P-05-03

Oskarshamn site investigation

Borehole KLX03A

Determination of P-wave velocity, transverse borehole core

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Norwegian Geotechnical Institute

February 2005

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ISSN 1651-4416
SKB P-05-03

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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 KLX03A at Simpevarp in November 2004. Thirtytwo P-wave velocity measurements have been carried out from a total of about 700 m core.

The results from the P-wave velocity measurements over the whole length of the borehole show maximum velocities between 5,671–6,209 m/s and a variable anisotropy ratio between 1.00 to 1.09. The maximum velocity appears to be constant with depth and lies between 5,671–6,209 m/s, with no outlying values.

The anisotropy ratio appears to be constant with depth and lies between 1.00 to 1.04 with outlying high values of 1.09 at 208.00 m, 1.05–1.07 between 458.80 to 498.78 and 1.07 at 853.07 m.

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

Sammanfattning

Norges Geotekniska Institut (NGI) har under November 2004 utfört P-vågsmätningar på borrkärnor från borrhål KLX03A i Simpevarp. Sammanlagt utfördes 32 st hastighetsbestämningar av P-vågen på kärnprover som utvalts från borrkärnor med en sammanlagd längd av 700 m.

Resultaten längs hela borrkärnelängden uppvisar en maximihastighet på mellan ca 5 671–6 209 m/s och en varierande anisotropikvot mellan 1.00 och 1.09. Den maximala hastigheten är relativt konstant mellan 5 671–6 209 m/s. Anisotropikvoten är relativt konstant mellan 1,00–1,04, med undantag där anisotropikvoten är 1,09 vid 208,00 m, 1,05–1,07 mellan 458,80 til 498,78 m och 1,07 vid 853,07 m.

Någon tydlig identifierbar foliation längs kärnan har inte kunnat identifieras och därmed har inte hastigheternas orienteering till foliationen kunnat bestämmas.

Contents

1 Introduction

The Norwegian Geotechnical Institute (NGI) has carried out P-wave velocity measurements on cores from borehole KLX03A at Simpevarp, see Figure 1-1, in Sweden in accordance with SKB Activity plan AP PS 400-04-107, version 1.0 (SKB internal controlling document).

The work was carried out by Panayiotis Chryssanthakis and Paweł Jankowski in November 2004 in accordance with SKB's method description MD 190.002, version 1.0 (SKB internal controlling document).

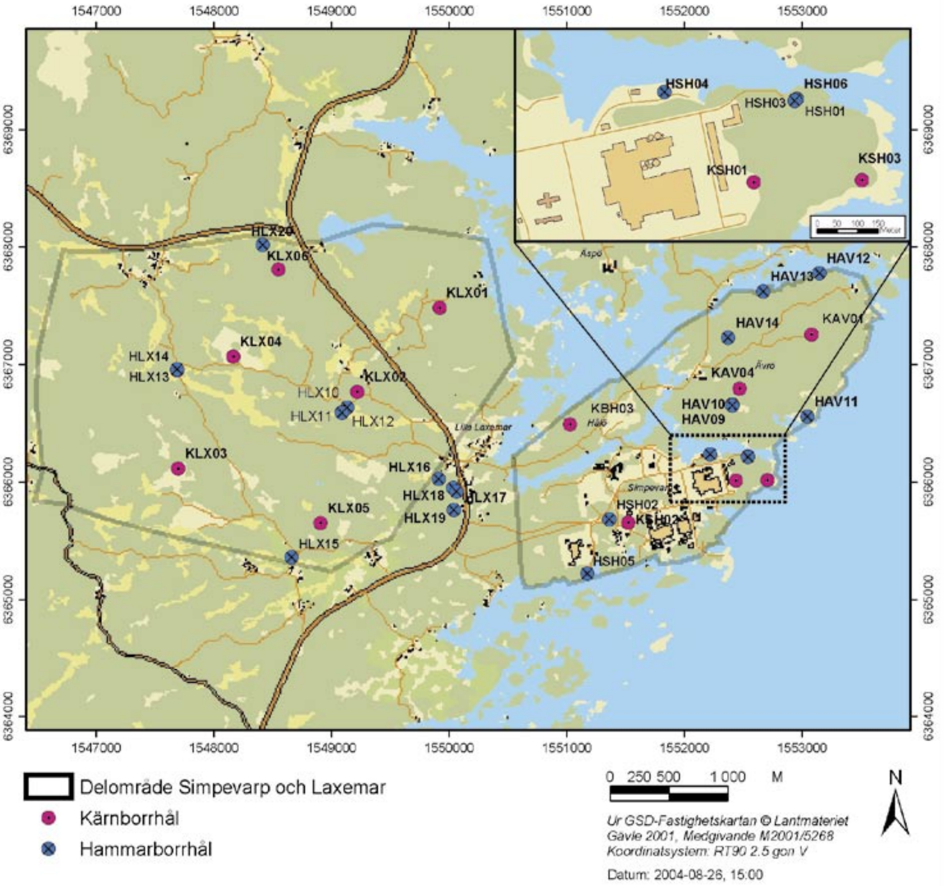

Figure 1-1. Location of drill hole KLX03A at the Oskarshamn site.

