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Forsmark site investigation

Calibration of one arm caliper and caliper mean data from core and percussion drilled boreholes

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Abstract

This report presents the calibration of one arm caliper and caliper mean data from the cored boreholes KFM01A, KFM01B, KFM01C, KFM01D, KFM02A, KFM02B, KFM03A, KFM03B, KFM04A, KFM05A, KFM06A, KFM06C, KFM07A, KFM07B, KFM08A, KFM08B, KFM08C, KFM08D, KFM09A, KFM09B, KFM10A, KFM11A, KFM12A and the percussion drilled boreholes HFM01–08, HFM10–22, HFM24–38.

The objective of the project was to generate calibrated caliper data by correction of the measured data with reference to technical borehole diameter information gained during the drilling activity.

Two different techniques were applied for the calibration procedure. The caliper mean data (average borehole diameter from the caliper 3D measurement, acoustic televiewer) were calibrated by correcting the travel time of the ultra sonic pulse at the reference points with known diameter, and then recalculating the diameter along the entire borehole.

The one arm caliper data (caliper1D) were filtered with a 15.1 m long median filter. The residual between the measured and filtered data were calculated and the residual data were then added to a linear function established from the technical borehole information.

The estimated accuracy after calibration is in average 0.55 mm for caliper1D and 0.39 mm for caliper mean in the core drilled boreholes. For percussion drilled boreholes the corresponding values after calibration are in average 1.09 mm for caliper1D and 0.19 mm for caliper3D. According to the method description the accuracy (absolute as well as relative) should be 0.5 mm or better.

Sammanfattning

Föreliggande rapport presenterar kalibreringen av en arms caliper och caliper ”mean” data från kärnborrhålen KFM01A, KFM01B, KFM01C, KFM01D, KFM02A, KFM02B, KFM03A, KFM03B, KFM04A, KFM05A, KFM06A, KFM06C, KFM07A, KFM07B, KFM08A, KFM08B, KFM08C, KFM08D, KFM09A, KFM09B, KFM10A, KFM11A, KFM12A samt hammarborrhålen HFM01–08, HFM10–22, HFM24–38.

Syftet med projektet var att skapa kalibrerade caliperdata genom att korrigera data mot uppmätta diametrar som erhållits i samband med utförandet av borrningarna.

Två olika tekniker användes för att kalibrera data från de två mätmetoderna. Data från caliper mean (medeldiameter från caliper 3D, acoustic televiewer) kalibrerades genom att korrigera uppmätt gångtid för ultraljudspulsen vid referenspunkter med känd borrhålsdiameter. Därefter korrigerades samtliga mätpunkter längs borrhålet.

En-arms caliperdata (caliper1D) filtrerades med ett 15,1 m medianfilter. Residualen mellan uppmätta data och filtrerade data beräknades. Residualen adderades sedan till en linjär funktion beräknad med regressionsanalys från referenspunkter med känd borrhålsdiameter.

Den uppskattade noggrannheten efter kalibrering är i genomsnitt 0,55 mm för caliper1D och 0,39 för caliper mean i kärnborrhålen. För hammarborrhålen är motsvarande värden 1,09 mm för caliper1D samt 0,19 mm för caliper3D. Kraven i metodbeskrivningen avseende absolut och relativ noggrannhet är 0,5 mm.

Contents

1 Introduction

SKB performs site investigations for localization of a deep repository for high level radioactive waste. The site investigations are performed at two sites, Forsmark and Simpevarp/Laxemar. The performance of the investigations is controlled by a general program /1/ and a site specific program for the initial stage of the site investigation at Forsmark /2/ and a program for the complete stage of the site investigation /3/. An important part in the analysis of a borehole is the different geophysical loggings that provide information about the physical characteristics of the rock in the vicinity of the borehole.

