denna testomgång, "-" indikerar att inget värde kunnat beräknas med valt utvärderingsmetod.

Sektion	HM sektion	Specifik kapacitet (m^2/s)	T_{MOYE} (m^2/s)	T_{eval} (m^2/s)	Skinfaktor
KA3550G01:2	X	(1)	(1)	(1)	(1)
KA3552G01:2	X	$1.6 \cdot 10^{-9}$	$1.0 \cdot 10^{-9}$	$6.5 \cdot 10^{-10}$	-1.8
KA3554G01:2	X	$8.3 \cdot 10^{-8}$	$5.3 \cdot 10^{-8}$	$5.3 \cdot 10^{-7}$	34
KA3554G02:4	X	$1.2 \cdot 10^{-9}$	$7.9 \cdot 10^{-10}$	$2.5 \cdot 10^{-8}$	120
KA3548A01:3	X	$1.0 \cdot 10^{-7}$	$6.9 \cdot 10^{-8}$	$9.8 \cdot 10^{-8}$	-0.3
KA3542G01:3	X	$4.9 \cdot 10^{-8}$	$3.2 \cdot 10^{-8}$	$9.7 \cdot 10^{-8}$	6
KA3544G01:2	X	$5.9 \cdot 10^{-10}$	$3.6 \cdot 10^{-10}$	-	-
KA3542G02:2	X	$4.9 \cdot 10^{-10}$	$3.1 \cdot 10^{-10}$	$1.9 \cdot 10^{-10}$	-1.3
KA3563G:4	-	(2)	(2)	(2)	(2)
KA3546G01:2	X	$6.0 \cdot 10^{-10}$	$3.9 \cdot 10^{-10}$	-	-
KA3566G01:2	-	(2)	(2)	(2)	(2)
KA3572G01:2	-	(2)	(2)	(2)	(2)
KA3574G01:3	-	(2)	(2)	(2)	(2)
KA3539G:2	X	$3.0 \cdot 10^{-7}$	$2.0 \cdot 10^{-7}$	$8.6 \cdot 10^{-7}$	1.6

Executive Summary

In Tables 1 to 4 below is a summary of the test results of the single hole tests so far. In the heading of each test campaign column is indicated the number of days since the heaters in canister hole 5 (DA3551G01) were turned on.

In Table 1 the evaluated specific capacity during the different test campaigns are shown. The specific capacity is obtained by dividing the final flowrate with the maximum decline in pressure during the flow period. It is a simple way to get an estimation of the hydrological capacity of a well or borehole.

Table 2 contains the evaluated T_{MOYE} which is a standard procedure to obtain a first and approximate, based on stationary evaluation methods, estimation of the transmissivity. The transmissivity gives the flow capacity of a 2D feature, thus transmissivity divided by the thickness of the feature (normally test section length) gives the hydraulic conductivity.

Table 3 details the evaluated transmissivity, based on transient evaluation of the pressure time curve, which can be looked upon as the best estimation of the transmissivity.

The evaluated skinfactor are shown in Table 4. The skinfactor gives an indication of the resistance of water to enter a borehole. It can usually be explained by clogging of the borehole walls or by a turbulent water flow.

Table 1 Specific capacity. For each test campaign is indicated the number of days since starting of the heaters in canister hole 5 (2003-05-08). (1) indicates packer system failure, (2) indicates no tests were done this test campaign, "-" indicates it was not possible to evaluate any value with selected method.

Section	HM section	Test campaign 1 (-0 days)	Test campaign 2 (-166 days)	Test campaign 3	Test campaign 4	Test campaign 5	Test campaign 6
KA3550G01:2	X	(1)	(1)				
KA3552G01:2	X	$9.4 \cdot 10^{-9}$	$1.6 \cdot 10^{-9}$				
KA3554G01:2	X	$8.2 \cdot 10^{-8}$	$8.3 \cdot 10^{-8}$				
KA3554G02:4	X	$1.3 \cdot 10^{-9}$	$1.2 \cdot 10^{-9}$				
KA3548A01:3	X	$1.1 \cdot 10^{-7}$	$1.0 \cdot 10^{-7}$				
KA3542G01:3	X	$5.4 \cdot 10^{-8}$	$4.9 \cdot 10^{-8}$				
KA3544G01:2	X	$7.8 \cdot 10^{-10}$	$5.9 \cdot 10^{-10}$				
KA3542G02:2	X	$5.4 \cdot 10^{-10}$	$4.9 \cdot 10^{-10}$				
KA3563G:4	-	$1.7 \cdot 10^{-8}$	(2)				
KA3546G01:2	X	$6.1 \cdot 10^{-10}$	$6.0 \cdot 10^{-10}$				
KA3566G01:2	-	$6.8 \cdot 10^{-10}$	(2)				
KA3572G01:2	-	$1.9 \cdot 10^{-10}$	(2)				
KA3574G01:3	-	$8.7 \cdot 10^{-10}$	(2)				
KA3539G:2	X	$1.9 \cdot 10^{-7}$	$3.0 \cdot 10^{-7}$				

Table 2 T_{MOYE} . For each test campaign is indicated the number of days since the starting of the heaters in canister hole 5 (2003-05-08). (1) indicates packer system failure, (2) indicates no tests were done this test campaign, "-" indicates it was not possible to evaluate any value with selected method.

Section	HM section	Test campaign 1 (-0 days)	Test campaign 2 (-166 days)	Test campaign 3	Test campaign 4	Test campaign 5	Test campaign 6
KA3550G01:2	X	(1)	(1)				
KA3552G01:2	X	$8.8 \cdot 10^{-9}$	$1.0 \cdot 10^{-9}$				
KA3554G01:2	X	$5.2 \cdot 10^{-8}$	$5.3 \cdot 10^{-8}$				
KA3554G02:4	X	$8.2 \cdot 10^{-10}$	$7.9 \cdot 10^{-10}$				
KA3548A01:3	X	$7.1 \cdot 10^{-8}$	$6.9 \cdot 10^{-8}$				
KA3542G01:3	X	$3.6 \cdot 10^{-8}$	$3.2 \cdot 10^{-8}$				
KA3544G01:2	X	$5.1 \cdot 10^{-10}$	$3.6 \cdot 10^{-10}$				
KA3542G02:2	X	$3.5 \cdot 10^{-10}$	$3.1 \cdot 10^{-10}$				
KA3563G:4	-	$5.6 \cdot 10^{-9}$	(2)				
KA3546G01:2	X	$3.9 \cdot 10^{-10}$	$3.9 \cdot 10^{-10}$				
KA3566G01:2	-	$4.4 \cdot 10^{-10}$	(2)				
KA3572G01:2	-	$1.3 \cdot 10^{-10}$	(2)				
KA3574G01:3	-	$6.1 \cdot 10^{-10}$	(2)				
KA3539G:2	X	$1.3 \cdot 10^{-7}$	$2.0 \cdot 10^{-7}$				

Table 3 Transmissivity . For each test campaign is indicated the number of days since the starting of the heaters in canister hole 5 (2003-05-08). (1) indicates packer system failure, (2) indicates no tests were done this test campaign, “-“ indicates it was not possible to evaluate any value with selected method.

Section	HM section	Test campaign 1 (-0 days)	Test campaign 2 (-166 days)	Test campaign 3	Test campaign 4	Test campaign 5	Test campaign 6
KA3550G01:2	X	(1)	(1)				
KA3552G01:2	X	-	$6.5 \cdot 10^{-10}$				
KA3554G01:2	X	$6.4 \cdot 10^{-7}$	$5.3 \cdot 10^{-7}$				
KA3554G02:4	X	$1.1 \cdot 10^{-8}$	$2.5 \cdot 10^{-8}$				
KA3548A01:3	X	$8.1 \cdot 10^{-8}$	$9.8 \cdot 10^{-8}$				
KA3542G01:3	X	$9.5 \cdot 10^{-8}$	$9.7 \cdot 10^{-8}$				
KA3544G01:2	X	-	-				
KA3542G02:2	X	$2.2 \cdot 10^{-10}$	$1.9 \cdot 10^{-10}$				
KA3563G:4	-	-	(2)				
KA3546G01:2	X	$7.8 \cdot 10^{-11}$	-				
KA3566G01:2	-	-	(2)				
KA3572G01:2	-	-	(2)				
KA3574G01:3	-	-	(2)				
KA3539G:2	X	$7.0 \cdot 10^{-7}$	$8.6 \cdot 10^{-7}$				

Table 4 Skinfactor. For each test campaign is indicated the number of days since the starting of the heaters in canister hole 5 (2003-05-08). (1) indicates packer system failure, (2) indicates no tests were done this test campaign, "-" indicates it was not possible to evaluate any value with selected method.

Section	HM section	Test campaign 1 (-0 days)	Test campaign 2 (-166 days)	Test campaign 3	Test campaign 4	Test campaign 5	Test campaign 6
KA3550G01:2	X	(1)	(1)				
KA3552G01:2	X	-	-1.8				
KA3554G01:2	X	43	34				
KA3554G02:4	X	51	120				
KA3548A01:3	X	-2	-0.3				
KA3542G01:3	X	5	6				
KA3544G01:2	X	-	-				
KA3542G02:2	X	-0.3	-1.3				
KA3563G:4	-	-	(2)				
KA3546G01:2	X	-2	-				
KA3566G01:2	-	-	(2)				
KA3572G01:2	-	-	(2)				
KA3574G01:3	-	-	(2)				
KA3539G:2	X	1.5	1.6				

Contents

Tables

Figures

1 Background

1.1 Äspö Hard Rock Laboratory

In order to prepare for the siting and licensing of a spent fuel repository SKB has constructed an underground research laboratory.

In the autumn of 1990, SKB began the construction of Äspö Hard Rock Laboratory (Äspö HRL), see *Figure 1-1,* near Oskarshamn in the southeastern part of Sweden. A 3.6 km long tunnel was excavated in crystalline rock down to a depth of approximately 460 m.

The laboratory was completed in 1995 and research concerning the disposal of nuclear waste in crystalline rock has since then been carried out.

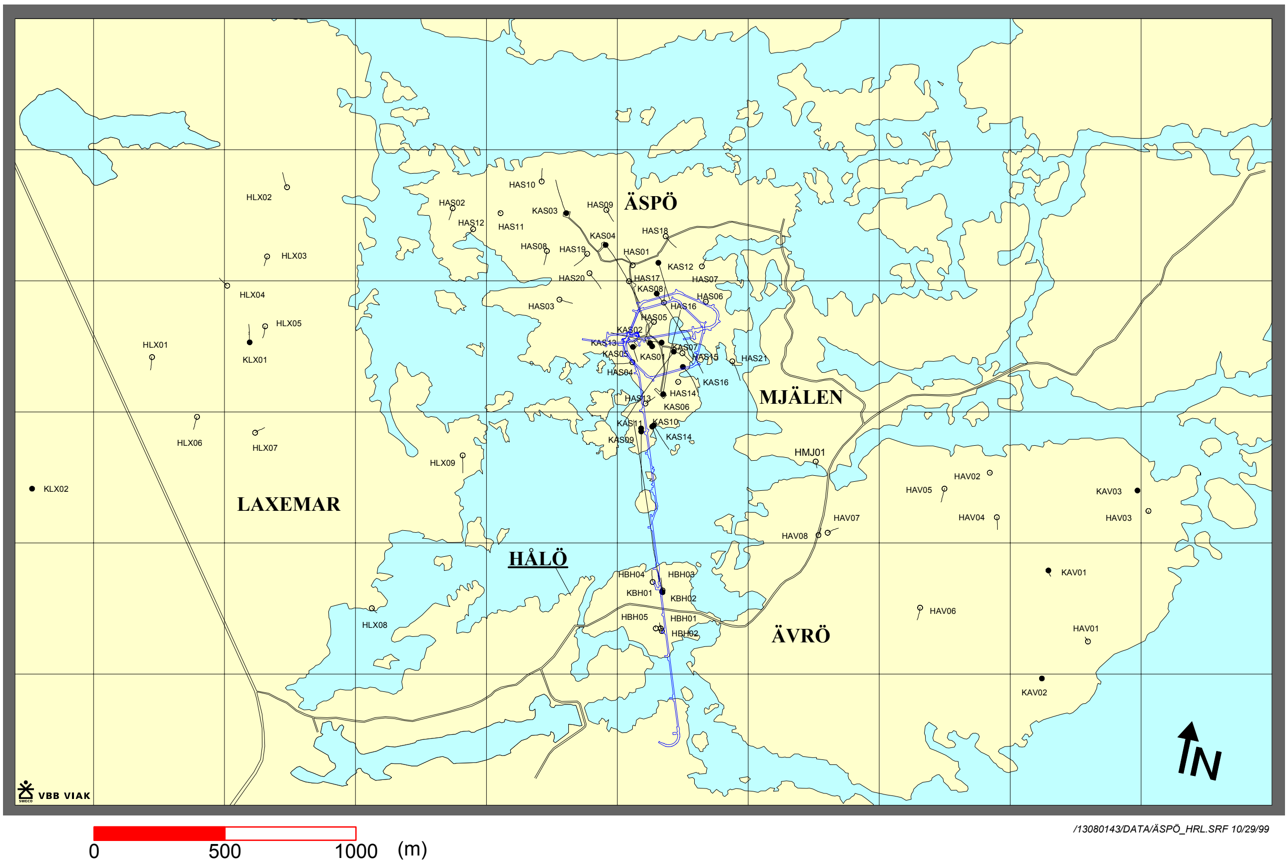


Figure 1-1 *Äspö Hard Rock Laboratory*

1.2 Prototype repository

The Äspö Hard Rock Laboratory is an essential part of the research, development, and demonstration work performed by SKB in preparation for construction and operation of the deep repository for spent fuel. Within the scope of the SKB program for RD&D 1995, SKB has decided to carry out a project with the designation "Prototype Repository Test". The aim of the project is to test important components in the SKB deep repository system in full scale and in a realistic environment.