2 Objective and scope

The purpose of the testing was 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 core specimens tested and the number of tests performed are given in Table 2-1.

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

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

Borehole	P-wave velocity test specimens	P-wave velocity measurements
KLX03A	29	32

3 Equipment

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 (see Figure 3-1). 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" /Eitzenberger, 2002/.

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 Figures 3-2 and 3-3). 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 (PC) made all the interpretations. The time pick was measured with a precision better than 0.01μs. 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 thin layer of a thick honey was used, as a coupling medium as this proved to be one of the most effective of different media tested and was easily removed by washing without damaging or contaminating the cores.

Figure 3-1. *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.*

***Figure 3-2.** NGI's equipment set-up for measuring acoustic P-wave travel time transverse borehole core.*

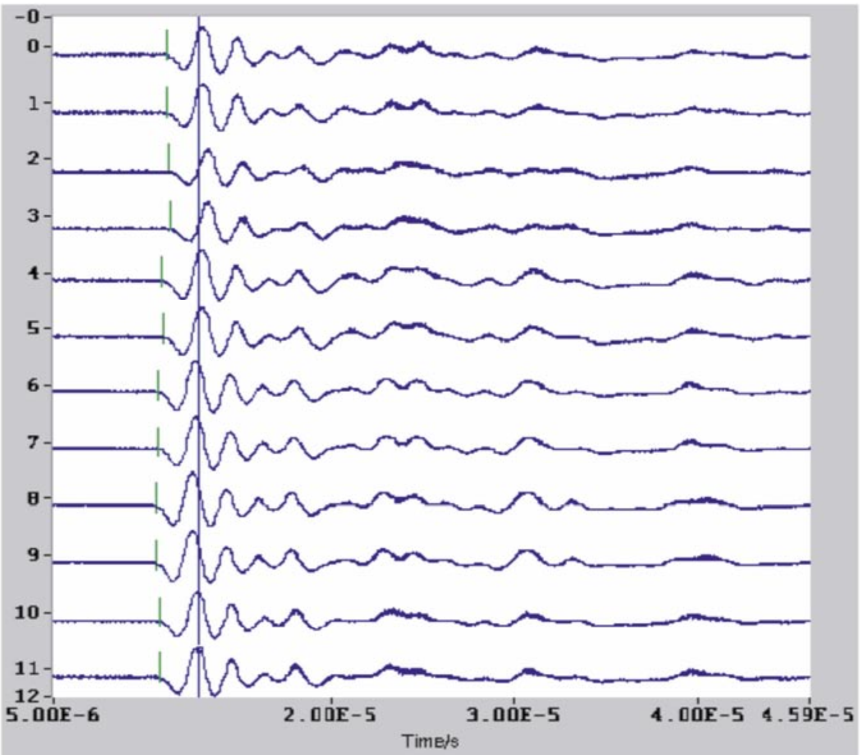

***Figure 3-3.** Example traces from 12 measurements of P-wave travel time transverse borehole core (two from each orientation). Time picks marked with green lines. Picture captured from NGI's oscilloscope emulation software.*

4 Execution

4.1 Sampling

Twenty nine core specimens of length app 200–500 mm and diameter about 50 mm were selected from borehole KLX03A while the complete length of the borehole was displayed on the racks in the core shed at Simpevarp. The specimens were selected together by NGI, Thomas Jansson and Björn Ljunggren representing SKB.

These specimens represent the Ävrö granite, with some veins of quartz monzonite and fine grained granodiorite, found over most of the length of the borehole. Geological logging of 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 Test method

Tests were made at 30° intervals around the core, starting at 0° parallel with the foliation. However, where the foliation was not identifiable the first test was made at a random orientation. 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 lengths and marked up with the locations for the tests. These marks were then transferred to the core with a permanent marker. The cores may thus be checked at any time to ascertain the location and orientation of 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 using a calliper with an accuracy of 0.01 mm and the P-wave velocity determined by dividing the diameter (in mm) by the travel time (in µs) and multiplying by 1,000 to obtain the velocity in m/s.

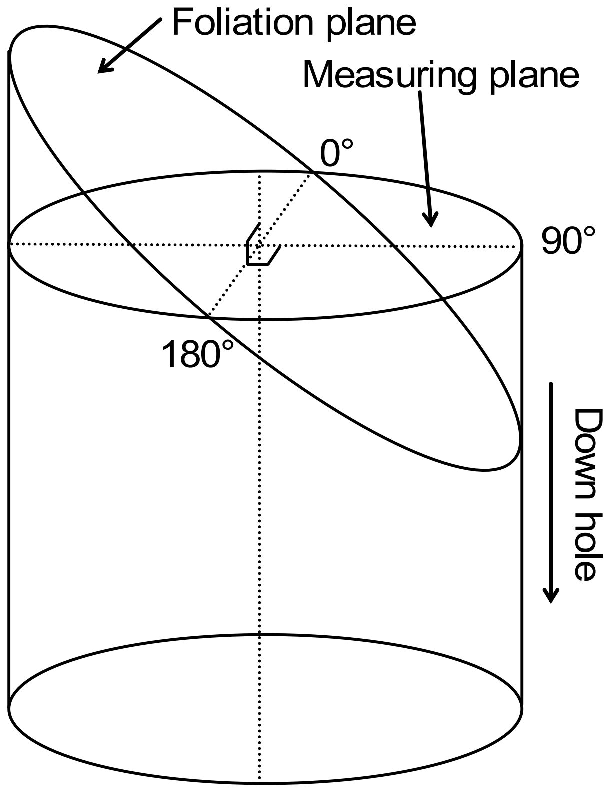

***Figure 4-1.** Orientation of measurements.*

Analysis

Since the acoustic velocity is dependent 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 V_x, V_y, and V_{xy} (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 were determined from the Eigen values and vectors of the 2D tensor matrix:

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

4.3 Nonconformities

Tests were made at 30° intervals around the core instead of the 45° intervals suggested in the Method Description. This was the only nonconformity to the controlling documents.

5 Results

5.1 Summary of results

The results of the determinations of the travel time and velocity for all the tests are presented in Table 5-1, and the velocity and anisotropy are shown diagrammatically versus borehole length in Figures 5-1 and 5-2.

The results of calculated principal velocities and the anisotropy ratio are presented in Table 5-2, and shown diagrammatically versus borehole length in Figures 5-3 to 5-4. The foliation was not identifiable over most of the core and therefore the orientation of the maximum velocity could not be determined.

The results of calibration determinations for the system are shown in Appendix A. The results are also reported to SICADA (FN 567).

5.2 Discussion

Accuracy and repeatability

Calibration tests on an aluminium cylinder indicated a variation of ± 0.020 μs in determination of the time pick, equivalent to differences in velocity of about ± 10 m/s. 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, 246.70 m, 498.78 m and 819.50 m, after the first series of tests were completed. These tests were repeated to investigate and determine typical values for repeatability of velocity determinations.

The repeatability of the diameter measurements was about ± 0.02mm which gives an error of about ± 2 m/s.

At 246.70 m the maximum difference in magnitude of the velocities is 180 m/s, the anisotropy ratios are the same and there is about 5° difference in orientation. At 498.78 m the maximum difference in magnitude of the velocities is 62 m/s, the anisotropy ratios are the same and there is no difference in orientation. At 819.50 m the maximum difference in magnitude of the velocities is 78 m/s, the anisotropy ratio is the same and there is about 10° difference in orientation.

The differences in the measured velocities on the calibration cylinder and rock cores are presumably due to temperature changes, the problems in seating the transducers and obtaining good signal contact with the material and due to the interpretation of the time pick.

Generally there is a good fit between the measurements and the best fit line (model fit) which suggests that random type errors are relatively small. At 246.70 m the maximum difference was 58 m/s, at 498.78 m the maximum difference was 46 m/s, and at 819.50 m the maximum difference was 43 m/s, see Figure 5-5.

Typically in the entire series of tests, the average deviation between the measured value and the model fit is about 0.4% (about 25 m/s), with a maximum error of 2.3% (137 m/s).

The deviation between the model fitted to the data and the measured data reported here is in agreement to the previous work /Chryssanthakis and Tunbridge, 2003a,b,c,d,e,f,g/. The results are also very consistent. It is therefore concluded that the measurement errors are similar to those determined previously.

It is therefore concluded that:

- the repeatability of the reported results for velocities is generally better than ± 100 m/s;
- the error in the orientation of the principal velocities is generally better than ± 10° where the anisotropy ratio is greater than 1.10 with greater errors below this limit (with an anisotropy ratio of less than about 1.03 the determination of the orientation is poorly constrained and has little significance in practice);
- errors in determining the anisotropy ratio and orientation are partly mitigated by the redundant data and regression analysis and it is considered that the error in the anisotropy ratio is generally better than ± 0.02.

Conclusions

The results from the P-wave velocity measurements over the whole length of the borehole show maximum velocities between 5,671–6,209 m/s and a variable anisotropy ratio between 1.00 to 1.09. The maximum velocity appears to be constant with depth and lies between 5,671–6,209 m/s, with no outlying values.

The anisotropy ratio appears to be constant with depth and lies between 1.00 to 1.04 with outlying high values of 1.09 at 208.00 m, 1.05–1.07 between 458.80 to 498.78 and 1.07 at 853.07 m.

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

Table 5-1. Measurements of acoustic velocity, transverse core in borehole KLX03A, Simpevarp. (Orientation clockwise looking down hole, 0° is parallel with foliation).