Variations in borehole diameter are estimated by two techniques, generally called caliper loggings. The one-arm caliper (caliper1D) is measured mechanically with a one-armed tool surveying in one direction, clamping the logging tool towards the borehole wall, and responding to shape variations of the borehole wall. The other method is acoustic, based on the Acoustic Televiewer logging. The measurement probe generates an ultrasonic pulse that propagates in the borehole fluid; it is reflected at the borehole wall and returns to the probe. The velocity of the pulse is estimated from the physical properties of the borehole fluid, which allows the calculation of the borehole diameter. The measurements are performed stepwise at 0–360° at each section co-ordinate, resulting in a 3D "image" of the borehole diameter called caliper3D. The mean diameter at each section co-ordinate is termed caliper mean and is calculated from the caliper3D data.

It has been shown that neither the one arm caliper nor the caliper mean data comply with the demands of accuracy stated by SKB. There are often fairly large differences between the caliper data and the borehole diameter as indicated by the technical information gained from the drilling activities. A calibration of all caliper data gained during the site investigation at Forsmark was therefore performed.

This document reports the results gained from the calibration of one arm caliper and caliper mean data from cored and percussion drilled boreholes. The following cored boreholes were included: KFM01A, KFM01B, KFM01C, KFM01D, KFM02A, KFM02B, KFM03A, KFM03B, KFM04A, KFM05A, KFM06A, KFM06C, KFM07A, KFM07B, KFM08A, KFM08B, KFM08C, KFM08D, KFM09A, KFM09B, KFM10A, KFM11A, KFM12A and the percussion drilled boreholes: HFM01–08, HFM10–22, HFM24–38.

The work was carried out in accordance with activity plan AP PF 400-06-075 version 1.0. No method description (SKB internal controlling document) was available for this activity.

2 Objective and scope

The objective of this work was to calibrate the logging data obtained from measurements with one arm caliper and acoustic televiewer (caliper mean). The calibration was performed with reference to the diameters of calibre rings gained during the core drillings and measured diameter on cutter heads obtained during percussion drilling activities.

3 Equipment

3.1 Description of equipment/interpretation tools

The software used for the calibration were Grapher v6 (Golden Software) and a number of in-house software developed by GeoVista AB on behalf of SKB.

4 Execution

4.1 General interpretation of caliper data

Before calibration some pre-processing is performed.

The general processing is performed in the following steps:

- Average filtering with a triangular 3-point filter.
- Calculation of noise levels.
- Re-sampling to even 0.1 m interval.

4.2 Calibration methods

The calibration of caliper data was performed with respect to borehole diameter information from the technical documents that originate from the drilling activities. For cored boreholes the technical document contains information about the diameter of the calibre-rings. For percussion boreholes it contains information about the diameter of the drill cutter and measured wear. The technical documents have been received from SKB in Microsoft Word format.

4.2.1 Calibration of one arm caliper data

The one arm caliper data were calibrated following four steps:

1. Filtering of caliper data by use of 15.1 m long (151 points) median filter. The filtered data contain mainly long wave length (often stepwise) anomalies that are not related to physically reliable variations in borehole diameter.
2. The median filtered data is subtracted from the measured data (with the aim of removing all artificial long wavelength anomalies), which results in a residual log only showing high frequency diameter anomalies.
3. The technical data (usually 3 diameter readings at 3 section co-ordinates) are plotted in a diagram and a linear function is fitted to these data points by use of linear regression. The linear function represents some kind of "background" diameter along the borehole.
4. The residual data (from 2) is added to the linear function (from 3), and the result is the calibrated caliper log.

