Attachment A-5

GeoVision Suspension Logging Report

GEOVision
geophysical services
a division of Blackhawk GeoServices

P-S SUSPENSION LOGGING
BOREHOLE B-2

CLINTON NUCLEAR POWER PLANT
CLINTON, ILLINOIS

October 10, 2002

REV2

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CLINTON, ILLINOIS

Prepared by

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REV2

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INTRODUCTION

Borehole geophysical measurements were performed in one borehole at the Clinton Nuclear Power Plant, Clinton, Illinois for the purpose of measuring in-situ soil velocities, both shear wave (S_H-wave) and compressional wave (P-wave). OYO P-S Suspension logging data acquisition was performed on August 8, 2002 by Antony Martin of **GEO***Vision*. Analysis was subsequently completed by Antony Martin and Quality Assurance review was completed by Rob Steller.

The OYO Model 170 Suspension Logging Recorder and Suspension Logging Probe were used to obtain in-situ horizontal shear and compressional wave velocity measurements at 1.64 ft intervals in borehole B-2, which was drilled to a depth of 323 ft. The acquired data was analyzed and a profile of velocity versus depth was produced for both compressional and horizontally polarized shear waves, where possible.

A detailed reference for the velocity measurement techniques used in this study is:

> Guidelines for Determining Design Basis Ground Motions, Report TR-102293, Electric Power Research Institute, Palo Alto, California, November 1993, Sections 7 and 8.

INSTRUMENTATION AND PROCEDURES

The **GEO***Vision* Procedure for Oyo P-S Suspension Seismic Velocity Logging (Exhibit A) was followed during this investigation. This procedure was supplied and approved in advance of the field work. Following is a summary.

Instrumentation

Suspension soil velocity measurements were performed using the Model 170 Suspension Logging system, manufactured by OYO Corporation. This system consisted of the following components: Model 3331A recorder (S/N 19029), Model 3348A head reducer (S/N 28063), Model 3385 receiver (S/N 23053), Model 3387 1 meter isolation tube (S/N 24053), Model 3304 source (S/N 37113), Model 3386A source driver (S/N 27073), Model 3302W weight (S/N 12007) and Model 3828A winch/depth encoder (S/N 18020). Calibration records for the recorder are presented in Exhibit B. The suspension logging system directly determines the average velocity of a segment of the soil column surrounding the borehole of interest by measuring the elapsed time between arrivals of a wave propagating upward through the soil column. The receivers that detect the wave, and the source that generates the wave, are moved as a unit in the borehole producing relatively constant amplitude signals at all depths.

The suspension system probe consists of a combined reversible polarity solenoid horizontal shear-wave source (S_H) and compressional-wave source (P), joined to two biaxial receivers by a flexible isolation cylinder, as shown in Figure 1. The separation of the two receivers is approximately 1 meter or 3.3 ft, allowing average wave velocity in the region between the receivers to be determined by inversion of the wave travel time between the two receivers. The total length of the probe as used in this survey is 19 ft, with the center point of the receiver pair 12.1 ft above the bottom end of the probe. The probe receives control signals from, and sends the amplified receiver signals to, instrumentation on the surface via an armored 7 or 4 conductor cable. The cable is wound onto the drum of a winch and is used to support the probe. Cable travel is measured to provide probe depth data.

The entire probe is suspended by the cable and centered in the borehole by nylon "whiskers", therefore, source motion is not coupled directly to the borehole walls; rather, the source motion creates a horizontally propagating impulsive pressure wave in the fluid filling the borehole and

surrounding the source. This pressure wave is converted to P and S_H-waves in the surrounding soil and rock as it impinges upon the borehole wall. These waves propagate through the soil and rock surrounding the borehole, in turn causing a pressure wave to be generated in the fluid surrounding the receivers as the soil waves pass their location. Separation of the P and S_H-waves at the receivers is performed using the following steps:

1. Orientation of the horizontal receivers is maintained parallel to the axis of the source, maximizing the amplitude of the recorded SH-wave signals.
2. At each depth, S_H-wave signals are recorded with the source actuated in opposite directions, producing S_H-wave signals of opposite polarity, providing a characteristic S_H-wave signature distinct from the P-wave signal.
3. The approximate 7 ft separation of source and first receiver permits the P-wave signal to pass and damp significantly before the slower S_H-wave signal arrives at the receiver. In faster soils or rock, the isolation cylinder is extended to allow greater separation of the P- and S_H-wave signals.
4. In saturated soils, the received P-wave signal is typically of much higher frequency than the received S_H-wave signal, permitting additional separation of the two signals by low pass filtering.
5. Direct arrival of the original pressure pulse in the fluid is not detected at the receivers because the wavelength of the pressure pulse in fluid is significantly greater than the dimension of the fluid annulus surrounding the probe (meter versus centimeter scale), preventing significant energy transmission through the fluid medium.

