P-04-43

Oskarshamn site investigation

Borehole: KAV01

Determination of P-wave velocity, transverse borehole core

Panayiotis Chryssanthakis, Lloyd Tunbridge
Norwegian Geotechnical Institute, Oslo

March 2003

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Keywords: Rock mechanics, P wave velocity, Anisotropy.

Summary

The Norwegian Geotechnical Institute has carried out P-wave measurements on drill cores from borehole KAV01 at Simpevarp in November 2003. Thirty-five P-wave velocity measurements have been carried out from a total of 746 m of core.

The results from the P-wave velocity measurements show a generally consistent pattern over the whole length of the borehole with maximum velocities between 5450–5750 m/s and a variable anisotropy ratio of generally between 1.00 to 1.09. At around 400 m depth there are two slightly lower vales of maximum velocity between 5150–5200 m/s. Below 650 m the maximum velocity has a more variable spread of values between 4700–5950 m/s, with values of anisotropy ratios of between 1.02–1.16.

The foliation is not identifiable over most of the core and the orientation of the principal velocities could not be identified relative to foliation.

Contents

1 Introduction

The Norwegian Geotechnical Institute (NGI) has carried out P-wave velocity measurements on cores from borehole KAV01 at Simpevarp in Sweden in accordance with SKB Activitetsplan AP PF400-03-72 (SKB internal controlling document).

The work was carried out by Panayiotis Chryssanthakis and Paweł Jankowski during the period 4–6 November 2003 in accordance with SKB's method description MD 190.002 version 1.0 (SKB internal controlling document).

KAV01 is an earlier borehole and was drilled in three stages; year 1977, 1986 and 1997. Revaluation of the core logging made it easy to take cores for determines the P wave velocity transverse to the core axis. The core diameter is about 4755 mm, which could be compared with the core diameter of about 51 mm for the new boreholes in the site investigation.

2 Objective and scope

The purpose of the testing is to determine the P wave velocity transverse to the core axis. The P wave velocity is a parameter used in the rock mechanical model which will be established for the candidate area selected for site investigations at Simpevarp.

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

Table 2-1. Total number of P wave velocity specimens and measurements.

Borehole	P wave velocity test specimens	P wave velocity measurements
KAV01	32	35

The results from the P wave velocity measurements are presented in this report by means of tables, figures and spreadsheets.

3 Equipment and methods

The measurements were conducted using Panametrics Videoscan transducers with a natural frequency of 0.5 MHz. These were mounted in a special frame to hold them in contact with the core. Special wave guides, metal shoes with a concave radius similar to the core, were installed between the transducers and the core. The equipment was designed and constructed specially for this contract by NGI, based on the information presented in SKB report entitled Detection of Anisotropy by Diametral Measurements of Longitudinal Wave Velocities on Rock Cores by /Eitzenberger, 2002/. The equipment set up is shown in Figure 3-1. The apparatus for measuring acoustic P-wave travel time is shown on Figure 3-2.

Figure 3-1*. NGI's equipment set up for measuring acoustic P-wave travel time transverse borehole core.*

Figure 3-2. *Detail of NGI's apparatus for measuring acoustic P-wave travel time transverse borehole core. The aluminium cylinder for calibration of the device is on the left.*

A strong sine-wave pulse at the natural frequency of the transducers was used as the acoustic signal source. The arrival of the signals was measured using a PC with a high speed data acquisition board and software to emulate an oscilloscope (see Figure 3-3 and previous work by /Chryssanthakis and Tunbridge, 2003a–d/). The time pick for the first break was taken as the beginning of the first transition, i.e. the point where the received signal first diverges from the zero volts line. In order to provide consistent interpretation of the time pick, one operator made all the interpretations. The time pick could be measured with a precision better than 0.01 μs. The instrumentation was calibrated using a cylinder of aluminium of known acoustic velocity of the same diameter as the core. Several measurements were taken each day on the calibration piece to check operation of the system.

A thick honey was used as a coupling medium as this proved to be one of the most effective medium and was easily removed by washing without damaging or contaminating the cores.