4.2.2 Calibration of caliper mean data

The caliper mean data originate from acoustic measurements. An ultrasonic pulse is generated by the logging tool. The pulse is reflected at the borehole wall and returns to the logging tool and the travel time is measured. Since the velocity of the pulse in the borehole fluid can be estimated by use of other logging data, the travelling distance (and thus the borehole diameter) can easily be calculated. The calibration process for caliper mean data is performed in the following steps:

2. Calculation of the measured travel time of the ultrasonic pulse is performed on the caliper mean data. The ultrasound velocity is estimated from the mean temperature of the borehole fluid.

$$Measured\ time\ [s] = \frac{Logged\ caliper\ diameter\ [m] - Tool\ diameter\ [m]}{Ultrasound\ velocity\ [m/s]} \quad (1)$$

3. Calculation of "true" time in the calibration (reference) points with known diameters from technical documents.

$$True\ time\ [s] = \frac{Known\ caliper\ diameter\ [m] - Tool\ diameter\ [m]}{Ultrasound\ velocity\ [m/s]} \quad (2)$$

4. Calculation of the apparent velocity at the section co-ordinate of the calibration point.

$$Apparent\ velocity\ [m/s] = \frac{True\ time\ [s]}{Measured\ time\ [s]} \times Ultrasound\ velocity\ [m/s] \quad (3)$$

5. Establish the calibration relation between apparent velocity and borehole length with linear regression analysis.

$$Ultrasound\ velocity = k \times length + 1 \quad (4)$$

6. Calculation of the calibrated diameter

$$Diam = ((k \times length + l) \times measured\ time) + tool\ diameter \quad (5)$$

The tool diameter of the Acoustic televiewer is 45 mm. The ultrasound velocity in water is approximately 1,403 m/s (0°C) and 1,529 m/s (40°C), neglecting the effect of varying salinity and pressure.

4.3 Preparations and data handling

All caliper data and technical documents have been delivered by SKB from Sicada as Microsoft Excel and Microsoft Word files. Then caliper data from each borehole has been saved separately as an ASCII-file. The data processing was performed on the ASCII-files.

Both calibrated caliper data and resampled caliper data are stored in the primary data base Sicada and are traceable by the activity plan number AP PF 400-06-075.

4.4 Analyses and interpretations

No analyses or interpretations were performed in this activity.

4.5 Nonconformities

No nonconformities are reported.

5 Results

5.1 Result of the calibration

In Figure 5-1 below examples of the results of the calibration of caliper mean and caliper1D data are presented for the borehole KFM04A. The caliper mean data are only slightly changed with reference to the raw data, but in the case of the caliper1D data the calibration procedure had removed the major stepwise variations (not related to true diameter variations), without affecting the local anomalies.