In operation, a distinct, repeatable pattern of impulses is generated at each depth as follows:

1. The source is fired in one direction producing dominantly horizontal shear with some vertical compression, and the signals from the horizontal receivers situated parallel to the axis of motion of the source are recorded.
2. The source is fired again in the opposite direction and the horizontal receiver signals are recorded.
3. The source is fired again and the vertical receiver signals are recorded. The repeated source pattern facilitates the picking of the P and S_H-wave arrivals; reversal of the source changes the polarity of the S_H-wave pattern but not the P-wave pattern.

The data from each receiver during each source activation is recorded as a different channel on the recording system. The Model 170 has six channels (two simultaneous recording channels), each with a 12 bit, 1024 sample record. The recorded data is displayed on a CRT display and on paper tape output as six channels with a common time scale. Data is stored on 3.5 inch floppy diskettes for further processing. Up to 8 sampling sequences can be summed to improve the signal to noise ratio of the signals.

Review of the displayed data on the CRT or paper tape allows the operator to set the gains, filters, delay time, pulse length (energy), sample rate, and summing number to optimize the quality of the data before recording. Verification of the calibration of the Model 170 digital recorder is performed every twelve months using a NIST traceable frequency source and counter.

Field Measurement Procedures

The borehole was logged as a 6-inch diameter open hole filled with drilling mud. The borehole probe was positioned with the mid-point of the receiver spacing at ground surface, and the mechanical and electronic depth counters were set to zero. The probe was lowered to the bottom of the 323-ft deep borehole and then returned to the surface, stopping at 1.64 ft intervals to collect data, as summarized below.

At each measurement depth the measurement sequence of two opposite horizontal records and one vertical record was performed, and the gains were adjusted as required. The data from each depth was printed on paper tape, checked, and recorded on diskette before moving to the next depth.

Upon completion of the measurements, the probe zero depth indication at grade was verified prior to removal from the borehole.

DATA ANALYSIS

The OYO Model 170 P-S Suspension Logger system offers the opportunity to measure ground velocity in two ways using the same data. The standard method is to measure the velocity from the travel time between the two receivers, as described under "Instrumentation" above. A second method is to use the travel time from the source to the first receiver. The difference between these methods is summarized as follows:

1. The receiver-to-receiver (R1-R2) method is normally more accurate, because the picks are made from the peak of the arrival waveform. The analyst picks the arrival waveform, and software is used to find the peaks. Travel time is then from peak-to-peak.
2. R1-R2 data has higher resolution, because the travel time is averaged over the nominal 1m or 3.3ft between receivers. The greater scatter in velocities is attributed to the changes in material from one measurement location to another. These measurements are very repeatable.
3. Averaging the "normal" and "reverse" travel times eliminates errors due to hysteresis of the source (difference in actuation pulses).
4. Source-to-receiver (S-R1) measurements are subject to a source delay, nominally 4 milliseconds for the 7-conductor systems and 3 milliseconds for the 4-conductor systems. This source delay is independently verifiable, but subject at times to change due to loss of source springs during the measurement program.
5. The S-R1 results are more subject to "picking errors", since the picks are based on the analyst's choice of first motion rather than software peak detection. These errors are less significant, however, since the total travel time is more than twice as long.
6. The S-R1 results exhibit less scatter, since the velocity is averaged over the greater distance from the source to the first receiver, approximately 7ft compared to 3.3ft. (NOTE: actual measured separations used in the analysis varied from 7.11 to 7.17ft))
7. The S-R1 results are less subject to possible effects of dispersion, if present.
8. The S-R1 data set extends about 5ft deeper than the R1-R2 data set. The reason is that the depth reference location between the source and the first receiver is about 5.1ft below

the depth reference between R1 and R2. On the other hand, for the same reason, R1-R2 data will extend closer to the surface by about 5.1ft.