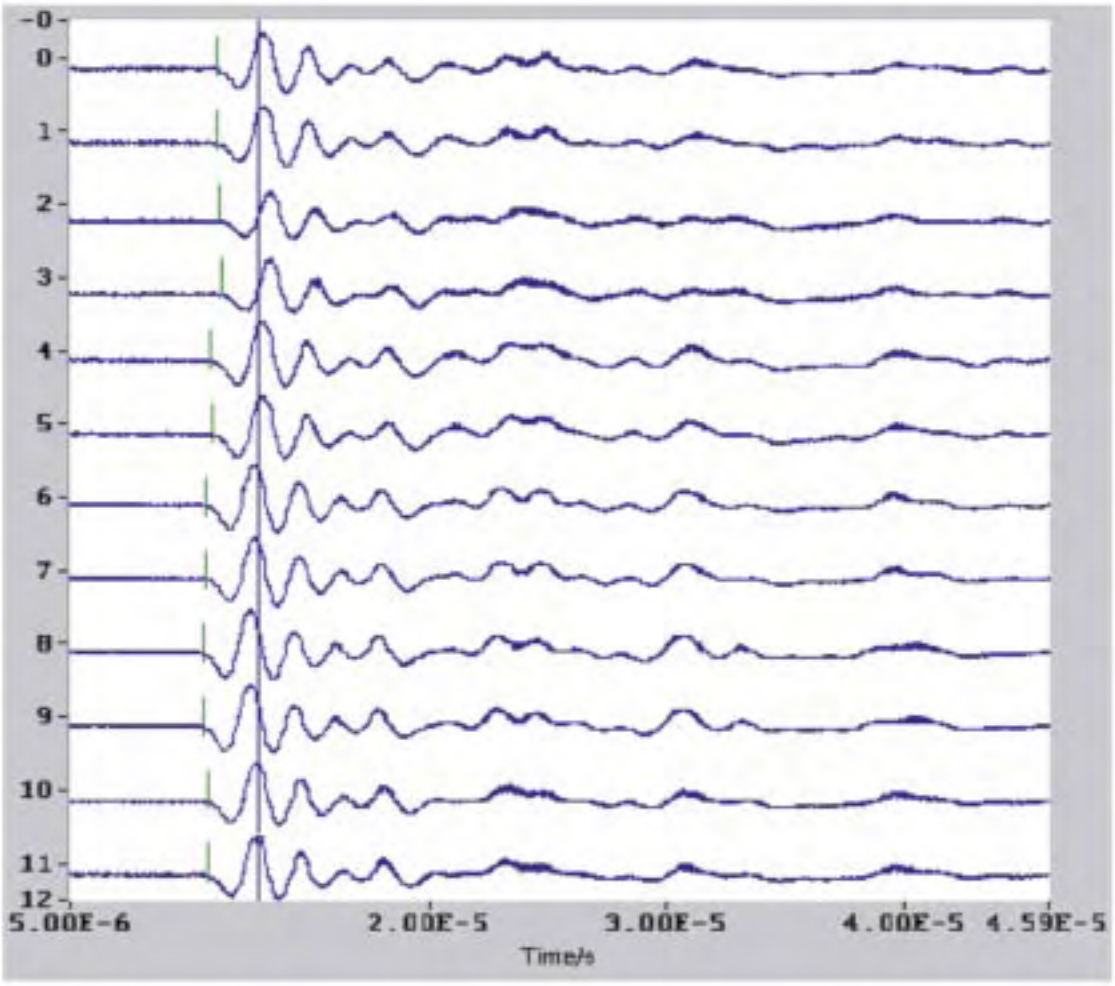

Figure 3-3. *Example traces from 12 measurements of P-wave travel time transverse borehole core (two from each orientation). Time picks marked with green lines. Picture captured from NGI's oscilloscope emulation software.*

4 Execution

4.1 Sampling

Thirty-two core specimens of length ca 200–500 mm and diameter about 41.5 mm were selected from borehole KAV01 while the complete length of the borehole (depth 0–746 m) was displayed on the racks in the core shed at Simpevarp. The specimens were selected jointly by NGI and SKB.

The rocks can be classified as mainly metamorphic rocks which include mainly granite-monzodiorite, with the main part of the borehole lying in Ävrö granite, with some intersecting veins of gabrodiorite and dioritoid. Geological logging of the core has been carried out by SKB. No detailed geological description has been attempted by NGI.

The depths used to describe the location are those marked on the core and core boxes at the time. Detailed description of the specimens is available from the detailed core log by SKB. At the time of sampling, the core had been exposed to the atmosphere at room temperature for an extended period and may be presumed to be air-dried, though no measurements of the moisture content were made.

4.2 Testing

Tests were made at 30° intervals around the core, starting at 0° parallel with the foliation. However, the foliation was generally not identifiable and the tests were thus made at random orientations. The cores were all oriented such that successive measurements were made clockwise looking down the borehole (see Figure 4-1). The cores were marked by attaching a piece of self-adhesive tape that had been previously cut to the appropriate length and marked up with the locations for the tests.

Each test sample comprised a minimum of two consecutive determinations of acoustic pulse travel time at each of six locations around the core (at 0°, 30°, 60°, 90°, 120° and 150°) at one cross section. The seating of the transducers and application of the coupling medium was adjusted in cases where there was a significant difference between the time picks, and additional measurements were made until two similar time picks were obtained. The average of the two measured time picks was recorded.

As the travel time includes a number of other factors such as travel through the wave guides, time pick method, and delay due to the oscilloscope triggering on the rising part of the sine-wave, the determination of the true travel time was calibrated using an aluminium cylinder with known P-wave velocity. The correction factor determined in the calibration tests was subtracted from all the measurements on the rock cores.

The diameter of the core was measured and the P-wave velocity determined by dividing the diameter (in mm) by the travel time (in μs) and multiplying by 1000 to obtain the velocity in m/s.