Depth	Diameter	Corrected time, mS						Velocity m/S						
		Parallel foliation	Perpendicular foliation					Parallel foliation	Perpendicular foliation					
m	mm	0º	30º	60º	90º	120º	150º	0º	30º	60º	90º	120º	150º	Anisotropy ratio
208.00	50.29	8.83	9.07	8.83	8.79	8.69	8.34	5695	5545	5695	5721	5787	6030	1.09
225.40	50.15	8.88	9.09	9.60	9.33	9.05	8.75	5648	5517	5224	5375	5542	5732	1.10
246.70	50.20	8.56	8.46	8.68	8.77	8.59	8.51	5865	5934	5784	5724	5844	5899	1.04
265.10	50.21	8.60	8.38	8.27	8.59	8.39	8.52	5839	5992	6071	5845	5985	5893	1.04
282.30	50.23	8.56	8.82	8.65	8.59	8.36	8.57	5868	5695	5807	5848	6009	5861	1.06
298.35	50.20	8.33	8.42	8.44	8.38	8.46	8.36	6027	5962	5948	5991	5934	6005	1.02
319.55	50.25	8.58	8.68	8.73	8.71	8.78	8.57	5857	5789	5756	5769	5723	5864	1.02
335.65	50.23	8.42	8.36	8.38	8.43	8.47	8.47	5966	6009	5994	5959	5930	5930	1.01
358.82	50.23	8.77	8.91	8.81	8.75	8.63	8.66	5728	5638	5702	5741	5821	5800	1.03
382.95	50.16	8.30	8.26	8.20	8.28	8.38	8.34	6044	6073	6117	6058	5986	6015	1.02
403.30	50.21	8.58	8.51	8.58	8.54	8.51	8.51	5852	5900	5852	5880	5900	5900	1.01
424.70	50.24	8.36	8.51	8.43	8.46	8.45	8.42	6010	5904	5960	5939	5946	5967	1.02
458.80	50.24	8.31	8.38	8.57	8.67	8.73	8.47	6046	5995	5862	5795	5755	5932	1.05
478.85	50.25	8.93	8.91	8.63	8.48	8.55	8.70	5627	5640	5823	5926	5877	5776	1.05
498.78	50.21	8.79	8.77	9.02	9.35	9.30	9.00	5712	5725	5567	5370	5399	5579	1.07
526.10	50.18	8.75	8.73	8.74	8.71	8.73	8.64	5735	5748	5742	5761	5748	5808	1.01
550.80	50.12	8.84	8.78	8.81	8.99	9.11	9.05	5670	5709	5689	5575	5502	5538	1.04
575.06	50.12	8.92	8.93	9.05	9.06	8.92	8.81	5619	5613	5538	5532	5619	5689	1.03
595.75	50.16	8.85	8.77	8.82	8.99	9.06	8.98	5668	5720	5687	5580	5537	5586	1.03
622.70	49.99	8.29	8.27	8.12	8.15	8.20	8.17	6030	6045	6157	6134	6096	6119	1.02
640.47	50.06	8.19	8.12	8.20	8.17	8.11	8.20	6112	6165	6105	6127	6173	6105	1.01
658.84	50.00	8.09	8.18	8.26	8.20	8.15	8.10	6178	6113	6053	6098	6135	6173	1.02
684.00	50.06	8.24	8.30	8.36	8.27	8.25	8.24	6075	6031	5988	6053	6068	6075	1.01
710.30	50.08	8.72	8.72	8.66	8.60	8.68	8.59	5743	5743	5783	5823	5770	5830	1.02
729.20	50.07	8.42	8.35	8.39	8.49	8.58	8.47	5947	5997	5968	5898	5836	5912	1.03
783.25	50.09	8.73	8.76	8.79	8.75	8.66	8.81	5738	5718	5699	5725	5784	5686	1.02
803.00	50.09	8.47	8.65	8.40	8.50	8.52	8.43	5914	5791	5963	5893	5879	5942	1.03
819.50	50.16	8.14	8.23	8.13	8.20	8.07	8.13	6162	6095	6170	6117	6216	6170	1.02
853.07	50.13	8.78	8.56	8.31	8.26	8.41	8.70	5710	5856	6033	6069	5961	5762	1.06
246.70	50.23	8.53	8.73	8.80	8.84	8.71	8.64	5889	5754	5708	5682	5767	5814	1.04
498.78	50.19	8.79	8.77	9.03	9.36	9.19	9.04	5710	5723	5558	5362	5461	5552	1.07
819.50	50.18	8.17	8.15	8.18	8.10	8.08	8.10	6142	6157	6135	6195	6211	6195	1.01

Table 5-2. Determinations of principal velocity and orientation, transverse core in borehole KLX03A, 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	f= foliation (clearly identifiabl
208.00	5912	135°	5579	45°	1.06	n	n=no identifiable foliation
225.40	5736	160°	5276	70°	1.09	n	w=weak f oliation (not good)
246.70	5923	175°	5760	85°	1.03	n	s=strong foliation (good)
265.10	5999	60°	5876	150°	1.02	n	x=disturbed sample
282.30	5960	125°	5736	35°	1.04	n	
298.35	6005	170°	5950	80°	1.01	n	
319.55	5852	175°	5734	85°	1.02	n	
335.65	6006	40°	5923	130°	1.01	n	
358.82	5821	130°	5655	40°	1.03	n	
382.95	6104	50°	5993	140°	1.02	n	
403.30	5895	135°	5867	45°	1.00	n	
424.70	5977	160°	5931	70°	1.01	n	
458.80	6042	10°	5754	100°	1.05	n	
478.85	5935	100°	5621	10°	1.06	n	
498.78	5752	15°	5366	105°	1.07	n	
526.10	5776	140°	5738	50°	1.01	n	
550.80	5725	35°	5503	125°	1.04	n	
575.06	5671	160°	5532	70°	1.03	x	
595.75	5722	30°	5537	120°	1.03	x	
622.70	6146	90°	6047	0°	1.02	n	
640.47	6138	100°	6125	10°	1.00	n	
658.84	6184	160°	6066	70°	1.02	n	
684.00	6088	145°	6010	55°	1.01	n	
710.30	5814	110°	5751	20°	1.01	n	
729.20	5997	30°	5855	120°	1.02	n	
783.25	5743	120°	5707	30°	1.01	n	
803.00	5920	120°	5875	30°	1.01	n	
819.50	6190	130°	6120	40°	1.01	n	
853.07	6087	85°	5710	175°	1.07	n	
246.70	5860	170°	5678	80°	1.03	n	Repeat
498.78	5738	15°	5385	105°	1.07	n	Repeat
819.50	6209	120°	6136	30°	1.01	n	Repeat