For the above reasons, normally R1-R2 results are considered the "primary" results, and S-R1 results are used only for quality assurance purposes, to check the validity of the R1-R2 results.

P-Wave Analysis

The recorded digital records were analyzed to locate the first minima or first arrival on the vertical axis records, indicating the arrival of P-wave energy. The difference in travel time between receiver 1 and receiver 2 (R1-R2) arrivals was used to calculate the P-wave velocity for that 3.3 ft segment of the soil column. When observable, P-wave arrivals on the horizontal axis records were used to verify the velocities determined from the vertical axis data. P-wave arrival data was of excellent quality in this borehole, except to the upper 20 ft which was of fair quality.

The P-wave velocity calculated from the travel time over the approximately 7 ft interval from source to receiver 1 (S-R1) was calculated and plotted for quality assurance of the velocity derived from the travel time between receivers. In this analysis, the depth values as recorded were increased by 5.1 ft to correspond to the mid-point of the approximately 7 ft S-R1 interval, as illustrated in Figure 1. Travel times were obtained by picking the first break of the P-wave signal at receiver 1 and subtracting the source delay; approximately 3 milliseconds, the calculated and experimentally verified delay from source trigger pulse (beginning of record) to source impact. This delay corresponds to the duration of acceleration of the solenoid before impact.

S_H-Wave Analysis

The recorded digital records were studied to establish the presence of clear S_H-wave pulses, as indicated by the presence of opposite polarity pulses on each pair of horizontal records. Ideally, the S_H-wave signals from the 'normal' and 'reverse' source pulses are very nearly inverted images of each other. Digital FFT - IFFT low-pass filtering was used to remove the higher frequency P-wave signal from the S_H-wave signal. Different filter cutoffs were used to separate P- and S_H-waves at different depths.

Generally, the first minima was picked for the 'normal' signals and the first maxima for the 'reverse' signals, although other points on the waveform were used if the first pulse was distorted. The absolute arrival time of the 'normal' and 'reverse' signals may vary by +/- 0.2 milliseconds, due to differences in the actuation time of the solenoid source caused by constant mechanical bias in the source or by borehole inclination. This variation does not affect the R1-R2 velocity determinations, as the differential time is measured between arrivals of waves created by the same source actuation. The final velocity value is the average of the values obtained from the 'normal' and 'reverse' source actuations.

The S_H-wave velocity calculated from the travel time over the approximate 7 ft interval from source to receiver 1 (S-R1) was calculated and plotted for verification of the velocity derived from the travel time between receivers. In this analysis, the depth values were increased by 5.1 ft to correspond to the mid-point of the 7 ft S-R1 interval, as illustrated in Figure 1. Travel times were obtained by picking the first break of the S_H-wave signal at the near receiver and subtracting 3.0 milliseconds, the calculated and experimentally verified delay from the source trigger pulse (beginning of the record) to source impact.

Figure 2 shows an example of R1 - R2 measurements on the unfiltered record for a depth of 126.3 ft in borehole B-2. Figure 3 displays the same record after filtering of the S_H-waveform record with a 1,000 Hz FFT - IFFT digital lowpass filter, illustrating the presence of higher frequency P-wave energy at the beginning of the record.

RESULTS

Suspension R1-R2 P- and S_H-wave velocities for borehole B-2 are plotted in Figure 4. The suspension velocity data presented in this figure is presented in Tables 1. P and S_H-wave velocity data from R1-R2 analysis and quality assurance analysis of S-R1 data are plotted together in Figures 5 to aid in visual comparison. It must be noted that R1-R2 data is an average velocity over a 3.3 ft segment of the soil column whereas S-R1 data is an average over 7 ft. S-R1 data is, therefore somewhat smoother. S-R1 data are presented in tabular format in Table 2. Good correspondence between the shape of the P- and S_H-wave velocity curves is observed for this data set. The velocities derived from S-R1 and R1-R2 data are in good agreement, providing verification of the higher resolution R1-R2 data.

Data Reliability

P- and S_H-wave velocity measurement using the Suspension Method gives average velocities over a 3.3 ft interval of depth. This high resolution results in the scatter of values shown in the graphs. Individual measurements are very reliable with estimated precision of +/- 5%. Standardized field procedures (Exhibit A) and quality assurance checks add to the reliability of these data.