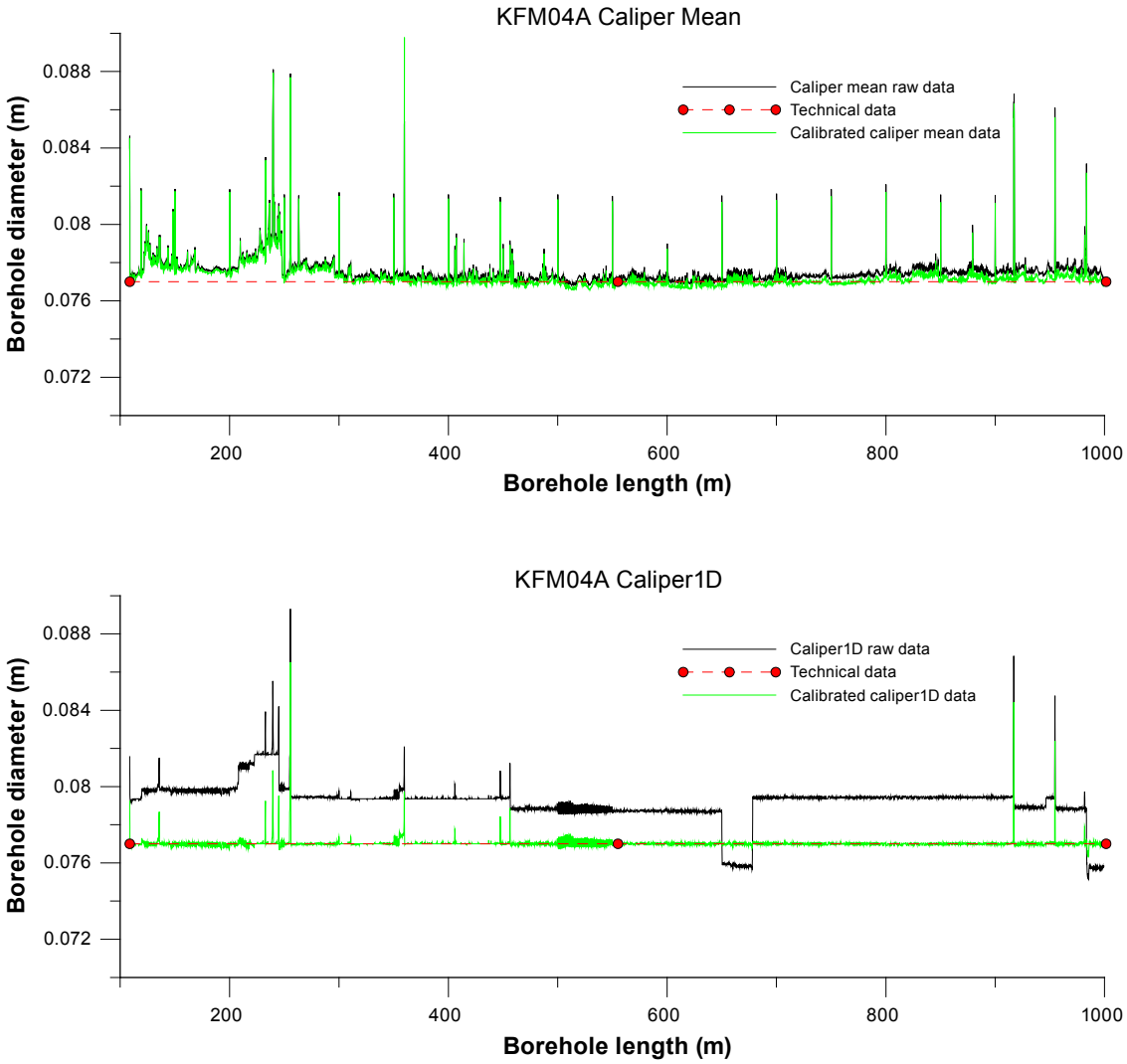

Figure 5-1. *Example showing caliper mean data (upper diagram) and caliper1D data (lower diagram) before and after calibration (borehole KFM04A).*

5.1.1 Estimation of the accuracy of the calibration

A quality control of the calibrated caliper data was performed by comparing the calibrated caliper diameter to the caliper diameter in the technical data at the corresponding borehole length (or as close as possible to the corresponding length). This was done for each of the calibrated logs, generally at three borehole section co-ordinates.

In Figure 5-2 the calibrated caliper borehole diameter is plotted versus borehole diameter based on the technical data from HFM01. The square root of the RMS (Residual Mean Square) value of the fitted line (solid line in Figure 5-2) statistically indicates the mean deviation of the calibrated diameters from the reference diameters, which thus indicates the accuracy of the calibration. However, the estimated accuracy is fairly rough (mainly indicative) due to the low number of checked data points, which makes the test very sensitive to local variations in borehole diameter.

The accuracy of each calibration is presented in Table 5-1 for core drilled boreholes and in Table 5-2 for percussion drilled boreholes.