The Prototype Repository Test is focused on testing and demonstrating the function of the SKB deep repository system. Activities aimed at contributing to development and testing of the practical, engineering measures required to rationally perform the steps of a deposition sequence are also included. However, efforts in this direction are limited, since these matters are addressed in the Demonstration of Repository Technology project and to some extent in the Backfill and Plug Test.

1.2.1 General objectives

The Prototype Repository should simulate as many aspects as possible a real repository, for example regarding geometry, materials, and rock environment. The Prototype Repository is a demonstration of the integrated function of the repository components. Results will be compared with models and assumptions to their validity.

The major objectives for the Prototype Repository are:

- To test and demonstrate the integrated function of the repository components under realistic conditions in full scale and to compare results with models and assumptions.
- To develop, test and demonstrate appropriate engineering standards and quality assurance methods.
- To simulate appropriate parts of the repository design and construction process.

The objective for the operation phase program is:

- To monitor processes and properties in the canister, buffer material, backfill and near-field rock mass

2 Objective

The objective of the single-hole tests is to estimate the transmissivity of the Hydro Mechanical (HM) test sections equipped with deformation sensors.

3 Scope

Single hole tests were done in 9 boreholes of the Prototype Repository tunnel. There is a tenth HM section in KA3550G01, which however could not be tested due to packer system failure. In the G-tunnel there is a hole with a HM-equipped section to be used as a reference hole. The tested intervals and basic test data are listed in *Table 3-1*. The first figure in the test number indicates this being the second single hole test campaign, while the second number indicates the chronological order of the single hole tests. The same numbering of the tests as used during test campaign 1 is used. Therefore no test number 2:8, 2:10, 2:11 and 2:12 exist as no tests were done in those boreholes during this campaign. Also indicated in the table are the sections where Hydro Mechanical (HM) measurements are done.

Table 3-1 Single hole tests during the campaign in October 2003. (1) indicates packer system failure, "X" indicates that section is equipped with HM sensors.

Bore hole	Section	HM section	Single hole test no.	Date of test	Start of test	Flow start	Flow stop	Test stop
KA3550G01:2(1)	5.20-7.30	X	-	-	-	-	-	-
KA3552G01:2	4.35-6.05	X	2:1	2003-10-21	10:30:00	12:30:00	14:30:00	15:30:00
KA3554G01:2	22.60-24.15	X	2:2	2003-10-21	13:30:00	15:30:00	16:00:00	17:00:00
KA3554G02:4	10.50-12.20	X	2:3	2003-10-22	05:45:00	07:45:00	09:45:00	10:45:00
KA3548A01:3	8.80-10.75	X	2:4	2003-10-22	16:15:00	18:15:00	18:45:00	19:45:00
KA3542G01:3	18.60-20.30	X	2:5	2003-10-22	14:45:00	16:45:00	17:15:00	18:15:00
KA3544G01:2	8.90-10.65	X	2:6	2003-10-22	08:45:00	10:45:00	12:45:00	13:45:00
KA3542G02:2	25.60-27.20	X	2:7	2003-10-23	05:15:00	07:15:00	09:15:00	10:15:00
KA3546G01:2	6.75-8.30	X	2:9	2003-10-22	11:45:00	13:45:00	15:45:00	16:45:00
KA3539G:2	15.85-17.6	X	2:13	2003-10-23	08:15:00	10:15:00	10:45:00	12:45:00

In chapter 6 the results of the tests are presented.

4 Equipment

4.1 Description of equipment

A large number of boreholes were instrumented with one or several packers. In all packed-off sections, the water pressure will be measured. Each borehole section is connected to a tube of polyamide that via lead-through holes ends in the G-tunnel. All pressure transducers are placed in the G-tunnel to facilitate easy calibration and exchange of transducers that are out of order. The transducers are connected to the HMS system at Äspö Laboratory and it is a flexible system for changing the sampling frequency (*Figure4-1*). The maximum scan frequency is every 3rd second. During periods with no hydraulic tests, preliminary the sampling (storing a value in the data base) frequency will be every 2nd hour with an automatic increase of the sampling frequency if the pressure change since last registration is larger than 2kPa. During hydraulic tests, the sampling frequency may be up to 3rd second.

Figure 4-1. *All pressure transducers are connected to the HMS system. In the G-tunnel there is a computer in the HMS system where logging frequencies easily can be changed.*

4.2 Sensors

The pressure in a borehole is transmitted via a plastic tube directly to a pressure transducer, *see Figure 4-2*.

The pressure transducers are either of the type DRUCK PTX 500 series or DRUCK PTX 600 series with a pressure range of 0 – 50 bar (absolute).

According to the manufacturer the uncertainty for these transducers is +/-0.2 % (type500) and +/-0.08 % (type 600) of full scale (F.S) for the best straight line (B.S.L.). For the 600 series types the time drift is given to max. 0.05 % F.S., while no figure is given for the 500 series types. Normally, a pressure value is scanned once every two seconds. If the change since the latest stored value exceeds a "change value" of approximately 2 kPa the newly scanned value is stored. A value is always stored once every second hour, regardless of any changes.

Figure 4-2 *Pressure transducers connections*

4.3 Deformation measurements

During storage of nuclear waste in the rock mass the temperature will increase due to the heat loss from the canisters with spent fuel. This will increase the rock stresses and the fractures will close, *see Rhen et al, 2004*.

It is of great interest to investigate the magnitude of this effect on the fracture transmissivity since the fracture transmissivity is essential of two reasons. First, enough transmissivity is needed to provide the bentonite buffer with water if no artificial moistening of the buffer is arranged. Secondly, the transmissivity should be as low as possible in order to minimise the hydraulic contact with the canisters. The increased temperature will decrease the transmissivity, which in principal is positive in perspective of Safety Assessment. The last effect is however limited in time and may not be of any greater importance in Safety Assessment.

In order to investigate the hydro mechanical response of the fractures as a result of the increased thermal load, two different approaches are considered.

The first approach is to measure the change of the fracture width as function of temperature and time. The displacement is both measured for the intact rock as for a section with one or more fractures.

The second approach implies that the mechanical response is evaluated indirect by using the results from hydraulic tests. Hydro tests will be performed in the same sections as the mechanical measurements are made, *see Table 3-1*.

Displacement measurements will be made continuously. Hydraulic tests will be made a number of times during the operation period for the ten measurement sections. Most tests will be made during the first years of operation when the largest displacements are expected to be measured.

4.3.1 Measurement equipment

In order to measure the fracture deformation (and to separate the fracture deformation from the deformation of the intact rock) due to the increased temperature measurement equipment has been developed.

The equipment consists of two hydraulic packers, which hydraulically isolate the test section. Between the packers three anchors are placed. These anchors are fixed to the borehole wall and in the sections between the anchors sensors (strain gage) are mounted. These sections are called mechanical measurement sections. The sensors will register any relative movement between the anchors; *see Figure 4-3 and 4-4*. The temperature is also measured in each sensor by a thermistor.

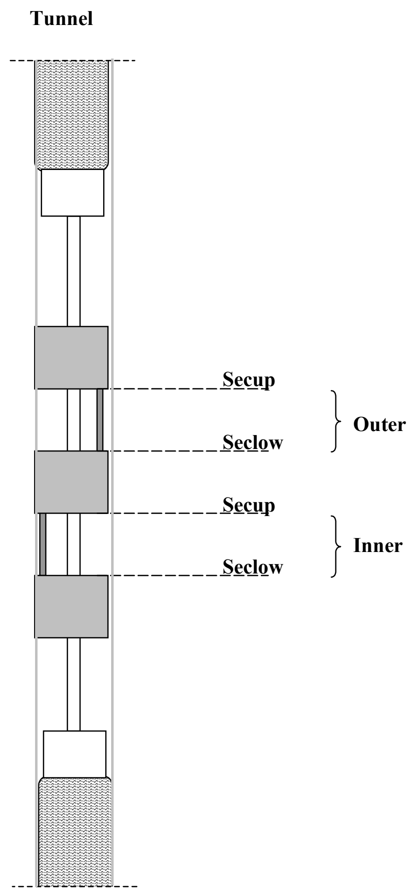


Figure 4-3 *A schematic figure, that shows the different parts of the test equipment and also the definitions of the terms outer and inner.*

The deformation is measured in two sections in each borehole. One mechanical measurement section is placed over a fracture (or fractures) and the other mechanical measurement section is placed over intact rock. That makes it possible to separate the fracture deformation from the deformation of the intact rock.

Of all boreholes in the prototype tunnel, ten are equipped as described above. Five of the measurement sections are placed over a single fracture and the rest are placed over two-six fractures, see *Table 4-1*.

Since hydraulic packers isolate the test sections and the test sections have contact with the tunnel (atmospheric pressure) via tubes and valves it is possible to perform hydraulic tests in the sections.

Table 4-1 Data of the measurement sections (sensors, length, number of fractures etc).

Label	Cable mark	Sensor S/N	Position	Secup	Seclow	Section length (m)	Number of fractures
KA3539G-2-1	HRA 1121	3511	Inner	16.77	16.97	0.20	2
KA3539G-2-2	HRA 1122	3510	Outer	16.47	16.67	0.20	0
KA3542G01-3-1	HRA 1231	3513	Inner	19.47	19.67	0.20	0
KA3542G01-3-2	HRA 1232	3512	Outer	19.17	19.37	0.20	1
KA3542G02-2-1	HRA 1321	3515	Inner	26.50	26.70	0.20	1
KA3542G02-2-2	HRA 1322	3514	Outer	26.20	26.40	0.20	0
KA3544G01-2-1	HRA 1621	3509	Inner	9.82	10.02	0.20	1
KA3544G01-2-2	HRA 1622	3508	Outer	9.52	9.72	0.20	0
KA3546G01-2-1	HRA 1721	3517	Inner	7.67	7.87	0.20	1
KA3546G01-2-2	HRA 1722	3516	Outer	7.37	7.57	0.20	0
KA3548A01-3-1	HRA 1831	3526	Inner	9.70	10.15	0.45	2
KA3548A01-3-2	HRA 1832	3518	Outer	9.40	9.60	0.20	0
KA3550G01-2-1	HRA 2121	3527	Inner	6.10	6.70	0.60	6
KA3550G01-2-2	HRA 2122	3519	Outer	5.80	6.00	0.20	0
KA3552G01-2-1	HRA 2521	3521	Inner	5.25	5.45	0.20	0
KA3552G01-2-2	HRA 2522	3520	Outer	4.95	5.15	0.20	2
KA3554G01-2-1	HRA 2821	3525	Inner	23.54	23.80	0.26	2
KA3554G01-2-2	HRA 2822	3522	Outer	23.24	23.44	0.20	0
KA3554G02-4-1	HRA 2941	3524	Inner	11.40	11.60	0.20	0
KA3554G02-4-2	HRA 2942	3523	Outer	11.10	11.30	0.20	1
KG0010B01-1-1	-	3238	Inner	3.66	3.86	0.20	-
KG0010B01-1-2	-	3507	Outer	3.36	3.56	0.20	-

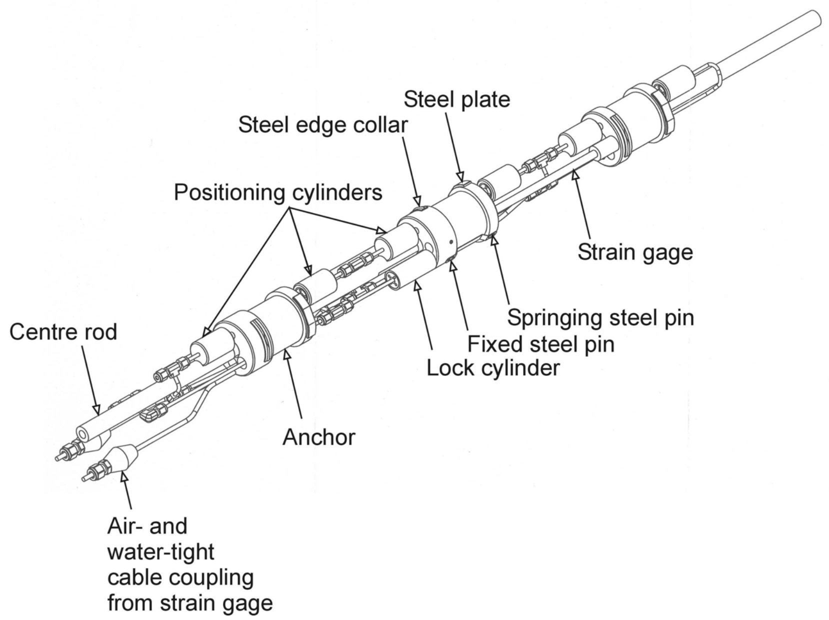


Figure 4-4 *A detailed figure of the three anchors, sensors (strain gage), positioning cylinder etc.*

5 Execution

5.1 Preparations

Planning is an important step in the preparation stage. No other activities, which may cause pressure responses, must occur in the neighbourhood of the test area. Such activities include drilling, blasting and flowing of boreholes.