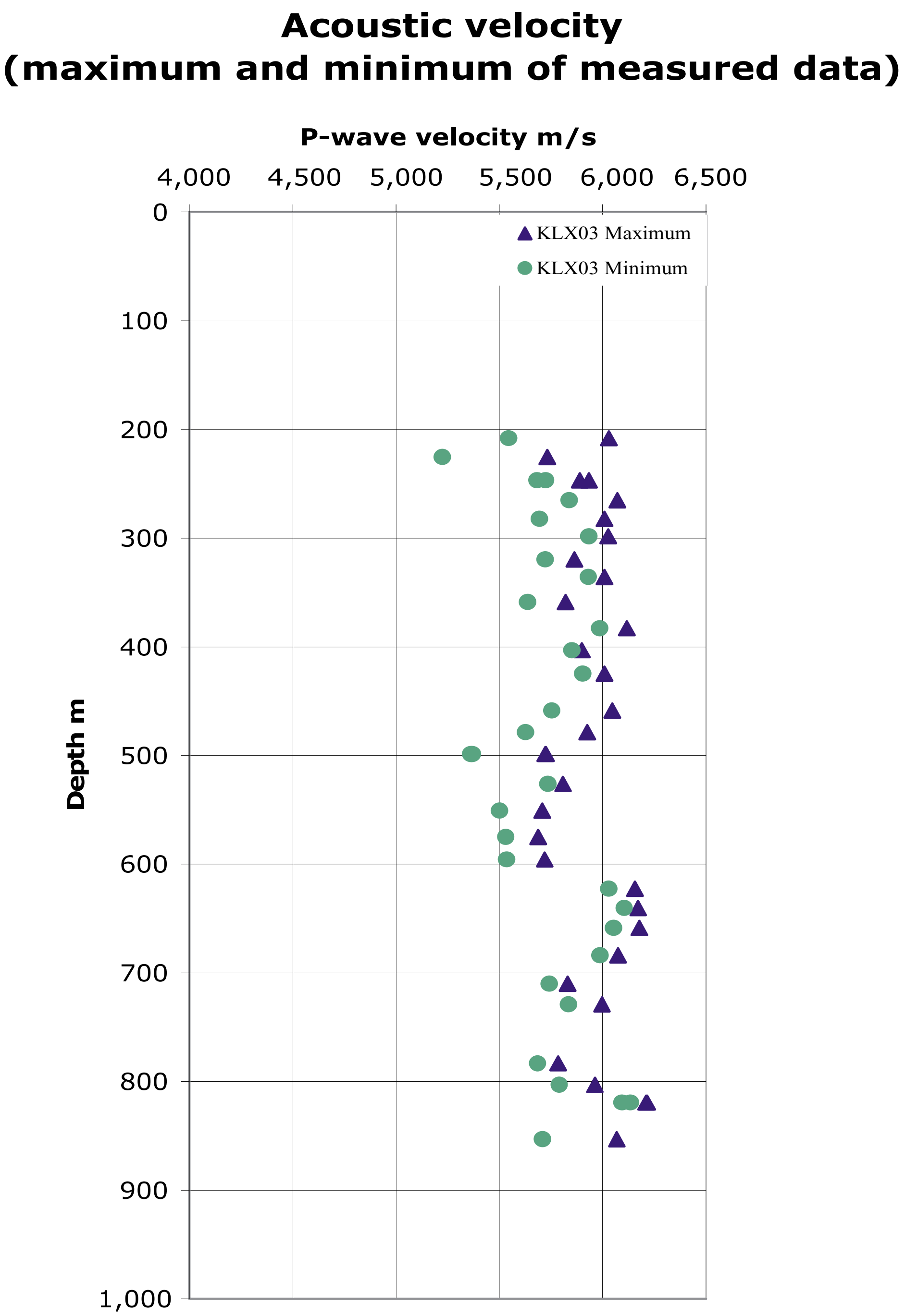

Figure 5-1. *Measured values of maximum and minimum acoustic velocities plotted versus borehole length in KLX03A.*