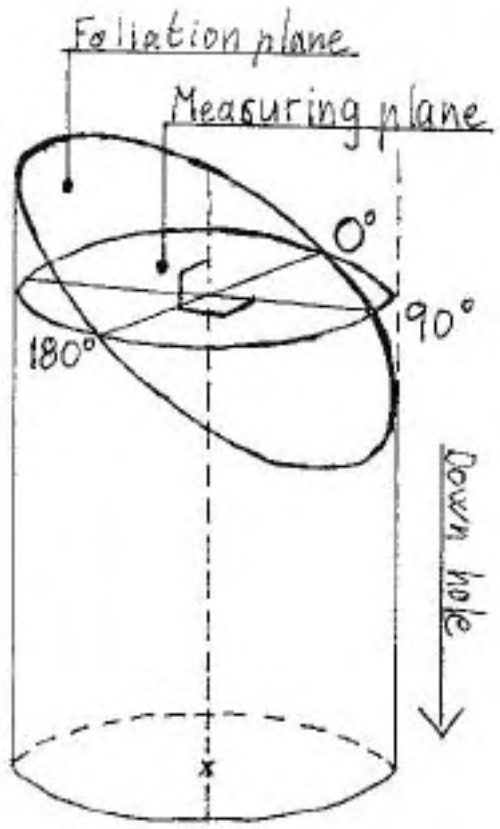

Figure 4-1. *Orientation of measurements.*

Analysis

Since the acoustic velocity is dependant on the elastic properties of the material the results were analysed similarly to determining the stress or strain tensor in the material. In this case the velocity in the orientation θ is given by:

$$V_\theta = V_x\cos^2\theta + V_y\sin^2\theta + 2\cdot V_{xy}\sin\theta\cos\theta \quad (1)$$

A simple regression analysis of the six measurements was used to determine the values of Vx, Vy, and Vxy (where the X-axis is parallel with the foliation where identifiable).

These values were used to model the complete velocity profile around the core.

The magnitude and orientation of the principal velocities was determined from the Eigen values and vectors of the 2D tensor matrix:

$$\begin{vmatrix} V_x & V_{xy} \\ V_{xy} & V_y \end{vmatrix} \quad (2)$$

5 Results

5.1 Summary of results

The results of measured values of travel time and velocity for all the tests are presented in Table 5-1, and the velocity and anisotropy are shown diagrammatically against depth in Figures 5-1 and 5-2.

The results of calculated principal velocities and anisotropy ratios are presented in Table 5-2 and are shown diagrammatically against depth in Figures 5-3 and 5-4. Since the cores did not exhibit any identifiable foliation the orientation of the principal velocities is not reported.

The results of calibration determinations for the system are shown in the Appendix A. The results are also reported to SICADA (FN 178)

5.2 Discussion

Accuracy and Repeatability

Calibration tests on an aluminium cylinder indicated a variation of ± 0.03 μs in determination of the time pick, this represents a variation of about ± 20 m/s in velocity. Some of this variation may be explained by temperature variations, thickness of coupling medium and seating of the shoes. Similar variations may be expected from the measurements on the cores.

Tests on cores were repeated at three locations, 309.78 m, 522.80 m and 671.15 m, after the first series of tests were completed. These tests were repeated to determine typical values for repeatability of velocity determinations. At 309.25 m the difference in magnitude of the velocities is about 0–75 m/s and the anisotropy ratio differs by 0.02. At 522.80 m the difference in magnitude is about 0–25 m/s and the anisotropy ratio is the same. At 671.15 m the difference in magnitude is about 0–60 m/s and the anisotropy ratio differs by 0.01. The differences in the measured velocities are presumed due to the different positions of the transducers, the problems in seating the transducers and obtaining good signal contact with the rock and due to the interpretation of the time pick.

Generally, there is a good fit between the measurements and the best fit line which suggests that random type errors are relatively small. At 309.78 m the maximum difference was 178 m/s, at 522.80 m the maximum difference was 24 m/s, and at 671.15 m the maximum difference was 31 m/s see Figure 5-5.

Typically in the whole series of tests the average deviation between the measured value and the model fit is about 0.52% (about 25 m/s), with a maximum error of 3.1% (about 180 m/s).

The deviation between the model fitted to the data and the measured data is somewhat better than in the previous work, for SKB:s site investigations /Chryssanthakis and Tunbridge, 2003a–d/. The results are also very consistent. It is therefore concluded that the measurement errors are probably less than those determined in the previous work with the repeatability of velocity measurements better than ± 100 m/s and the error in the anisotropy ratio better than ± 0.02. This is considered due to increasing operator experience.

Conclusions

The results from the P-wave velocity measurements show a generally consistent pattern over the whole length of the borehole with maximum velocities between 5450–5750 m/s and a variable anisotropy ratio of generally between 1.00 to 1.09. At around 400 m depth there are two slightly lower vales of maximum velocity between 5150–5200 m/s. Below 650m the maximum velocity has a more variable spread of values between 4700–5950 m/s, with values of anisotropy ratios of between 1.02–1.16.