Preparations also include checking of equipment to be used in the tests. The equipment included

- measuring glasses of various sizes
- synchronizing watches with the HMS system (only normal time)
- protocols for flow measurements
- water sampling bottles
- hand calculator

5.2 Execution of tests/measurements

5.2.1 Test principle

The main purpose of a single hole pressure build-up test is to do a test, which makes it possible to evaluate the hydraulic properties of the bedrock around the tested borehole section.

5.2.2 Test procedure

The following measurement cycle was used:

- Initialising of the HMS system 30 minutes before flow start with logger frequency 5 minutes
- A couple of minutes before flow start and until 5 minutes after flow start the highest logging frequency of 3 seconds was used. Thereafter the logging frequency was 30 seconds, which was used until 30 minutes after flow start. Then a logging frequency of 5 minutes was used
- From shortly before flow stop until 5 minutes after flow stop the highest logging frequency of 2 seconds were used. Thereafter the logging frequency was 30 seconds which was used until 30 minutes after flow start and a logging frequency of 5 minutes was used
- The flow was measured manually 2-3 times the first 5 minutes after flow start, 2-3 times the following 60 minutes and 3 times shortly before flow stop
- The valve shutting was done as swiftly as possible

5.3 Data handling

The test operator was keeping a diary during the test period. Data from the hydro tests includes:

- daily logs in accordance with Äspö Hard Rock Laboratory routines
- Protocols from flow measurements

The test coordinator collected all data and delivered it to the data handling responsible person at Äspö for further SICADA handling.

5.4 Analyses and interpretation

5.4.1 Single hole tests

When plotting the data, three different kinds of graphs can be produced. The first plot is made in a linear scale. The time, date and hours is indicated on the horizontal axis. The pressure (p), expressed in bar or metres of water head is indicated on the vertical axis. The second plot is made in a semi-logarithmic diagram, where the pressure change, Δp, is plotted versus the equivalent time, dt_e, in minutes. The equivalent time, dt_e, is defined as

$$dt_e = (t_p \cdot dt) / (t_p + dt) \qquad \text{where}$$

t_p = the flowing time of the borehole before shutting the valve

dt = the time after shutting the valve

The pressure change Δp is calculated as

Δp	=	p(dt) - p(tp)
p(dt)	=	measured pressure after shutting the valve
p(tp)	=	measured pressure just before shutting the valve

The third plot is made in a logarithmic diagram, where the change of pressure, Δp, is plotted versus the equivalent time, dt_e, in minutes. The derivative of the pressure is also plotted in this diagram.

The pressure normally is signed using the p and a change of pressure using a Δp. In the diagrams the pressure can be expressed in bar, kPa or in metres of water head. In the formulas below however the praxis is to use the s for the change of water head and Δs for the difference of pressure over one decade in a logarithmic diagram. The s or Δs values shall be expressed in metres before used in the formulas.

Hydrogeologic test analysis based on the derivative of pressure (i.e., rate of pressure change) with respect to the natural logarithm of time has been shown to significantly improve the diagnostic and quantitative analysis of slug and constant-rate discharge tests (i.e., pumping tests). The improvement in hydrogeologic test analysis is attributed to the sensitivity of the derivative response to small variations in the rate of pressure change that occurs during testing, which would otherwise be less obvious with standard pressure change versus time analysis techniques. The sensitivity of pressure derivatives to pressure change responses facilitates their use in identifying the presence of wellbore storage, boundaries, and establishment of flow conditions, as e.g. radial flow, within the test data record. Specifically, pressure derivative analysis can be used to:

- diagnostically determine formation response (homogeneous vs. heterogeneous) and boundary conditions (impermeable or constant head) that are evident during the test,

- determine when radial flow conditions are established and, therefore, when straight-line solution analysis of draw down data is valid, and

- assist in log-log type-curve matching to determine hydraulic properties for test data exhibiting wellbore storage and/or leakage effects.

The software DERIV is used to produce the derivative. DERIV is software for converting slug and constant-rate discharge test data and type curves to derivative format. The software has features that permit the smoothing of noisy test data, accounts for pressure derivative end-effects, and can be used to convert slug test data to equivalent constant-rate test responses.

Two different geohydrological parameters of the borehole can easily be evaluated. These parameters are:

- the specific capacity, Q/s (m^2/s)
- the transmissivity, T (m^2/s)

The specific capacity is as mentioned above, Q/s, where Q is the calculated average water flow before shutting the valve and s is the maximum change of pressure, in metres, during the test.

To evaluate the transmissivity, T, the following methodology should be used:

The flow regime can be estimated from the logarithmic plot. In most cases the flow can be said to be radial to the borehole approximately 1.0-1.5 decades after the time the curve has left the 1:1 curve. The 1:1 curve indicates the well bore storage, WBS. The transmissivity is then calculated with Jacob's semi logarithmic approximation of Theis well function,

$$T = 0.183 \cdot Q / \Delta s$$

Q = the average flow rate before shutting the valve (m^3/s)
Δs = the pressure change in metres during a decade along <u>the straight line</u> (radial flow period) in the semi logarithmic diagram (m).

Sometimes both the logarithmic and the semi logarithmic diagrams indicate a more complicated flow regime than described above (WBS, transition, radial flow) and in these cases it is necessary to decide what part of the curve and what evaluation method that is appropriate for estimating the hydraulic properties.

The Moye formula can be used for interpretation of stationary tests in order to get an estimate of the transmissivity

$$T_{Moye} = Q \cdot (1 + \ln(L/(2 \cdot r_w))) / (2 \cdot \pi \cdot \Delta h) \text{ where}$$

$\Delta h = (p_0 - p_p) / (\rho_w \cdot g)$	[m]
L = test section length	[m]
p_0 = absolute pressure in test section before start of flow period	[Pa]
p_p = absolute pressure in test section before stop of flow period	[Pa]
ρ_w = water density	[kg/m^3]
g = acceleration of gravity	[m/s^2]

6 RESULTS

6.1 Single hole tests

6.1.1 KA3552G01:2 , test No 2:1

General test data for the pressure build-up test in the interval 4.35-6.05 m of borehole KA3552G01 are presented in *Table 6-1*.

Table 6-1 General test data for the pressure build-up test in section 4.35-6.05 m of borehole KA3552G01

General test data			
Borehole section	KA3552G01:2		
Test No	2:1		
Field crew	A. Blom (SWECO VIAK)		
Test equipment system	HMS		
General comment	Single hole test		
	Nomen-clature	Unit	Value
Test section- secup	Secup	m	4.35
Test section- seclow	Seclow	m	6.05
Test section length	L_w	m	1.70
Test section diameter	$2 \cdot r_w$	mm	76
Test start (start of pressure registration)		yymmdd hh:mm	20031021 10:30:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	20031021 12:30:00
Stop of flow period		yymmdd hh:mm:ss	20031021 14:30:00
Test stop (stop of pressure registration)		yymmdd hh:mm	20031021 15:30:00
Total flow time	t_p	min	120
Total recovery time	t_F	min	60

Pressure data

Pressure data	Nomen-clature	Unit	Value	Comment
Absolute pressure in borehole before start of flow period	p_0	kPa	373.94	
Absolute pressure in test section before stop of flow	p_p	kPa	101.61	
Absolute pressure in test section at stop of recovery period	p_f	kPa	330.77	
Maximal pressure change during flow period	dp_p	kPa	272.33	

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$4.34 \cdot 10^{-8}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	-
Total volume discharged during flow period	V_p	m^3	-

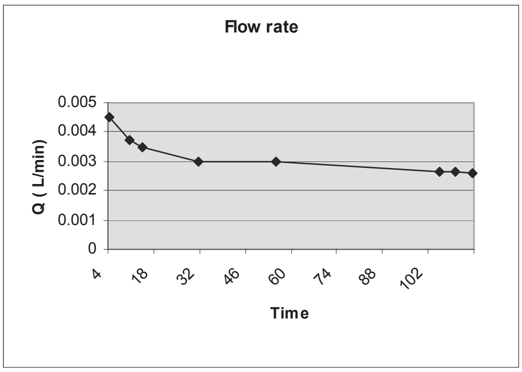


Figure 6-1 *Flow rates during draw down in KA3552G01:2. Time in minutes.*

Comments to the test

The test was successful in regard of pressure responses, but the recovery was too short for a final recovery.

Interpreted flow regimes

0 – 1.5 minutes	Well Bore Storage (WBS)
1.5 – 5 minutes	Transition period
5 – 8 minutes	Radial flow period
8 – 30 minutes	Transition period
30 – 40 minutes	Radial flow period

Calculated parameters

Quantitative analysis was made for recovery phases in lin-log- and log-log diagrams according to the methods described in Section 5.4.1.

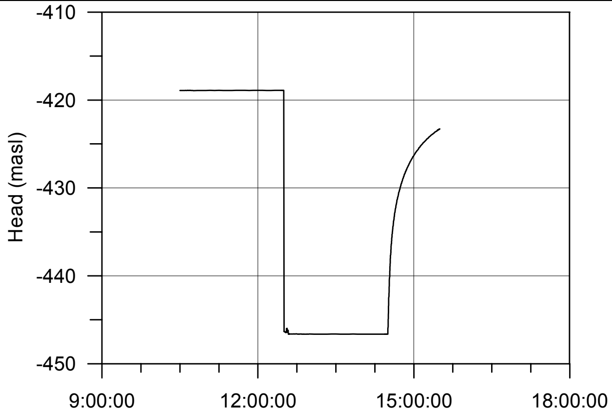
Selected representative parameters

The selected representative parameters from the test in the interval 4.35-6.05 m in KA3552G01 are presented in the Test Summary Sheet below. The selected parameters are derived from the recovery period.

Test Summary Sheet

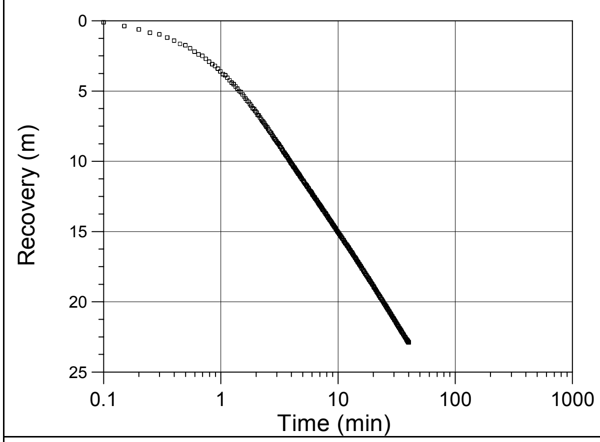
Project:	PROTOTYPE	Test type:	PBT
Area:	ÄSPÖ	Test no:	2:1
Borehole ID:	KA3552G01	Test start:	2003-10-21 10:30
Test section (m):	4.35-6.05	Responsible for test performance:	SWECO VIAK AB A. Blom
Section diameter, $2 \cdot r_w$ (m):	0.076	Responsible for test evaluation:	SWECO VIAK AB T. Forsmark

Linear plot Head



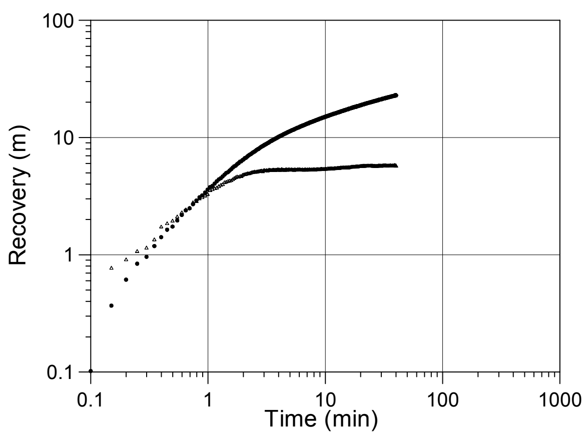
Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	373.94		
p_i (kPa)			
p_p(kPa)	101.61	p_F (kPa)	330.77
Q_p (m^3/s)	$4.34 \cdot 10^{-8}$		
tp (min)	120	t_F (min)	60
S*	$1 \cdot 10^{-6}$	S*	$1 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	

Lin-Log plot



Results		**Results**	
Q/s (m^2/s)	$1.6 \cdot 10^{-9}$	Flow regime:	Radial
T_{Moye}(m^2/s)	$1.0 \cdot 10^{-9}$	dt_{e1} (min)	5
Flow regime:		dt_{e2} (min)	8
dt_1 (min)		T (m^2/s)	$6.5 \cdot 10^{-10}$
dt_2 (min)		S (-)	
T (m^2/s)		K_s (m/s)	
S (-)		S_s (1/m)	
K_s (m/s)		C (m^3/Pa)	
S_s (1/m)		C_D (-)	
C (m^3/Pa)		ξ (-)	-1.8
C_D (-)			
ξ (-)			

Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.