Quality Assurance

These velocity measurements were performed using industry-standard or better methods for both measurements and analyses. All work was performed under **GEO***Vision* quality assurance procedures, which include:

- Use of NIST-traceable calibrations, where applicable, for field and laboratory instrumentation
- Use of standard field data logs
- Use of independent verification of data by comparison of receiver-to-receiver and source-to-receiver velocities
- Independent review of calculations and results by a registered professional engineer, geologist, or geophysicist.

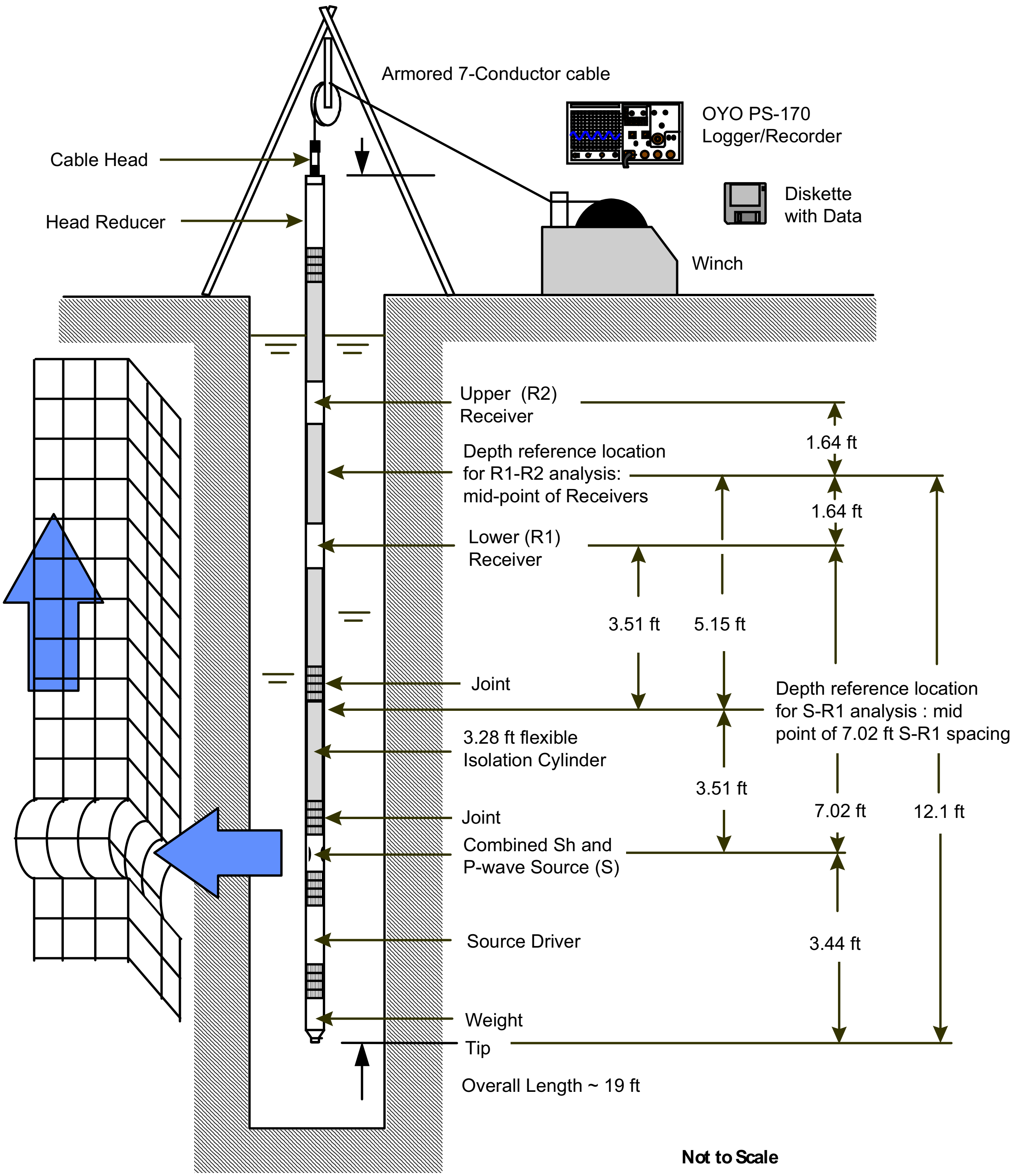


Figure 1: Concept illustration of P-S logging system

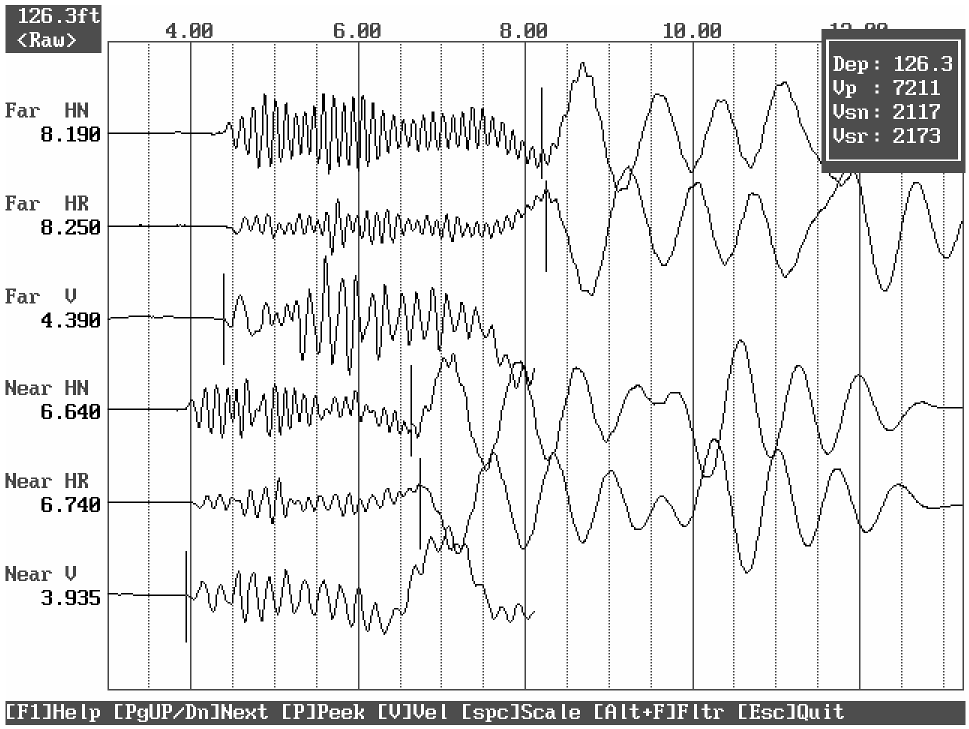


Figure 2: Unfiltered Record for a Depth of 126.3 ft.