The foliation is not identifiable over most of the core and the orientation of the principal velocities could not be identified relative to foliation.

Table 5-1. Measurements of acoustic velocity, transverse core in borehole KAV01, Simpevarp. (Orientation clockwise looking down hole, 0° is parallel with foliation where identified.)

Depth	Diameter	Corrected time, mS						Velocity m/S						Anisotropy
		Parallel foliation	Perpendicular foliation					Parallel foliation	Perpendicular foliation					
m	mm	0°	30°	60°	90°	120°	150°	0°	30°	60°	90°	120°	150°	ratio
196,40	41,57	7,51	7,70	7,77	7,87	7,68	7,63	5533	5397	5348	5280	5411	5446	1,05
220,55	41,42	7,54	7,43	7,50	7,61	7,52	7,53	5492	5573	5521	5441	5506	5499	1,02
244,05	41,52	7,61	7,60	7,61	7,53	7,67	7,75	5454	5461	5454	5512	5412	5356	1,03
268,30	41,23	7,81	7,61	7,48	7,48	7,64	7,76	5277	5416	5510	5510	5395	5311	1,04
287,50	41,19	7,18	7,55	7,84	7,79	7,63	7,45	5735	5454	5252	5286	5397	5527	1,09
309,78	40,92	7,73	7,70	7,46	7,42	7,54	7,21	5292	5313	5483	5513	5425	5674	1,07
327,80	41,33	7,53	7,66	7,55	7,62	7,65	7,67	5487	5394	5472	5422	5401	5387	1,02
348,00	40,95	7,39	7,46	7,62	7,71	7,57	7,40	5539	5487	5372	5310	5408	5532	1,04
368,25	41,16	7,78	7,83	7,82	7,57	7,51	7,77	5289	5255	5262	5435	5479	5296	1,04
390,45	41,10	8,05	7,95	8,10	8,25	8,34	8,23	5104	5168	5073	4980	4927	4992	1,05
408,65	41,21	8,15	7,92	7,88	8,00	8,17	8,18	5055	5202	5228	5150	5043	5036	1,04
426,85	41,56	7,58	7,48	7,56	7,65	7,55	7,61	5481	5554	5496	5431	5503	5459	1,02
447,50	41,41	7,26	7,58	7,78	7,59	7,21	7,47	5702	5461	5321	5454	5741	5542	1,08
465,30	41,36	7,37	7,36	7,46	7,26	7,23	7,36	5610	5618	5542	5695	5719	5618	1,03
488,35	41,57	7,60	7,58	7,64	7,70	7,59	7,66	5468	5482	5439	5397	5475	5425	1,02
510,80	41,41	7,25	7,26	7,28	7,14	7,22	7,29	5710	5702	5686	5798	5734	5678	1,02
522,80	41,40	7,57	7,47	7,47	7,49	7,52	7,54	5467	5540	5540	5526	5504	5489	1,01
535,62	41,51	7,62	7,56	7,51	7,68	7,81	7,71	5446	5489	5525	5403	5313	5382	1,04
549,32	41,58	7,21	7,30	7,45	7,54	7,59	7,33	5765	5694	5579	5513	5476	5671	1,05
565,20	41,61	7,55	7,56	7,67	7,58	7,47	7,57	5509	5502	5423	5488	5568	5495	1,03
580,15	41,71	7,57	7,48	7,34	7,30	7,41	7,51	5508	5574	5681	5712	5627	5552	1,04
595,44	41,76	7,80	7,65	7,72	7,65	7,61	7,73	5352	5457	5408	5457	5486	5401	1,02
614,65	41,64	7,37	7,38	7,34	7,38	7,35	7,31	5648	5640	5671	5640	5663	5694	1,01
626,25	41,60	7,51	7,38	7,47	7,46	7,43	7,44	5537	5635	5567	5575	5597	5590	1,02
640,35	41,58	7,32	7,28	7,29	7,30	7,36	7,39	5678	5710	5702	5694	5648	5625	1,02
657,80	41,61	7,59	7,80	7,96	8,11	8,00	7,76	5480	5333	5226	5129	5200	5360	1,07
671,15	41,66	8,08	7,91	7,78	7,73	7,96	8,03	5154	5265	5353	5388	5232	5186	1,05
686,00	41,67	8,01	7,24	6,91	7,31	7,84	7,90	5201	5754	6028	5698	5313	5273	1,16
700,65	41,80	7,77	7,86	7,92	7,99	7,87	7,85	5378	5316	5276	5230	5310	5323	1,03
714,90	41,52	9,03	8,69	9,09	9,48	9,51	9,30	4597	4777	4566	4379	4365	4463	1,09
730,20	41,42	7,55	7,33	7,37	7,60	7,57	7,41	5484	5649	5618	5448	5470	5588	1,04
743,50	41,48	7,90	7,75	7,61	7,71	7,79	7,88	5249	5351	5449	5378	5323	5262	1,04
309,78	40,88	7,41	7,72	7,48	7,42	7,56	7,34	5515	5294	5463	5508	5406	5568	1,05
522,80	41,41	7,57	7,50	7,52	7,46	7,48	7,55	5469	5520	5505	5549	5534	5483	1,01
671,15	41,68	8,02	7,88	7,78	7,81	7,84	7,98	5195	5288	5356	5335	5315	5221	1,03

Table 5-2. Determinations of principal velocity and orientation, transverse core in borehole KAV01, Simpevarp. (Orientation clockwise looking down hole, 0° is parallel with foliation where identified.)