Flow regime:	Radial	C (m^3/Pa)	
dt_1 (min)	5	C_D (-)	
dt_2 (min)	8	ξ (-)	-1.8
T_T (m^2/s)	$6.5 \cdot 10^{-10}$		
S (-)			
K_s (m/s)			
S_s (1/m)			

Comments: The test was successful in regard of pressure responses, but the recovery may have been too short for a final recovery.

6.1.2 KA3554G01:2 , test No 2:2

General test data for the pressure build-up test in the interval 22.60-24.15 m of borehole KA3554G01 are presented in *Table 6-2*.

Table 6-2 General test data for the pressure build-up test in section 22.60-24.15 m of borehole KA3554G01

General test data			
Borehole section	KA3554G01:2		
Test No	2:2		
Field crew	A. Blom (SWECO VIAK)		
Test equipment system	HMS		
General comment	Single hole test		
	Nomen-clature	Unit	Value
Test section- secup	Secup	m	22.60
Test section- seclow	Seclow	m	24.15
Test section length	L_w	m	1.55
Test section diameter	$2 \cdot r_w$	mm	76
Test start (start of pressure registration)		yymmdd hh:mm	20031021 13:30:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	20031021 15:30:00
Stop of flow period		yymmdd hh:mm:ss	20031021 16:00:00
Test stop (stop of pressure registration)		yymmdd hh:mm	20031021 17:00:00
Total flow time	t_p	min	30
Total recovery time	t_F	min	60

Pressure data

Pressure data	Nomen-clature	Unit	Value	Comment
Absolute pressure in borehole before start of flow period	p_0	kPa	3730.2	
Absolute pressure in test section before stop of flow	p_p	kPa	555.2	
Absolute pressure in test section at stop of recovery period	p_f	kPa	3720.8	
Maximal pressure change during flow period	dp_p	kPa	3175.0	

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$2.63 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	-
Total volume discharged during flow period	V_p	m^3	-

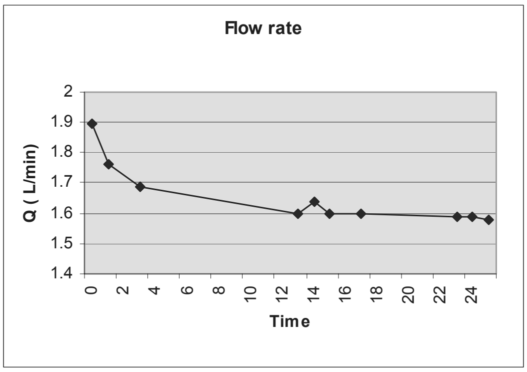


Figure 6-2 *Flow rates during draw down in KA3554G01:2. Time in minutes.*

Comments to the test

The test was successful in regard to pressure response.

Interpreted flow regimes

0 – 0.3 minutes	Well Bore Storage (WBS)
0.3 – 9 minutes	Transition period
9 – 20 minutes	Radial flow period

Calculated parameters

Quantitative analysis was made for recovery phases in lin-log- and log-log diagrams according to the methods described in Section 5.4.1.

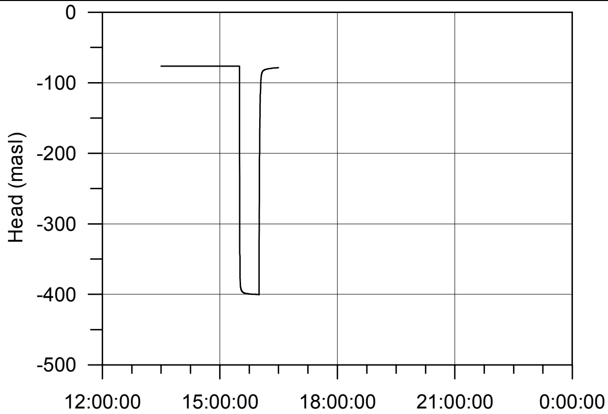
Selected representative parameters

The selected representative parameters from the test in the interval 22.60-24.15 m in KA3554G01 are presented in the Test Summary Sheet below. The selected parameters are derived from the recovery.

Test Summary Sheet

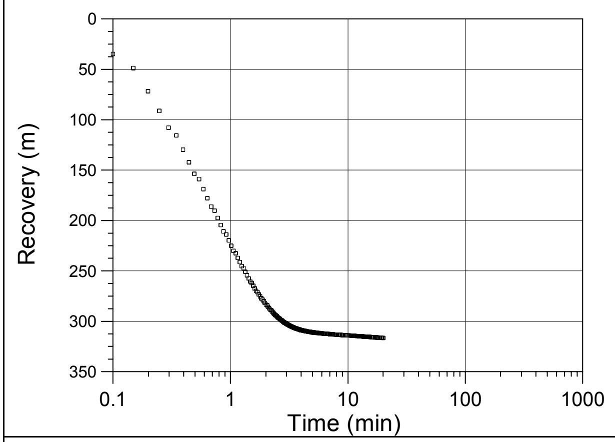
Project:	PROTOTYPE	Test type:	PBT
Area:	ÄSPÖ	Test no:	2:2
Borehole ID:	KA3554G01	Test start:	2003-10-21 13:30
Test section (m):	22.60-24.15	Responsible for test performance:	SWECO VIAK AB A. Blom
Section diameter, $2 \cdot r_w$ (m):	0.076	Responsible for test evaluation:	SWECO VIAK AB T. Forsmark

Linear plot Head



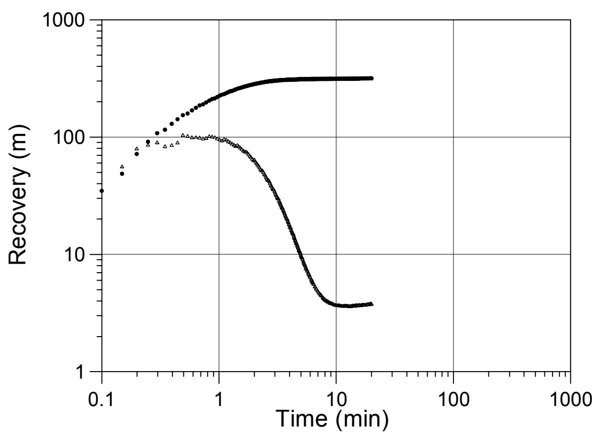
Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	3730.2		
p_i (kPa)			
p_p(kPa)	555.2	p_F (kPa)	3655.0
Q_p (m^3/s)	$2.63 \cdot 10^{-5}$		
tp (min)	30	t_F (min)	60
S*		S*	$1 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	0.2

Lin-Log plot



Results		**Results**	
Q/s (m^2/s)	$8.3 \cdot 10^{-8}$	Flow regime:	Radial
T_{Moye}(m^2/s)	$5.3 \cdot 10^{-8}$	dt_{e1} (min)	9
Flow regime:		dt_{e2} (min)	20
dt_1 (min)		T (m^2/s)	$5.3 \cdot 10^{-7}$
dt_2 (min)		S (-)	
T (m^2/s)		K_s (m/s)	
S (-)		S_s (1/m)	
K_s (m/s)		C (m^3/Pa)	
S_s (1/m)		C_D (-)	
C (m^3/Pa)		ξ (-)	34
C_D (-)			
ξ (-)			

Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.			
Flow regime:	Radial	C (m^3/Pa)	
dt_1 (min)	9	C_D (-)	
dt_2 (min)	20	ξ (-)	34
T_T (m^2/s)	$5.3 \cdot 10^{-7}$		
S (-)			
K_s (m/s)			
S_s (1/m)			

Comments: The test was successful in regard to pressure response.

6.1.3 KA3554G02:4 , test No 2:3

General test data for the pressure build-up test in the interval 10.50-12.20 m of borehole KA3554G02 are presented in *Table 6-3*.

Table 6-3 General test data for the pressure build-up test in section 10.50-12.20 m of borehole KA3554G02

General test data			
Borehole section	KA3554G02:4		
Test No	2:3		
Field crew	A. Blom (SWECO VIAK)		
Test equipment system	HMS		
General comment	Single hole test		
	Nomen-clature	Unit	Value
Test section- secup	Secup	m	10.50
Test section- seclow	Seclow	m	12.20
Test section length	L_w	m	1.70
Test section diameter	$2 \cdot r_w$	mm	76
Test start (start of pressure registration)		yymmdd hh:mm	20031022 05:45:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	20031022 07:45:00
Stop of flow period		yymmdd hh:mm:ss	20031022 09:45:00
Test stop (stop of pressure registration)		yymmdd hh:mm	20031022 10:45:00
Total flow time	t_p	min	120
Total recovery time	t_F	min	60

Pressure data

Pressure data	Nomenclature	Unit	Value	Comment
Absolute pressure in borehole before start of flow period	p_0	kPa	2379.8	
Absolute pressure in test section before stop of flow	p_p	kPa	102.5	
Absolute pressure in test section at stop of recovery period	p_f	kPa	2345.2	
Maximal pressure change during flow period	dp_p	kPa	2277.3	

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$2.75 \cdot 10^{-7}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	-
Total volume discharged during flow period	V_p	m^3	-

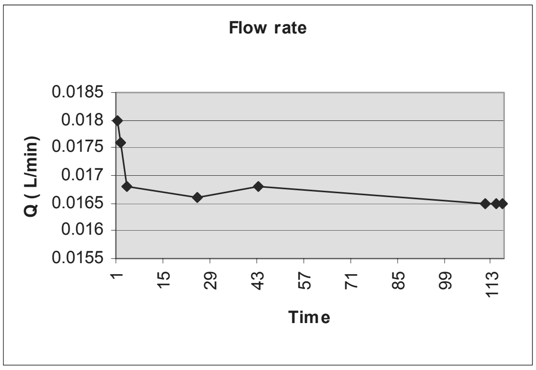


Figure 6-3 *Flow rates during draw down in KA3554G02:4. Time in minutes.*

Comments to the test

The test was successful in regard to pressure response.

Interpreted flow regimes

0 – 1.2 minutes	Well Bore Storage (WBS)
1.2 – 24 minutes	Transition period
25 – 37 minutes	Radial flow period

Calculated parameters

Quantitative analysis was made for recovery phases in lin-log- and log-log diagrams according to the methods described in Section 5.4.1.

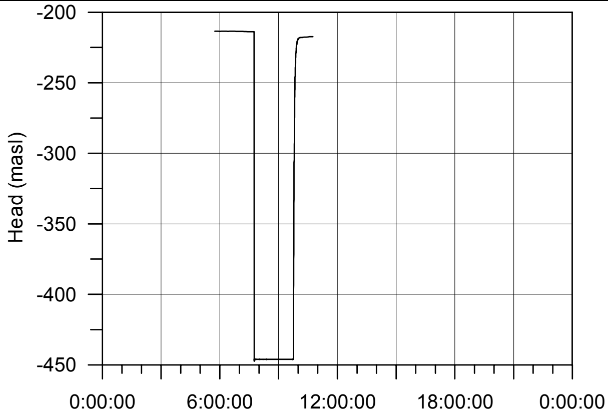
Selected representative parameters

The selected representative parameters from the test in the interval 10.50-12.20 m in KA3554G02 are presented in the Test Summary Sheet below. The selected parameters are derived from the recovery.