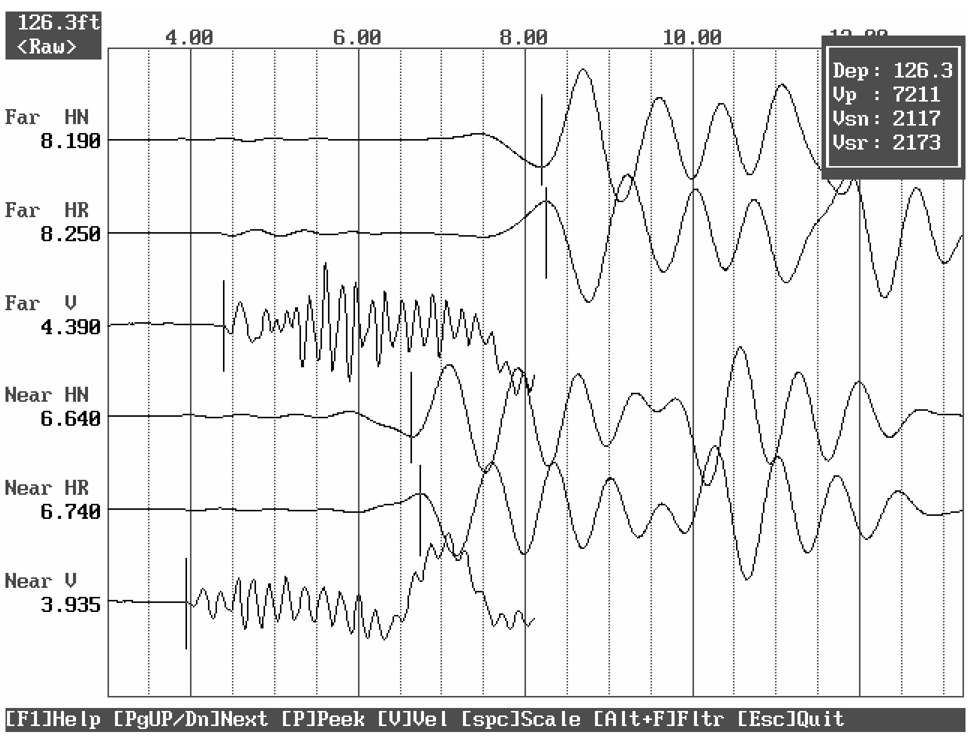


Figure 3: Filtered Record for a Depth of 126.3 ft.

CLINTON NUCLEAR POWER PLANT, BOREHOLE B-2
Receiver to Receiver V_s and V_p Analysis

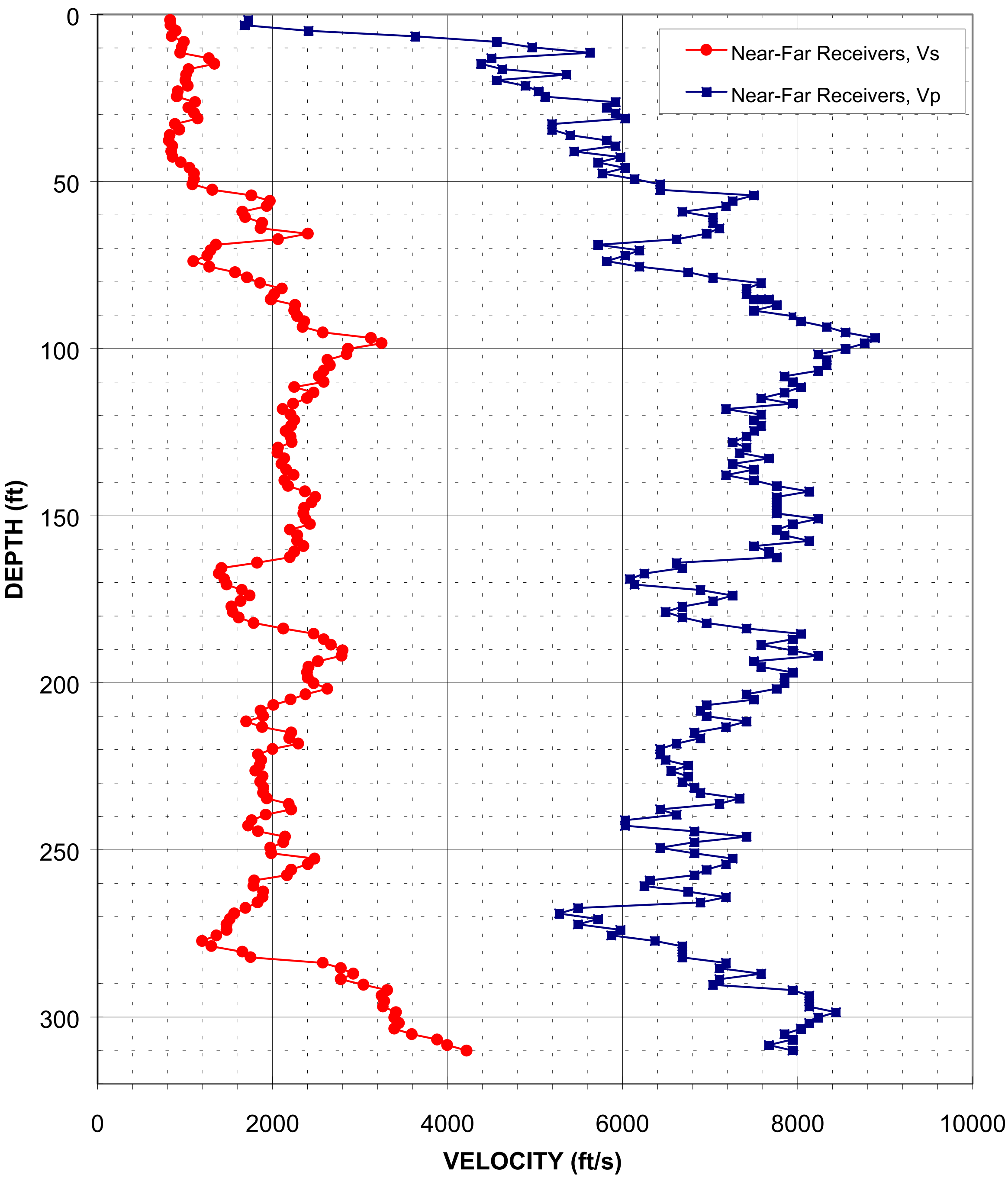


Figure 4: Borehole B-2, Suspension P- and S_H-wave Velocities

Table 1: Summary of Compressional Wave Velocity, Shear Wave Velocity, and Poisson's Ratio Based on Receiver-to-Receiver Travel Time Data - Borehole B-2, Clinton NPP