Depth m	Maximum velocity m/s	Orientation	Minimum velocity m/s	Orientation	Anisotropy ratio	Foliation
196,40	5506	170°	5299	80°	1,04	n
220,55	5541	25°	5470	115°	1,01	n
244,05	5492	60°	5391	150°	1,02	n
268,30	5528	75°	5279	165°	1,05	n
287,50	5656	170°	5227	80°	1,08	n
309,78	5556	120°	5344	30°	1,04	n
327,80	5451	35°	5404	125°	1,01	n
348,00	5560	175°	5323	85°	1,04	n
368,25	5446	110°	5226	20°	1,04	n
390,45	5156	25°	4926	115°	1,05	n
408,65	5227	55°	5011	145°	1,04	n
426,85	5519	25°	5456	115°	1,01	n
447,50	5699	150°	5375	60°	1,06	f
465,30	5694	120°	5573	30°	1,02	n
488,35	5471	10°	5425	100°	1,01	n
510,80	5754	95°	5681	5°	1,01	n
522,80	5545	65°	5477	155°	1,01	n
535,62	5521	40°	5332	130°	1,04	n
549,32	5757	10°	5476	100°	1,05	n
565,20	5538	140°	5457	50°	1,01	n
580,15	5710	85°	5509	175°	1,04	n
595,44	5468	95°	5385	5°	1,02	n
614,65	5673	140°	5646	50°	1,00	n
626,25	5588	60°	5578	150°	1,00	n
640,35	5717	50°	5635	140°	1,01	n
657,80	5450	0°	5126	90°	1,06	n
671,15	5379	75°	5148	165°	1,04	n
686,00	5953	60°	5136	150°	1,16	n
700,65	5365	175°	5246	85°	1,02	n
714,90	4718	25°	4331	115°	1,09	n
730,20	5614	30°	5472	120°	1,03	n
743,50	5428	70°	5242	160°	1,04	w
309,78	5521	135°	5396	45°	1,02	n
522,80	5543	90°	5477	0°	1,01	n
671,15	5365	80°	5205	170°	1,03	n

f= foliation (clearly identifiable)
n=no identifiable foliation
w=weak f oliation (not good)
s=strong foliation (good)