Test Summary Sheet

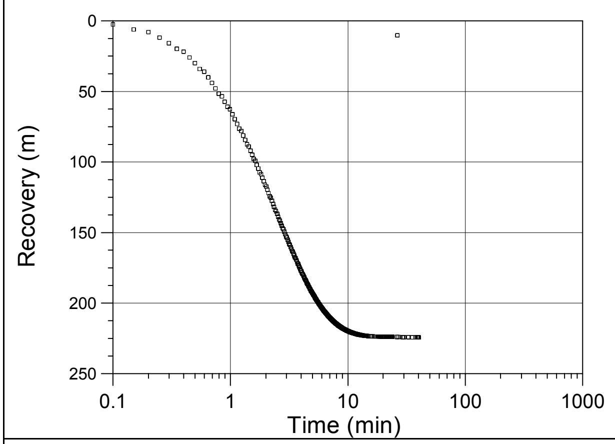
Project:	PROTOTYPE	Test type:	PBT
Area:	ÄSPÖ	Test no:	2:3
Borehole ID:	KA3554G02	Test start:	2003-10-22 05:45
Test section (m):	10.50-12.20	Responsible for test performance:	SWECO VIAK AB A. Blom
Section diameter, $2 \cdot r_w$ (m):	0.076	Responsible for test evaluation:	SWECO VIAK AB T. Forsmark

Linear plot Head



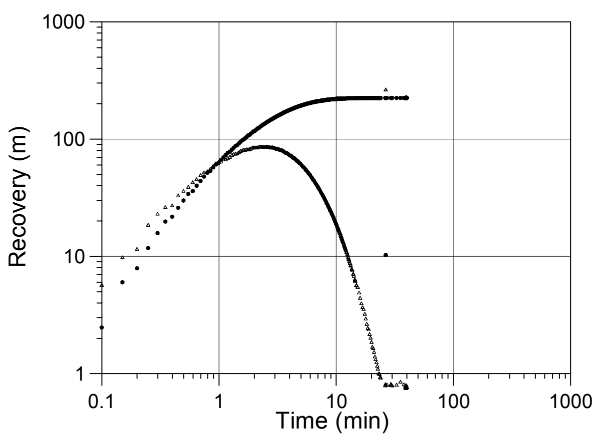
Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	2379.8		
p_i (kPa)			
p_p(kPa)	102.5	p_F (kPa)	2345.2
Q_p (m^3/s)	$2.75 \cdot 10^{-7}$		
tp (min)	120	t_F (min)	60
S*		S*	$1 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	0.2

Lin-Log plot



Results		**Results**	
Q/s (m^2/s)	$1.2 \cdot 10^{-9}$	Flow regime:	Radial
T_{Moye}(m^2/s)	$7.9 \cdot 10^{-10}$	dt_{e1} (min)	25
Flow regime:		dt_{e2} (min)	37
dt_1 (min)		T (m^2/s)	$2.5 \cdot 10^{-8}$
dt_2 (min)		S (-)	
T (m^2/s)		K_s (m/s)	
S (-)		S_s (1/m)	
K_s (m/s)		C (m^3/Pa)	
S_s (1/m)		C_D (-)	
C (m^3/Pa)		ξ (-)	120
C_D (-)			
ξ (-)			

Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.			
Flow regime:	Radial	C (m^3/Pa)	
dt_1 (min)	25	C_D (-)	
dt_2 (min)	37	ξ (-)	120
T_T (m^2/s)	$2.5 \cdot 10^{-8}$		
S (-)			
K_s (m/s)			
S_s (1/m)			

Comments: The test was successful in regard to pressure response.

6.1.4 KA3548A01:3 , test No 2:4

General test data for the pressure build-up test in the interval 8.80-10.75 m of borehole KA3548A01 are presented in *Table 6-4*.

Table 6-4 General test data for the pressure build-up test in section 8.80-10.75 m of borehole KA3548A01

General test data			
Borehole section	KA3548A01:3		
Test No	2:4		
Field crew	A. Blom (SWECO VIAK)		
Test equipment system	HMS		
General comment	Single hole test		
	Nomen-clature	Unit	Value
Test section- secup	Secup	m	8.80
Test section- seclow	Seclow	m	10.75
Test section length	L_w	m	1.95
Test section diameter	$2 \cdot r_w$	mm	76
Test start (start of pressure registration)		yymmdd hh:mm	20031022 16:15:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	20031022 18:15:00
Stop of flow period		yymmdd hh:mm:ss	20031022 18:45:00
Test stop (stop of pressure registration)		yymmdd hh:mm	20031022 19:45:00
Total flow time	t_p	min	30
Total recovery time	t_F	min	60

Pressure data

Pressure data	Nomenclature	Unit	Value	Comment
Absolute pressure in borehole before start of flow period	p_0	kPa	3506.3	
Absolute pressure in test section before stop of flow	p_p	kPa	577.9	
Absolute pressure in test section at stop of recovery period	p_f	kPa	3470.9	
Maximal pressure change during flow period	dp_p	kPa	2928.4	

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$2.97 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	-
Total volume discharged during flow period	V_p	m^3	-

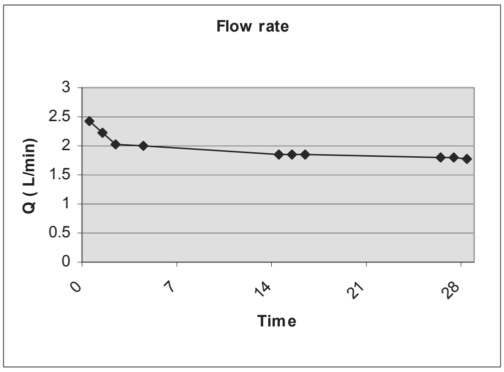


Figure 6-4 *Flow rates during draw down in KA3548A01:3. Time in minutes.*

Comments to the test

The test was successful in regard to pressure response. The test in KA3542G01:3 (Test 2:5) is influencing the test period during its flow phase, see lin-lin plot below.

Interpreted flow regimes

0 – 0.15 minutes	Well Bore Storage (WBS)
0.15 – 0.4 minutes	Transition period
0.4 – 1 minutes	Radial flow period
1 – 5 minutes	Transition period
5 – 10 minutes	Spherical flow period
10 – 15 minutes	Transition period
15 – 20 minutes	Radial flow period

Calculated parameters

Quantitative analysis was made for recovery phases in lin-log- and log-log diagrams according to the methods described in Section 5.4.1.

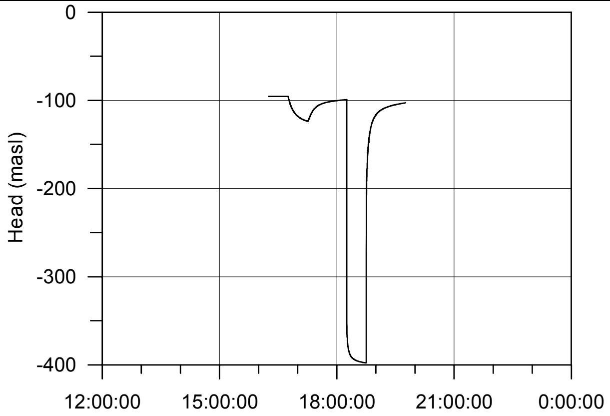
Selected representative parameters

The selected representative parameters from the test in the interval 8.80-10.75 m in KA3548A01 are presented in the Test Summary Sheet below. The selected parameters are derived from the recovery period.

Test Summary Sheet

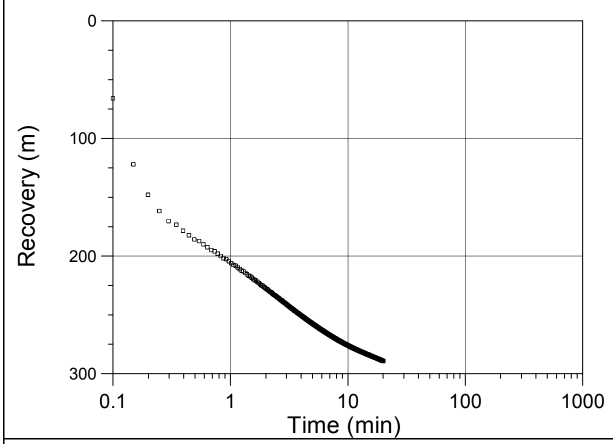
Project:	PROTOTYPE	Test type:	PBT
Area:	ÄSPÖ	Test no:	2:4
Borehole ID:	KA3548A01	Test start:	2003-10-22 16:15
Test section (m):	8.80-10.75	Responsible for test performance:	SWECO VIAK AB A. Blom
Section diameter, $2 \cdot r_w$ (m):	0.076	Responsible for test evaluation:	SWECO VIAK AB T. Forsmark

Linear plot Head



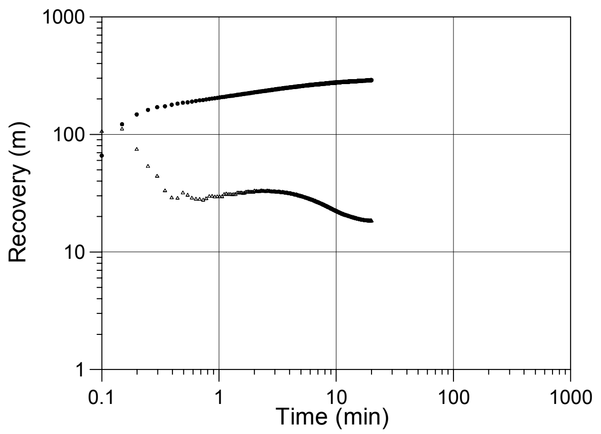
Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	3506.3		
p_i (kPa)			
p_p(kPa)	577.9	p_F (kPa)	3470.9
Q_p (m^3/s)	$2.97 \cdot 10^{-5}$		
tp (min)	120	t_F (min)	60
S*		S*	$1 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	0.2

Lin-Log plot



Results		Results	
Q/s (m^2/s)	$1.0 \cdot 10^{-7}$	Flow regime:	Radial
T_{Moye}(m^2/s)	$6.9 \cdot 10^{-8}$	dt_{e1} (min)	0.4
Flow regime:		dt_{e2} (min)	1
dt_1 (min)		T (m^2/s)	$9.8 \cdot 10^{-8}$
dt_2 (min)		S (-)	
T (m^2/s)		K_s (m/s)	
S (-)		S_s (1/m)	
K_s (m/s)		C (m^3/Pa)	
S_s (1/m)		C_D (-)	
C (m^3/Pa)		ξ (-)	-0.3
C_D (-)			
ξ (-)			

Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.			
Flow regime:	Radial	C (m^3/Pa)	
dt_1 (min)	0.4	C_D (-)	
dt_2 (min)	1	ξ (-)	-0.3
T_T (m^2/s)	$9.8 \cdot 10^{-8}$		
S (-)			
K_s (m/s)			
S_s (1/m)			

Comments: A successful test. The test in KA3542G01:3 (Test 2:5) is influencing the test period during test 2:5´s flow phase, see the linear plot.

6.1.5 KA3542G01:3 , test No 2:5

General test data for the pressure build-up test in the interval 18.60-20.30 m of borehole KA3542G01 are presented in *Table 6-5*.

Table 6-5 General test data for the pressure build-up test in section 18.60-20.30 m of borehole KA3542G01

General test data			
Borehole section	KA3542G01:3		
Test No	2:5		
Field crew	A. Blom (SWECO VIAK)		
Test equipment system	HMS		
General comment	Single hole test		
	Nomen-clature	Unit	Value
Test section- secup	Secup	m	18.60
Test section- seclow	Seclow	m	20.30
Test section length	L_w	m	1.70
Test section diameter	$2 \cdot r_w$	mm	76
Test start (start of pressure registration)		yymmdd hh:mm	20031022 14:45:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	20031022 16:45:00
Stop of flow period		yymmdd hh:mm:ss	20031022 17:15:00
Test stop (stop of pressure registration)		yymmdd hh:mm	20031022 18:15:00
Total flow time	t_p	min	30
Total recovery time	t_F	min	60

Pressure data

Pressure data	Nomenclature	Unit	Value	Comment
Absolute pressure in borehole before start of flow period	p_0	kPa	3488.7	
Absolute pressure in test section before stop of flow	p_p	kPa	250.6	
Absolute pressure in test section at stop of recovery period	p_f	kPa	3438.9	
Maximal pressure change during flow period	dp_p	kPa	3238.1	

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$1.59 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	-
Total volume discharged during flow period	V_p	m^3	-

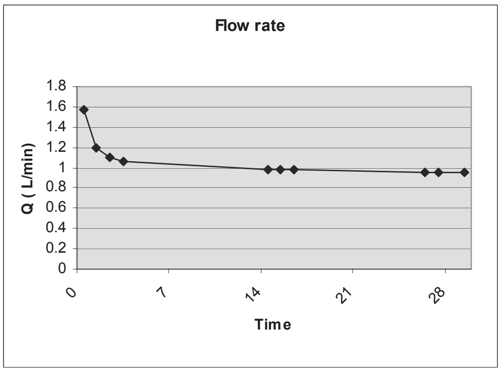


Figure 6-5 *Flow rate during draw down in KA3542G01:3. Time in minutes.*

Comments to the test

The test was successful in regard to pressure response.