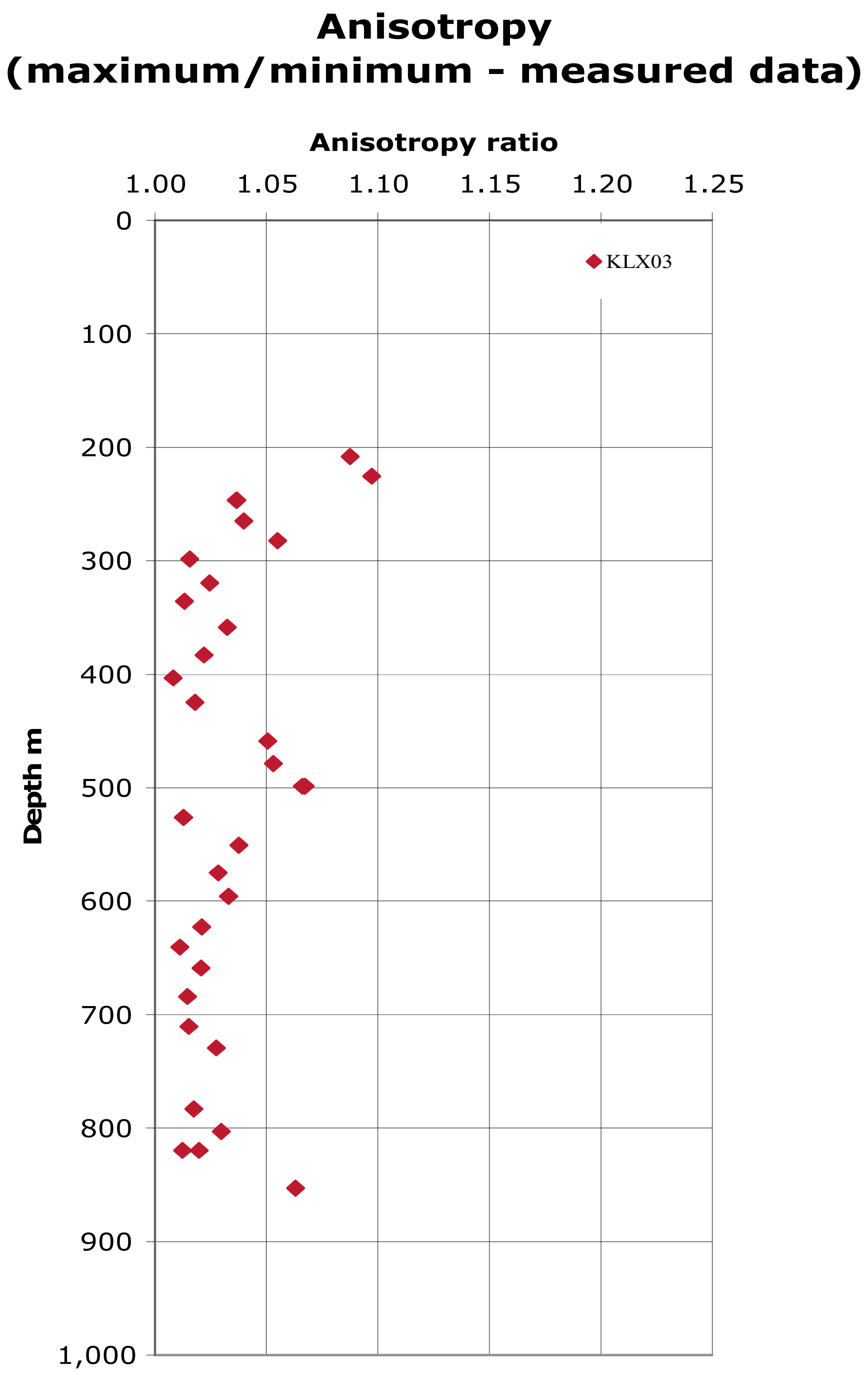

Figure 5-2. *Measured values of acoustic velocities anisotropy plotted versus borehole length in KLX03A.*