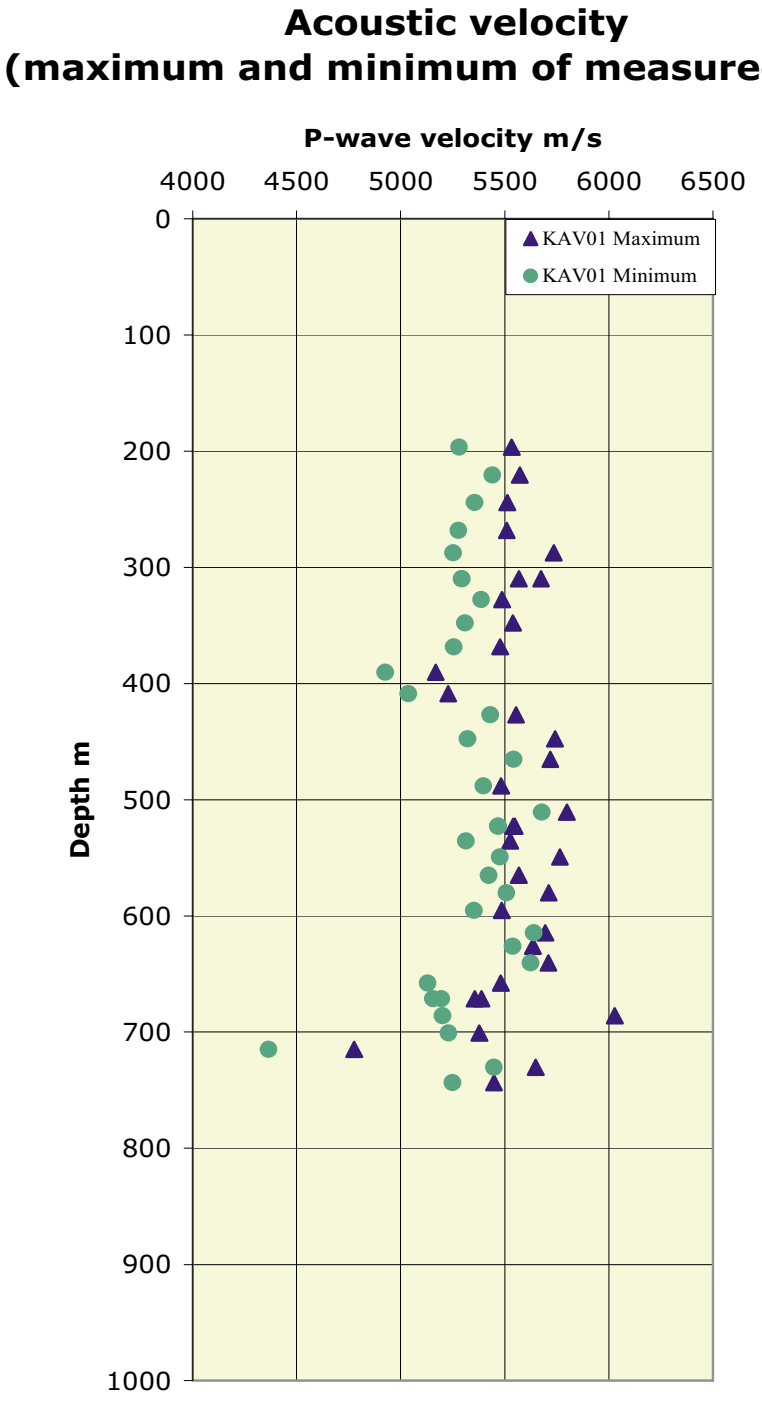

Figure 5-1. *Measured values of maximum and minimum acoustic velocities plotted against depth down borehole KAV01.*

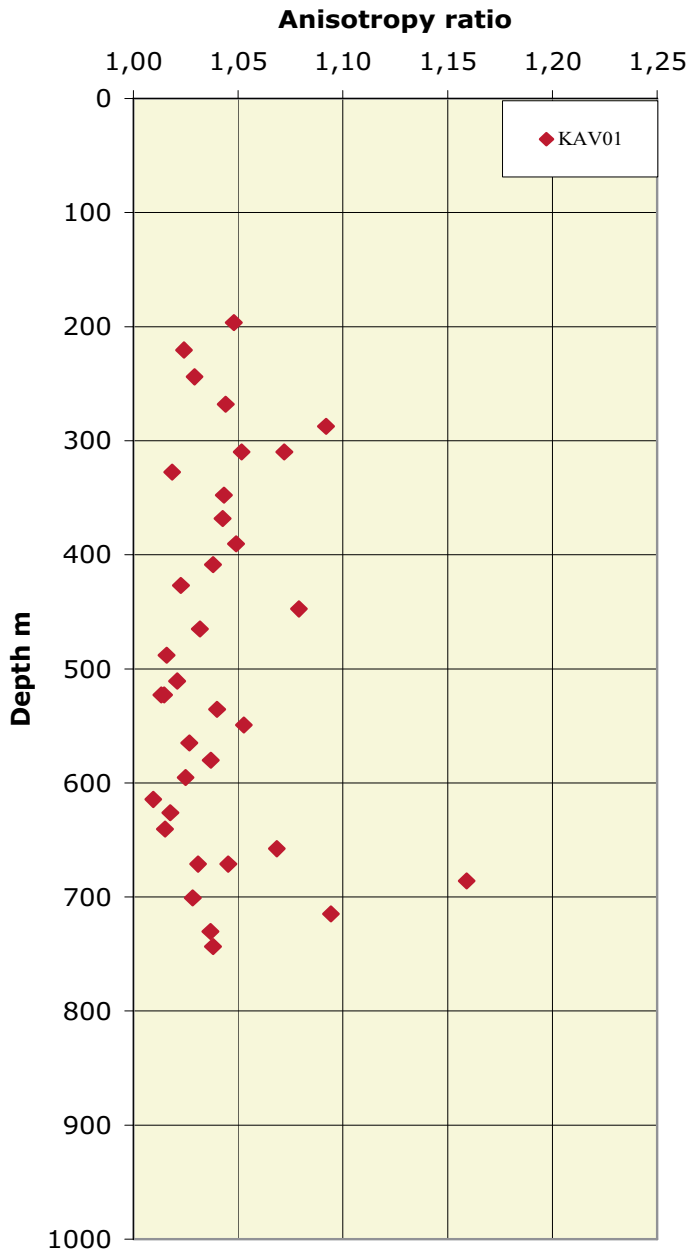

Figure 5-2. *Measured values of acoustic velocity anisotropy plotted against depth down borehole KAV01.*