Interpreted flow regimes

0 – 0.2 minutes	Well Bore Storage (WBS)
0.2 – 4 minutes	Transition period
4 – 10 minutes	Spherical flow period
10 – 15 minutes	Transition period
15 – 20 minutes	Possible radial flow period.

Calculated parameters

Quantitative analysis was made for recovery phases in lin-log- and log-log diagrams according to the methods described in Section 5.4.1.

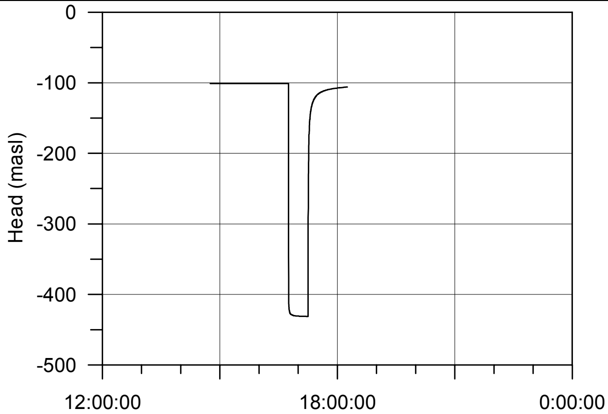
Selected representative parameters

The selected representative parameters from the test in the interval 18.60-20.30 m in KA3542G01 are presented in the Test Summary Sheet below. The selected parameters are derived from the recovery period.

Test Summary Sheet

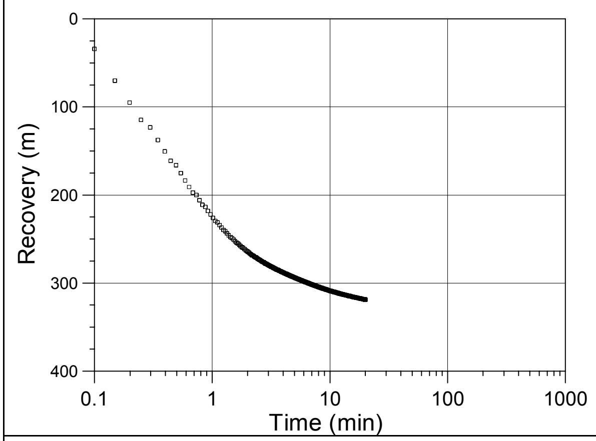
Project:	PROTOTYPE	Test type:	PBT
Area:	ÄSPÖ	Test no:	2:5
Borehole ID:	KA3542G01	Test start:	2003-10-22 14:45
Test section (m):	18.60-20.30	Responsible for test performance:	SWECO VIAK AB A. Blom
Section diameter, $2 \cdot r_w$ (m):	0.076	Responsible for test evaluation:	SWECO VIAK AB T. Forsmark

Linear plot Head



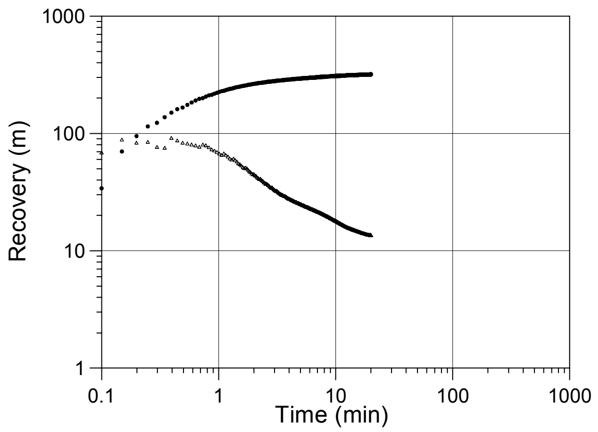
Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	3488.7		
p_i (kPa)			
p_p(kPa)	250.6	p_F (kPa)	3439.8
Q_p (m^3/s)	$1.59 \cdot 10^{-5}$		
tp (min)	30	t_F (min)	60
S*		S*	$1 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	0.2

Lin-Log plot



Results		Results	
Q/s (m^2/s)	$4.9 \cdot 10^{-8}$	Flow regime:	Radial
T_{Moye}(m^2/s)	$3.2 \cdot 10^{-8}$	dt_{e1} (min)	15
Flow regime:		dt_{e2} (min)	20
dt_1 (min)		T (m^2/s)	$9.7 \cdot 10^{-8}$
dt_2 (min)		S (-)	
T (m^2/s)		K_s (m/s)	
S (-)		S_s (1/m)	
K_s (m/s)		C (m^3/Pa)	
S_s (1/m)		C_D (-)	
C (m^3/Pa)		ξ (-)	6.2
C_D (-)			
ξ (-)			

Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.			
Flow regime:	Radial	C (m^3/Pa)	
dt_1 (min)	15	C_D (-)	
dt_2 (min)	20	ξ (-)	6.2
T_T (m^2/s)	$9.7 \cdot 10^{-8}$		
S (-)			
K_s (m/s)			
S_s (1/m)			

Comments: A successful test. However, T_T is uncertain due to the fact that possibly no radial flow is established.

6.1.6 KA3544G01:2 , test No 2:6

General test data for the pressure build-up test in the interval 8.90-10.65 m of borehole KA3544G01 are presented in *Table 6-6*.

Table 6-6 General test data for the pressure build-up test in section 8.90-10.65 m of borehole KA3544G01

General test data			
Borehole section	KA3544G01:2		
Test No	2:6		
Field crew	A. Blom (SWECO VIAK)		
Test equipment system	HMS		
General comment	Single hole test		
	Nomen-clature	Unit	Value
Test section- secup	Secup	m	8.90
Test section- seclow	Seclow	m	10.65
Test section length	L_w	m	1.75
Test section diameter	$2 \cdot r_w$	mm	76
Test start (start of pressure registration)		yymmdd hh:mm	20031022 08:45:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	20031022 10:45:00
Stop of flow period		yymmdd hh:mm:ss	20031022 12:45:00
Test stop (stop of pressure registration)		yymmdd hh:mm	20031022 13:45:00
Total flow time	t_p	min	120
Total recovery time	t_F	min	60

Pressure data

Pressure data	Nomenclature	Unit	Value	Comment
Absolute pressure in borehole before start of flow period	p_0	kPa	1957.2	
Absolute pressure in test section before stop of flow	p_p	kPa	107.8	
Absolute pressure in test section at stop of recovery period	p_f	kPa	1863.3	
Maximal pressure change during flow period	dp_p	kPa	1849.4	

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$1.10 \cdot 10^{-7}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	-
Total volume discharged during flow period	V_p	m^3	-

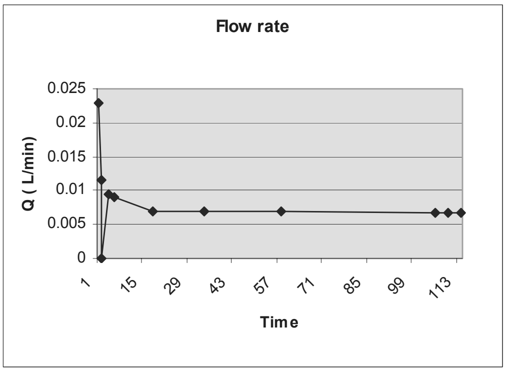


Figure 6-6 *Flow rate during draw down in KA3544G01:2. Time in minutes.*

Comments to the test

The test was successful in regard to pressure response. However the pressure recovery period was too short to establish a radial flow regime.

Interpreted flow regimes

0 – 30 minutes Well Bore Storage (WBS)

30 – 40 minutes Transition period

No radial flow regime is established.

Calculated parameters

Quantitative analysis was made for recovery phases in lin-log- and log-log diagrams according to the methods described in Section 5.4.1.

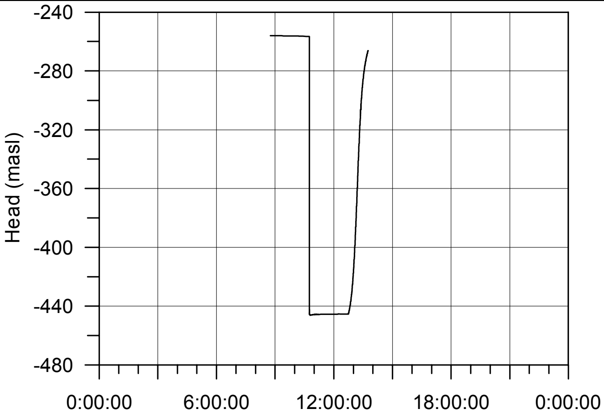
Selected representative parameters

The selected representative parameters from the test in the interval 8.90-10.65 m in KA3544G01 are presented in the Test Summary Sheet below. The selected parameters are derived from the recovery period.

Test Summary Sheet

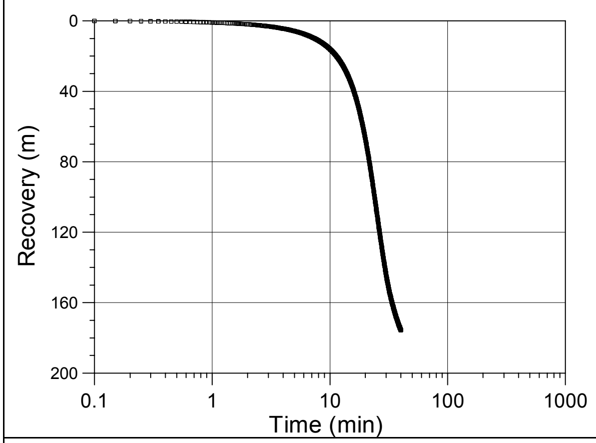
Project:	PROTOTYPE	Test type:	PBT
Area:	ÄSPÖ	Test no:	2:6
Borehole ID:	KA3544G01	Test start:	2003-10-22 08:45
Test section (m):	8.90-10.65	Responsible for test performance:	SWECO VIAK AB A. Blom
Section diameter, $2 \cdot r_w$ (m):	0.076	Responsible for test evaluation:	SWECO VIAK AB T. Forsmark

Linear plot Head



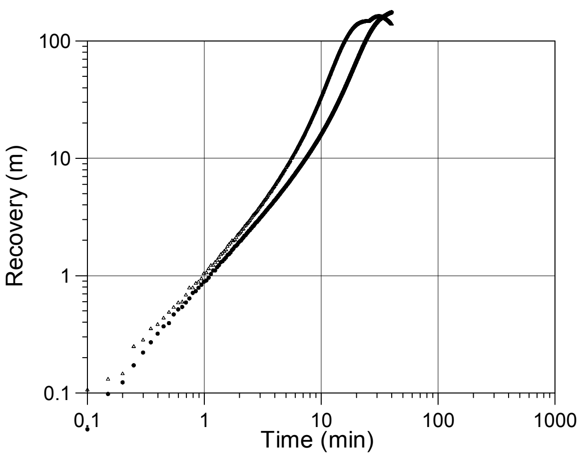
Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	1957.2		
p_i (kPa)			
p_p(kPa)	107.8	p_F (kPa)	1863.3
Q_p (m^3/s)	$1.10 \cdot 10^{-7}$		
tp (min)	120	t_F (min)	60
S*		S*	$1 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	0.2

Lin-Log plot



Results		**Results**	
Q/s (m^2/s)	$5.9 \cdot 10^{-10}$	Flow regime:	Radial
T_{Moye}(m^2/s)	$3.6 \cdot 10^{-10}$	dt_{e1} (min)	-
Flow regime:		dt_{e2} (min)	-
dt_1 (min)		T (m^2/s)	-
dt_2 (min)		S (-)	
T (m^2/s)		K_s (m/s)	
S (-)		S_s (1/m)	
K_s (m/s)		C (m^3/Pa)	
S_s (1/m)		C_D (-)	
C (m^3/Pa)		ξ (-)	-
C_D (-)			
ξ (-)			

Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.			
Flow regime:		C (m^3/Pa)	
dt_1 (min)		C_D (-)	
dt_2 (min)		ξ (-)	
T_T (m^2/s)			
S (-)			
K_s (m/s)			
S_s (1/m)			

Comments: No radial flow occurred during the test period. Possibly air may have entered the system.

6.1.7 KA3542G02:2 , test No 2:7

General test data for the pressure build-up test in the interval 25.60-27.20 m of borehole KA3542G02 are presented in *Table 6-7*.