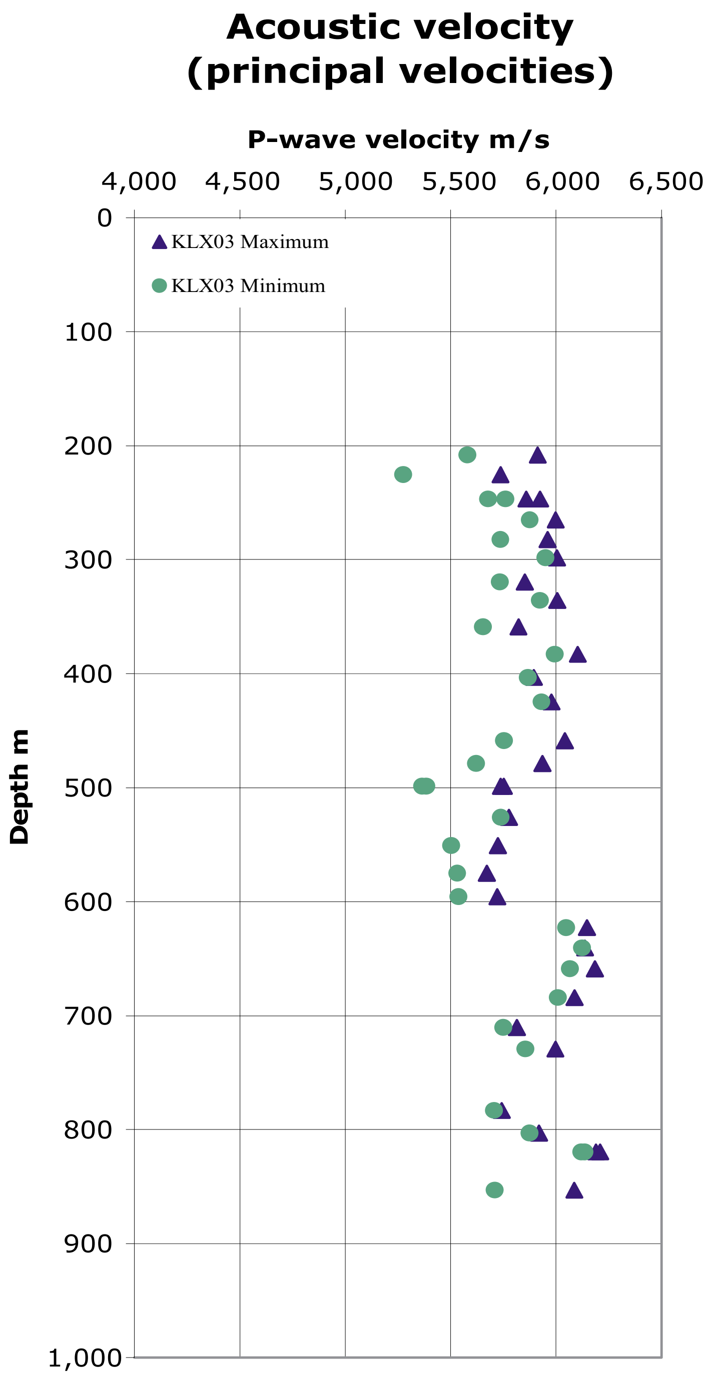

Figure 5-3. *Calculated values of maximum and minimum principal acoustic velocities plotted versus borehole length in KLX03A.*

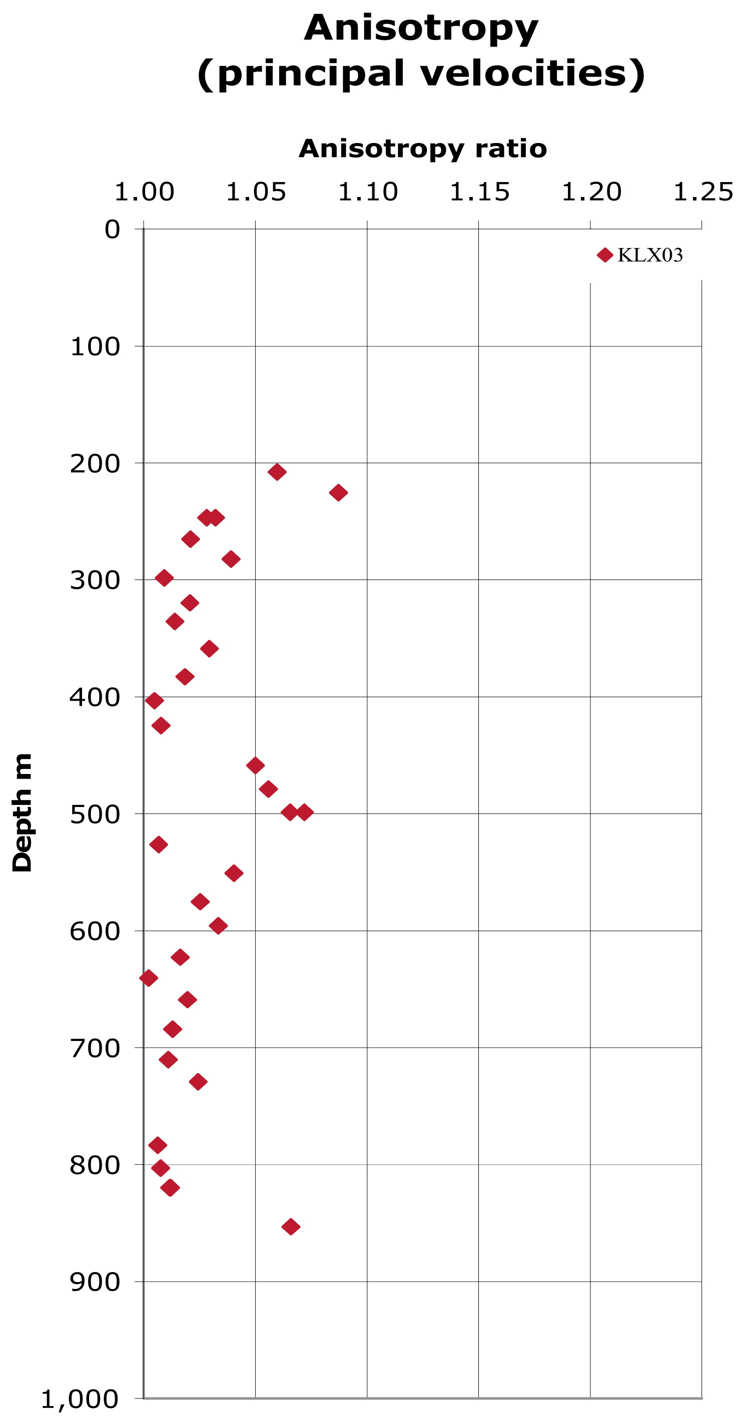

Figure 5-4. *Calculated values of maximum and minimum principal acoustic velocity anisotropy plotted versus borehole length in borehole KLX03A.*