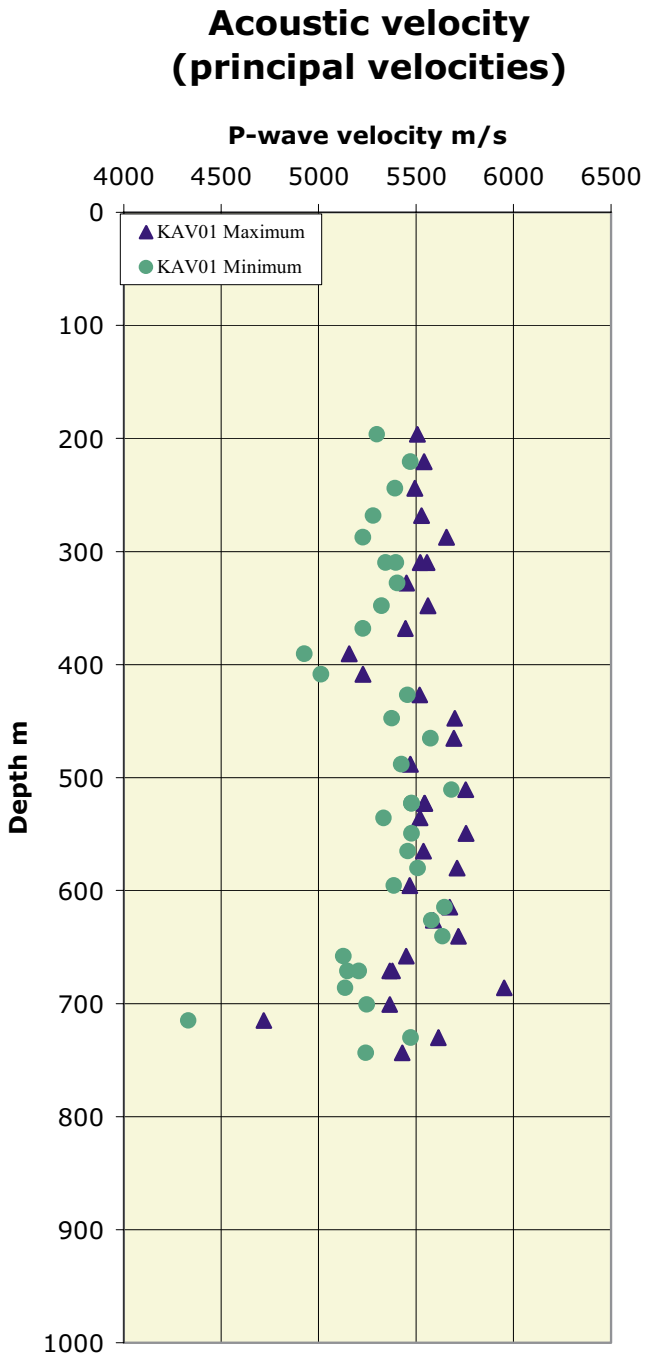

Figure 5-3. *Calculated values of maximum and minimum principal acoustic velocities plotted against depth down borehole KAV01.*

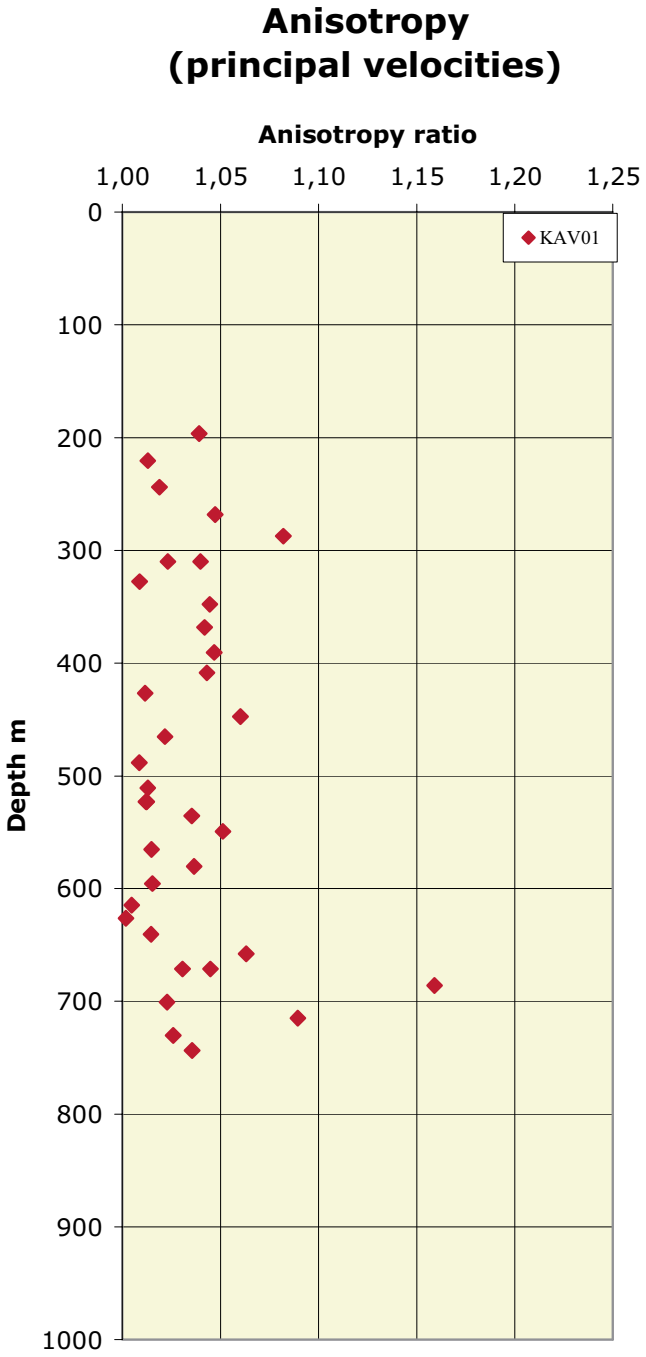

Figure 5-4. *Calculated values of maximum and minimum principal acoustic velocity anisotropy plotted against depth down borehole KAV01.*