Table 6-7 General test data for the pressure build-up test in section 25.60-27.20 m of borehole KA3542G02

General test data			
Borehole section	KA3542G02:2		
Test No	2:7		
Field crew	A. Blom (SWECO VIAK)		
Test equipment system	HMS		
General comment	Single hole test		
	Nomen-clature	Unit	Value
Test section- secup	Secup	m	25.60
Test section- seclow	Seclow	m	27.20
Test section length	L_w	m	1.60
Test section diameter	$2 \cdot r_w$	mm	76
Test start (start of pressure registration)		yymmdd hh:mm	20031023 05:15:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	20031023 07:15:00
Stop of flow period		yymmdd hh:mm:ss	20031023 09:15:00
Test stop (stop of pressure registration)		yymmdd hh:mm	20031023 10:15:00
Total flow time	t_p	min	120
Total recovery time	t_F	min	60

Pressure data

Pressure data	Nomenclature	Unit	Value	Comment
Absolute pressure in borehole before start of flow period	p_0	kPa	2504.9	
Absolute pressure in test section before stop of flow	p_p	kPa	105.4	
Absolute pressure in test section at stop of recovery period	p_f	kPa	2171.1	
Maximal pressure change during flow period	dp_p	kPa	2399.5	

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$1.17 \cdot 10^{-7}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	-
Total volume discharged during flow period	V_p	m^3	-

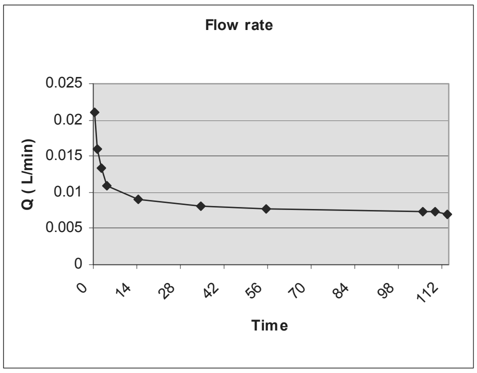


Figure 6-7 *Flow rate during draw down in KA3542G02:2. Time in minutes.*

Comments to the test

The test was successful in regard to pressure response. No radial flow regime period could however be evaluated.

Interpreted flow regimes

0 – 1.2 minutes	Well Bore Storage (WBS)
1.2 – 40 minutes	Transition period

No radial flow regime period was established.

Calculated parameters

Quantitative analysis was made for recovery phases in lin-log- and log-log diagrams according to the methods described in Section 5.4.1.

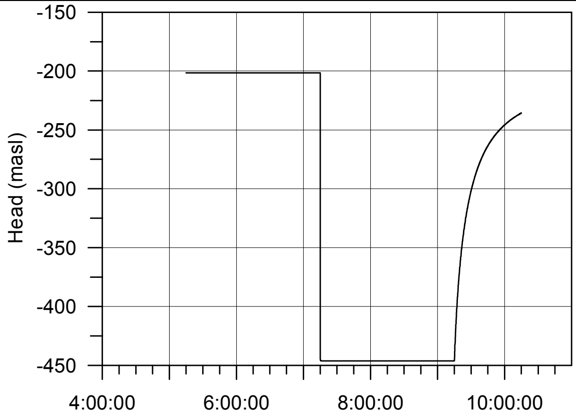
Selected representative parameters

The selected representative parameters from the test in the interval 25.60-27.20 m in KA3542G02 are presented in the Test Summary Sheet below. The selected parameters are derived from the recovery period.

Test Summary Sheet

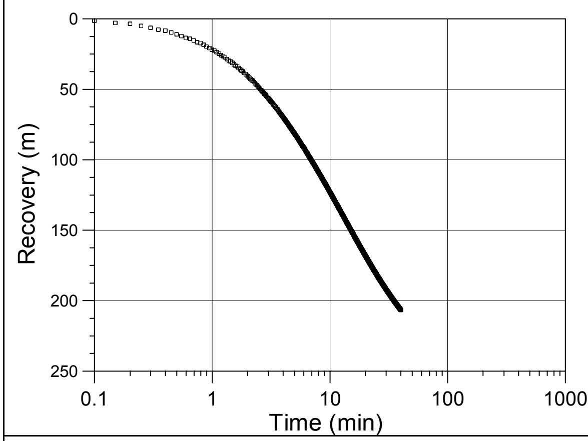
Project:	PROTOTYPE	Test type:	PBT
Area:	ÄSPÖ	Test no:	2:7
Borehole ID:	KA3542G02	Test start:	2003-10-23 05:15
Test section (m):	25.60-27.20	Responsible for test performance:	SWECO VIAK AB A. Blom
Section diameter, $2 \cdot r_w$ (m):	0.076	Responsible for test evaluation:	SWECO VIAK AB T. Forsmark

Linear plot Head



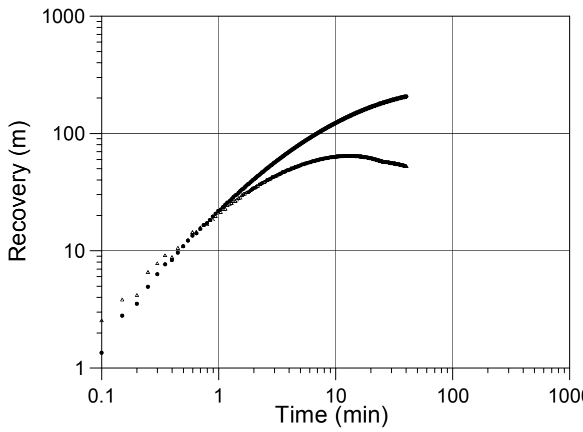
Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	2504.9		
p_i (kPa)			
p_p(kPa)	105.4	p_F (kPa)	2171.1
Q_p (m^3/s)	$1.17 \cdot 10^{-7}$		
tp (min)	120	t_F (min)	60
S*		S*	$1 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	

Lin-Log plot



Results		**Results**	
Q/s (m^2/s)	$4.9 \cdot 10^{-10}$	Flow regime:	Radial
T_{Moye}(m^2/s)	$3.1 \cdot 10^{-10}$	dt_{e1} (min)	30
Flow regime:		dt_{e2} (min)	40
dt_1 (min)		T (m^2/s)	$1.9 \cdot 10^{-10}$
dt_2 (min)		S (-)	
T (m^2/s)		K_s (m/s)	
S (-)		S_s (1/m)	
K_s (m/s)		C (m^3/Pa)	
S_s (1/m)		C_D (-)	
C (m^3/Pa)		ξ (-)	-1.3
C_D (-)			
ξ (-)			

Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.			
Flow regime:	Radial	C (m^3/Pa)	
dt_1 (min)	30	C_D (-)	
dt_2 (min)	40	ξ (-)	
T_T (m^2/s)	$1.9 \cdot 10^{-10}$		
S (-)			
K_s (m/s)			
S_s (1/m)			

Comments: Probably no radial flow occurred until very late during the test period. Therefore the evaluated transmissivity may be too low to be representative for the formation.

6.1.8 KA3546G01:2 , test No 2:9

General test data for the pressure build-up test in the interval 6.75-8.30 m of borehole KA3546G01 are presented in *Table 6-8*.

Table 6-8 General test data for the pressure build-up test in section 6.75-8.30 m of borehole KA3546G01

General test data			
Borehole section	KA3546G01:2		
Test No	2:9		
Field crew	A. Blom (SWECO VIAK)		
Test equipment system	HMS		
General comment	Single hole test		
	Nomen-clature	Unit	Value
Test section- secup	Secup	m	6.75
Test section- seclow	Seclow	m	8.30
Test section length	L_w	m	1.55
Test section diameter	$2 \cdot r_w$	mm	76
Test start (start of pressure registration)		yymmdd hh:mm	20031022 11:45:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	20031022 13:45:00
Stop of flow period		yymmdd hh:mm:ss	20031022 15:45:00
Test stop (stop of pressure registration)		yymmdd hh:mm	20031022 16:45:00
Total flow time	t_p	min	120
Total recovery time	t_F	min	60

Pressure data

Pressure data	Nomenclature	Unit	Value	Comment
Absolute pressure in borehole before start of flow period	p_0	kPa	305.4	
Absolute pressure in test section before stop of flow	p_p	kPa	107.0	
Absolute pressure in test section at stop of recovery period	p_f	kPa	292.6	
Maximal pressure change during flow period	dp_p	kPa	198.4	

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$1.22 \cdot 10^{-8}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	-
Total volume discharged during flow period	V_p	m^3	-

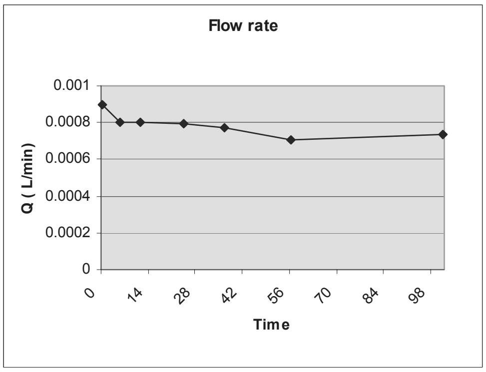


Figure 6-8 *Flow rate during draw down in KA3546G01:2. Time in minutes.*

Comments to the test

The test only generated a pressure drop and following recovery of some 20 metres, which was however considerably a larger pressure response than in test 1:9 in May 2003.

Interpreted flow regimes

0 –7 minutes Well Bore Storage (WBS)

7 – 40 minutes Transition period

No radial flow regime period was established.

Calculated parameters

Quantitative analysis was made for recovery phases in lin-log- and log-log diagrams according to the methods described in Section 5.4.1.

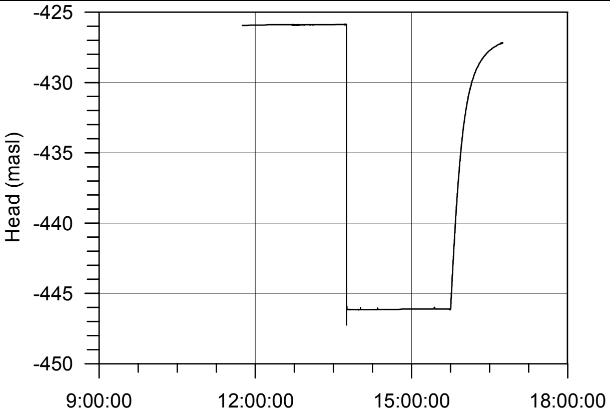
Selected representative parameters

The selected representative parameters from the test in the interval 6.75-8.30 m in KA3546G01 are presented in the Test Summary Sheet below. The selected parameters are derived from the recovery period since this period have a more certain flow value than the flow period.

Test Summary Sheet

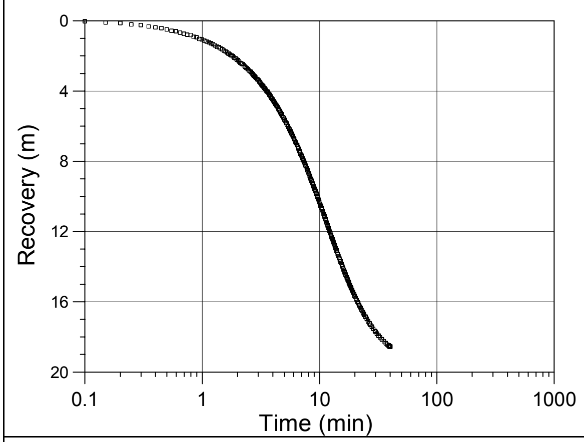
Project:	PROTOTYPE	Test type:	PBT
Area:	ÄSPÖ	Test no:	2:9
Borehole ID:	KA3546G01	Test start:	2003-10-22 11:45
Test section (m):	6.75-8.30	Responsible for test performance:	SWECO VIAK AB A. Blom
Section diameter, $2 \cdot r_w$ (m):	0.076	Responsible for test evaluation:	SWECO VIAK AB T. Forsmark

Linear plot Head



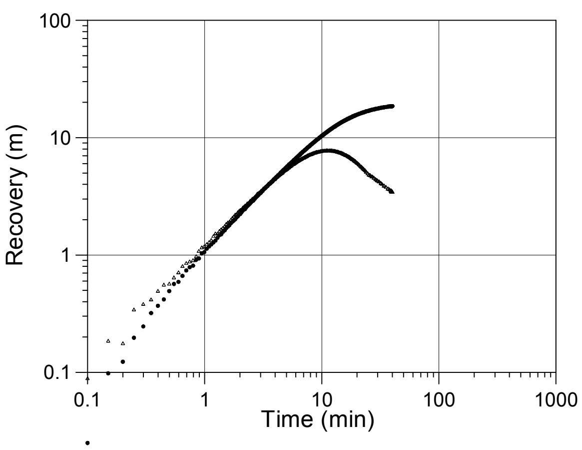
Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	305.4		
p_i (kPa)			
p_p(kPa)	107.0	p_F (kPa)	292.6
Q_p (m^3/s)	$1.22 \cdot 10^{-8}$		
tp (min)	120	t_F (min)	60
S*		S*	$1 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	0.2

Lin-Log plot



Results		**Results**	
Q/s (m^2/s)	$6.1 \cdot 10^{-10}$	Flow regime:	Radial
T_{Moye}(m^2/s)	$6.6 \cdot 10^{-10}$	dt_{e1} (min)	-
Flow regime:		dt_{e2} (min)	-
dt_1 (min)		T (m^2/s)	-
dt_2 (min)		S (-)	
T (m^2/s)		K_s (m/s)	
S (-)		S_s (1/m)	
K_s (m/s)		C (m^3/Pa)	
S_s (1/m)		C_D (-)	
C (m^3/Pa)		ξ (-)	
C_D (-)			
ξ (-)			

Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.			
Flow regime:		C (m^3/Pa)	
dt_1 (min)		C_D (-)	
dt_2 (min)		ξ (-)	
T_T (m^2/s)			
S (-)			
K_s (m/s)			
S_s (1/m)			

Comments: No radial flow regime occurred during the test period.