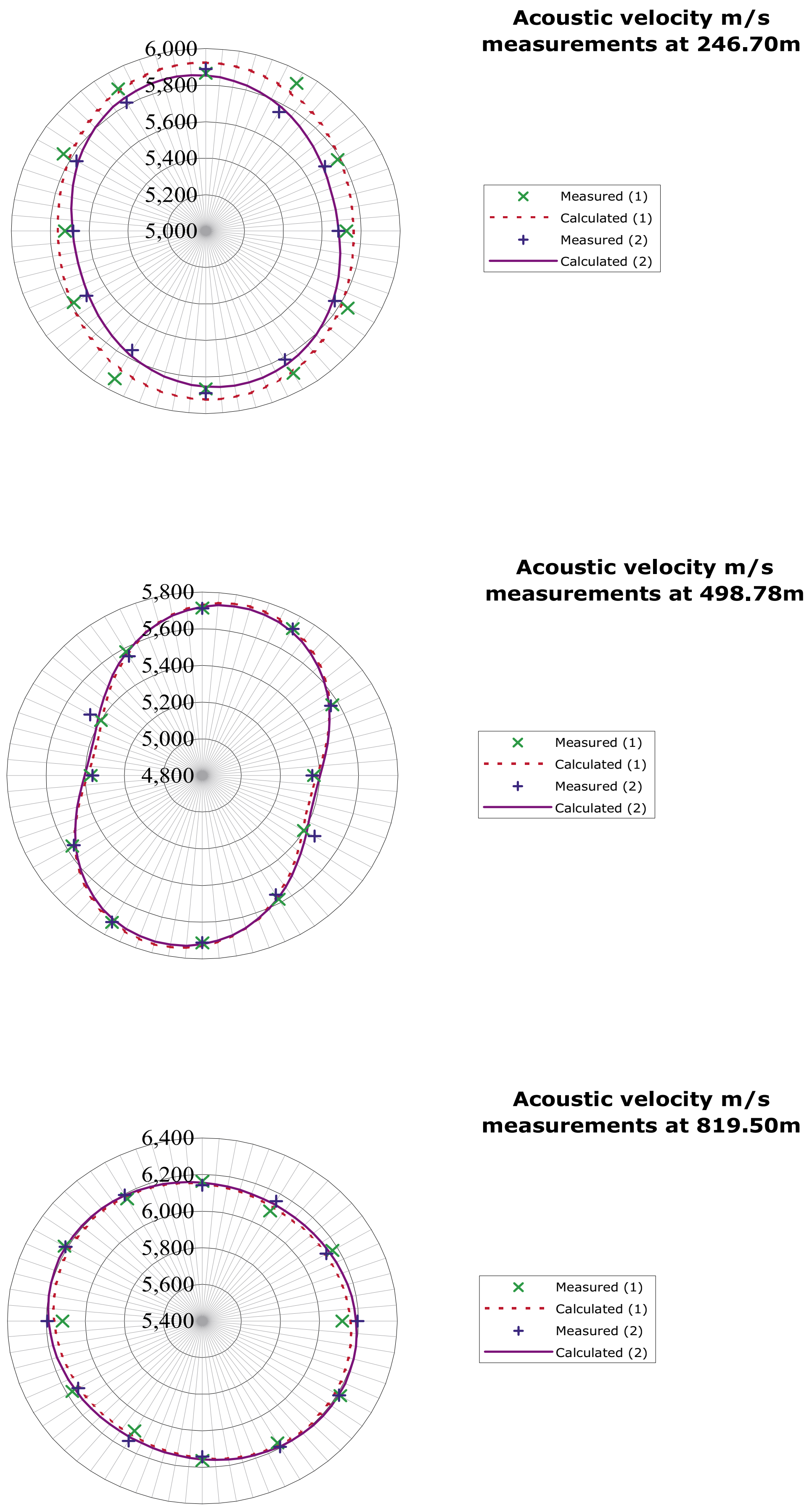

Figure 5-5. *Comparison of measured and calculated values (model fit) of acoustic velocity for each of two determinations at three different depths in borehole KLX03A.*

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Appendix A

Calibration measurements on aluminium cylinder diameter 50.90 mm with known velocity 6,320 m/s

Date and time	Known velocity m/S	Diameter mm	Time Measured µS	Calculated µS	Correction µS
20041123 – 1130 hrs	6,320	50.90	9.21	8.05	1.16
20041123 – 1330 hrs	6,320	50.90	9.16	8.05	1.10
20041123 – 1730 hrs	6,320	50.90	9.17	8.05	1.11
20041124 – 0900 hrs	6,320	50.90	9.20	8.05	1.14
20041124 – 1200 hrs	6,320	50.90	9.20	8.05	1.14
Average			9.184		1.130