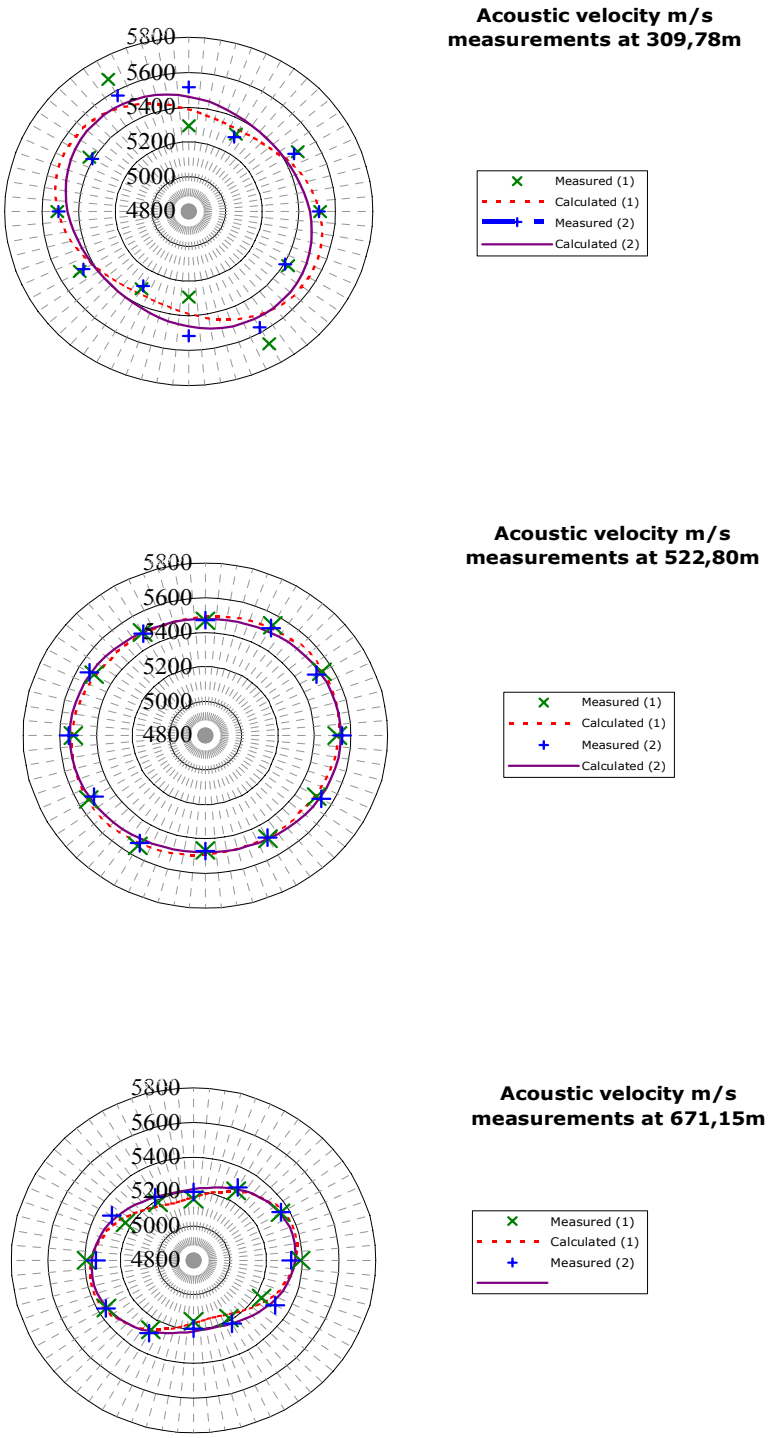

Figure 5-5. *Comparison of measured and calculated values (model fit) of acoustic velocity for each of three determinations at the same depths in borehole KAV01.*

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Appendix A

Calibration measurements on aluminium cylinder diameter 41.50 mm with known velocity 6320 m/s (this page).

Calibration measurements on aluminium cylinder Diameter 41.50 mm with known velocity 6320 m/s.

Date and time	Known velocity m/S	Diameter mm	Time Measured µS	Calculated µS	Correction µS
20031105 – 0845 hrs	6320	41.50	7.72	6.57	1.15
20031105 – 1700 hrs	6320	41.50	7.73	6.57	1.16
20031105 – 1331 hrs	6320	41.50	7.70	6.57	1.13
20031106 – 0845 hrs	6320	41.50	7.72	6.57	1.15
20031106 – 1000 hrs	6320	41.50	7.70	6.57	1.13
Average			**7.71**		**1.148**