6.1.9 KA3539G:2, test No 2:13

General test data for the pressure build-up test in the interval 15.85-17.60 m of borehole KA3539G are presented in *Table 6-9*.

Table 6-9 General test data for the pressure build-up test in section 15.85-17.60 m of borehole KA3539G

General test data			
Borehole section	KA3539G:2		
Test No	2:13		
Field crew	A. Blom (SWECO VIAK)		
Test equipment system	HMS		
General comment	Single hole test		
	Nomen-clature	Unit	Value
Test section- secup	Secup	m	15.85
Test section- seclow	Seclow	m	17.60
Test section length	L_w	m	1.75
Test section diameter	$2 \cdot r_w$	mm	76
Test start (start of pressure registration)		yymmdd hh:mm	20031023 08:15:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	20031023 10:15:00
Stop of flow period		yymmdd hh:mm:ss	20031023 10:45:00
Test stop (stop of pressure registration)		yymmdd hh:mm	20031023 12:45:00
Total flow time	t_p	min	30
Total recovery time	t_F	min	120

Pressure data

Pressure data	Nomenclature	Unit	Value	Comment
Absolute pressure in borehole before start of flow period	p_0	kPa	2369.0	
Absolute pressure in test section before stop of flow	p_p	kPa	1005.0	
Absolute pressure in test section at stop of recovery period	p_f	kPa	2268.7	
Maximal pressure change during flow period	dp_p	kPa	1364.0	

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$4.08 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	-
Total volume discharged during flow period	V_p	m^3	-

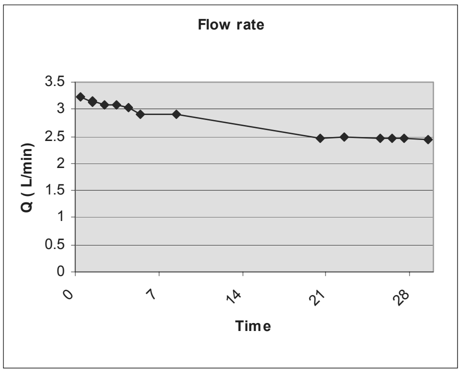


Figure 6-9 *Flow rate during draw down in KA3539G:2. Time in minutes.*

Comments to the test

The test was successful in regard to pressure response.

Interpreted flow regimes

0 – 0.05 minutes	Well Bore Storage (WBS)
0.05 – 0.2 minutes	Transition period
0.2 – 0.7 minutes	Radial flow period
0.7 – 2 minutes	Transition period
2 – 4 minutes	Linear channel flow period
4 – 25 minutes	Transition period

Calculated parameters

Quantitative analysis was made for recovery phases in lin-log- and log-log diagrams according to the methods described in Section 5.4.1.

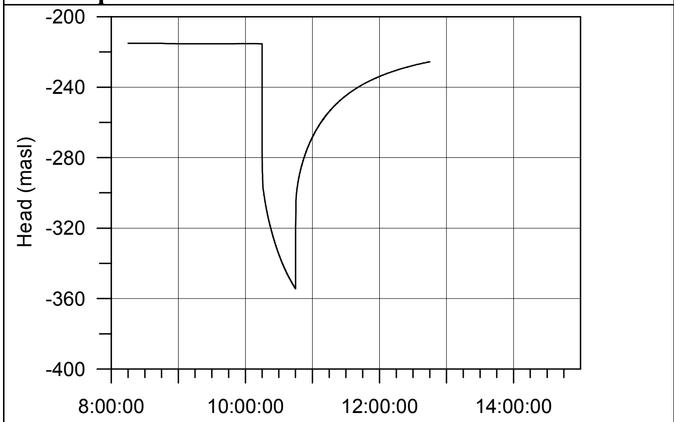
Selected representative parameters

The selected representative parameters from the test in the interval 15.85-17.60 m in KA3539G are presented in the Test Summary Sheet below. The selected parameters are derived from the recovery period.

Test Summary Sheet

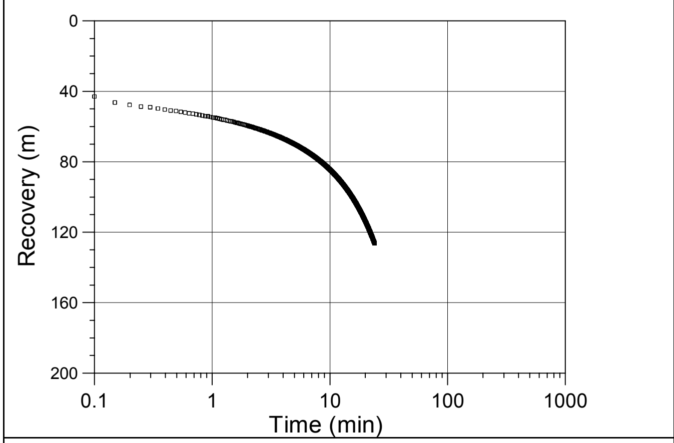
Project:	PROTOTYPE	Test type:	PBT
Area:	ÄSPÖ	Test no:	2:13
Borehole ID:	KA3539G	Test start:	2003-10-23 08:15
Test section (m):	15.85-17.60	Responsible for test performance:	SWECO VIAK AB A. Blom
Section diameter, $2 \cdot r_w$ (m):	0.076	Responsible for test evaluation:	SWECO VIAK AB T. Forsmark

Linear plot Head



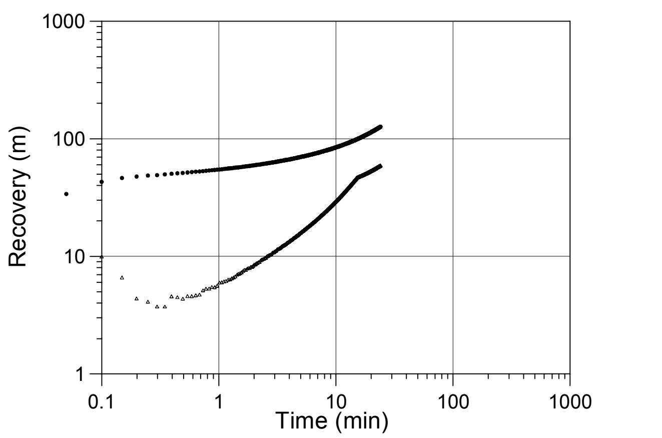
Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	2369.0		
p_i (kPa)			
p_p(kPa)	1005.0	p_F (kPa)	2268.7
Q_p (m^3/s)	$4.08 \cdot 10^{-5}$		
tp (min)	30	t_F (min)	120
S*		S*	$1 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	0.2

Lin-Log plot



Results		Results	
Q/s (m^2/s)	$3.0 \cdot 10^{-7}$	Flow regime:	Radial
T_{Moye}(m^2/s)	$4.1 \cdot 10^{-5}$	dt_{e1} (min)	0.2
Flow regime:		dt_{e2} (min)	0.8
dt_1 (min)		T (m^2/s)	$8.6 \cdot 10^{-7}$
dt_2 (min)		S (-)	
T (m^2/s)		K_s (m/s)	
S (-)		S_s (1/m)	
K_s (m/s)		C (m^3/Pa)	
S_s (1/m)		C_D (-)	
C (m^3/Pa)		ξ (-)	1.6
C_D (-)			
ξ (-)			

Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.			
Flow regime:	Radial	C (m^3/Pa)	
dt_1 (min)	0.2	C_D (-)	
dt_2 (min)	0.8	ξ (-)	1.6
T_T (m^2/s)	$8.6 \cdot 10^{-7}$		
S (-)			
K_s (m/s)			
S_s (1/m)			

Comments: A channel flow regime is established during this test.

6.2 Deformation measurements

Deformation measurements started 2003-05-06. However due to technical malfunction no loggings of the measurements were done between 2003-10-20 16:00:00 and 2003-10-22 15:08:00. Therefore recordings from four tests only exist, tests 2:4, 2:5, 2:7, 2:13 and the later part of test 2:9. The measurements were made every 30 seconds. The times are not in normal time but in Swedish summertime (HMS time + 1 hr). Only an overview of deformations is given in this section. Evaluation of the deformations will be made in a separate report.

A negative value of deformation corresponds to a compression.

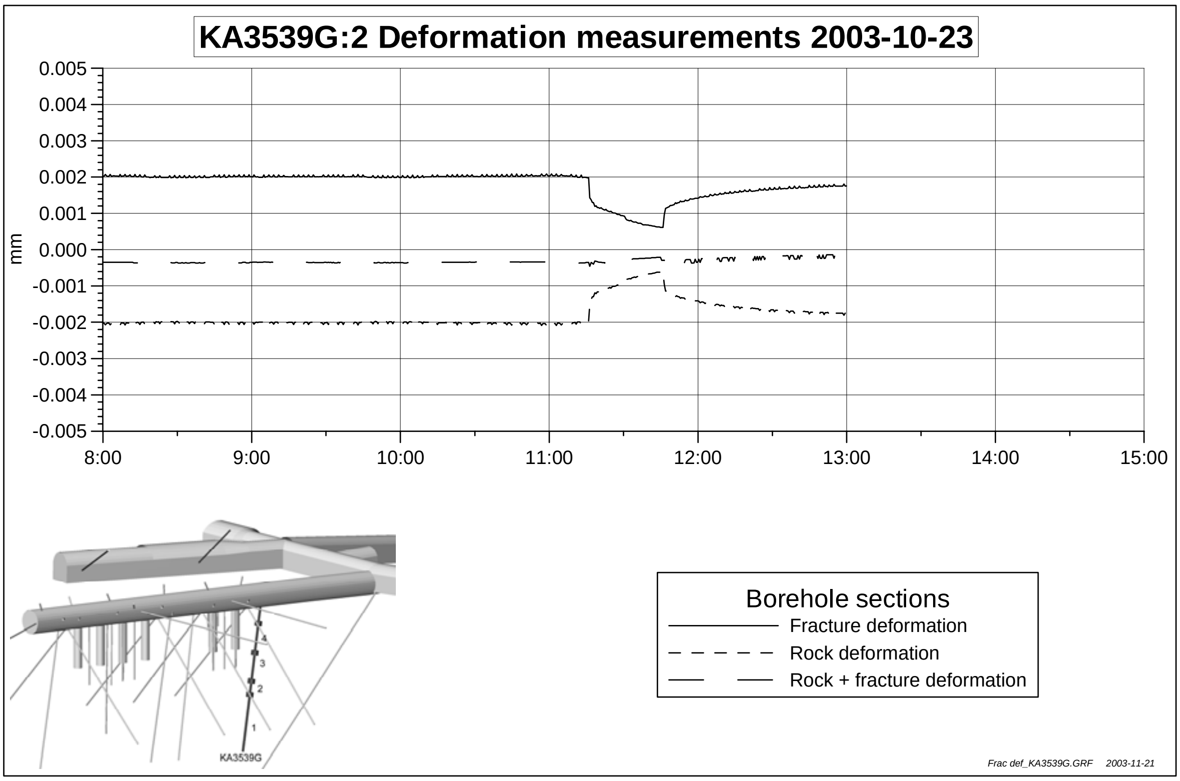


Figure 6-10 *Deformation measurements in KA3539G:2 (Test 2:13)*

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Forsmark T, Rhén I, 1999. Äspö HRL - Prototype repository Hydrogeology – Interference test campaign 1 after drill campaign 3. SKB IPR-00-07.

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Rhen I, Alm P, Forsmark T, 2004. Äspö HRL – Prototype repository - Measurements of flow into tunnels, water pressure, in the rock and Hydro mechanical responses in boreholes during the operation phase of the Prototype Repository. SKB IPR-XX-XX. (in prep)