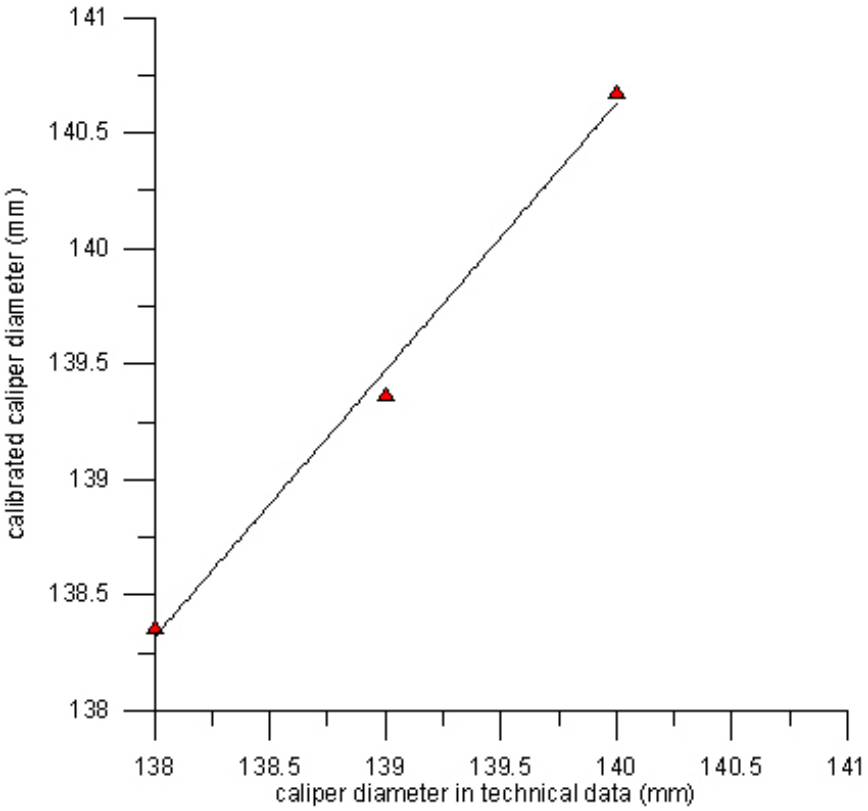

Figure 5-2. *Cross plot of calibrated caliper diameter versus caliper diameter from technical data from the percussion drilled borehole HFM01.*

Table 5-1. Estimated accuracy for cored boreholes.

Borehole	Caliper1D Accuracy [mm]	Caliper mean Accuracy [mm]
KFM01A	0.00	0.06
KFM01B	0.08	0.20
KFM01C	1.11	0.10
KFM01D	0.22	0.07
KFM02A	0.19	0.43
KFM02B	0.55	No data
KFM03A	0.22	0.28
KFM03B	0.23	0.16
KFM04A	1.00	0.27
KFM05A	1.55	0.20
KFM06A	0.08	0.15
KFM06C	0.07	0.15
KFM07A	0.77	0.42
KFM07B	0.16	0.11
KFM08A	3.61	0.50
KFM08B	0.07	0.10
KFM08C	0.45	0.31
KFM08D	0.25	0.52
KFM09A	0.14	0.10
KFM09B	0.58	0.31
KFM10A	0.53	0.21
KFM11A	0.76	4.00
KFM12A	0.08	0.02
Average	0.55	0.39
Median	0.23	0.20

Table 5-2. Estimated accuracy for percussion drilled boreholes.

Borehole	Caliper1D Accuracy [mm]	Caliper mean Accuracy [mm]
HFM01	0.78	0.21
HFM02	0.12	0.10
HFM03	0.49	No data
HFM04	0.93	No data
HFM05	0.85	No data
HFM06	3.14	No data
HFM07	0.53	0.14
HFM08	0.06	No data
HFM10	0.00	0.04
HFM11	0.48	0.11
HFM12	0.05	0.24
HFM13	0.65	0.11
HFM14	0.49	0.24
HFM15	0.00	0.07
HFM16	0.41	0.12
HFM17	0.32	0.20
HFM18	0.11	0.39
HFM19	0.38	0.25
HFM20	0.24	0.27
HFM21	0.56	0.01
HFM22	1.34	0.50
HFM24	1.90	0.07
HFM25	4.11	0.32
HFM26	0.33	0.15
HFM27	0.50	0.33
HFM28	3.26	0.28
HFM29	3.86	0.02
HFM30	2.38	0.18
HFM31	0.36	No data
HFM33	2.61	0.17
HFM34	0.72	0.29
HFM35	3.89	0.28
HFM38	0.05	0.05
Average	1.09	0.19
Median	0.50	0.18

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