American Units			
Depth at Midpoint Between Receivers	Velocity		Poisson's Ratio
	V_s	V_p	
(ft)	(ft/s)	(ft/s)	
1.6	830	1720	0.35
3.3	830	1680	0.34
4.9	890	2410	0.42
6.6	850	3630	0.47
8.2	990	4560	0.48
9.8	960	4960	0.48
11.5	940	5630	0.49
13.1	1270	4500	0.46
14.8	1340	4380	0.45
16.4	1040	4620	0.47
18.0	1010	5360	0.48
19.7	1000	4560	0.47
21.3	1030	4890	0.48
23.0	920	5040	0.48
24.6	910	5110	0.48
26.3	1110	5920	0.48
27.9	1040	5820	0.48
29.5	1100	5920	0.48
31.2	1140	6030	0.48
32.8	880	5190	0.49
34.5	930	5190	0.48
36.1	830	5400	0.49
37.7	820	5820	0.49
39.4	860	5920	0.49
41.0	840	5440	0.49
42.7	860	5970	0.49
44.3	950	5720	0.49
45.9	1050	6030	0.48
47.6	1100	5770	0.48
49.2	1100	6140	0.48
50.9	1090	6430	0.49
52.5	1310	6430	0.48
54.1	1760	7500	0.47
55.8	1970	7260	0.46
57.4	1930	7180	0.46
59.1	1650	6680	0.47
60.7	1690	7030	0.47
62.3	1880	7030	0.46
64.0	1860	7110	0.46

Metric Units			
Depth at Midpoint Between Receivers	Velocity		Poisson's Ratio
	V_s	V_p	
(m)	(m/s)	(m/s)	
0.5	250	520	0.35
1.0	250	510	0.34
1.5	270	730	0.42
2.0	260	1110	0.47
2.5	300	1390	0.48
3.0	290	1510	0.48
3.5	290	1710	0.49
4.0	390	1370	0.46
4.5	410	1340	0.45
5.0	320	1410	0.47
5.5	310	1630	0.48
6.0	310	1390	0.47
6.5	310	1490	0.48
7.0	280	1540	0.48
7.5	280	1560	0.48
8.0	340	1800	0.48
8.5	320	1770	0.48
9.0	340	1800	0.48
9.5	350	1840	0.48
10.0	270	1580	0.49
10.5	280	1580	0.48
11.0	250	1650	0.49
11.5	250	1770	0.49
12.0	260	1800	0.49
12.5	260	1660	0.49
13.0	260	1820	0.49
13.5	290	1740	0.49
14.0	320	1840	0.48
14.5	340	1760	0.48
15.0	340	1870	0.48
15.5	330	1960	0.49
16.0	400	1960	0.48
16.5	540	2290	0.47
17.0	600	2210	0.46
17.5	590	2190	0.46
18.0	500	2040	0.47
18.5	510	2140	0.47
19.0	570	2140	0.46
19.5	570	2170	0.46

TABLE 1 (cont.)
Summary of Compressional Wave Velocity, Shear Wave Velocity, and Poisson's Ratio Based on Receiver-to-Receiver Travel Time Data - Borehole B-2, Clinton NPP

American Units				Metric Units			
Depth at Midpoint Between Receivers	Velocity		Poisson's Ratio	Depth at Midpoint Between Receivers	Velocity		Poisson's Ratio
	V_s	V_p			V_s	V_p	
(ft)	(ft/s)	(ft/s)		(m)	(m/s)	(m/s)	
65.6	2400	6960	0.43	20.0	730	2120	0.43
67.3	2060	6620	0.45	20.5	630	2020	0.45
68.9	1350	5720	0.47	21.0	410	1740	0.47
70.5	1290	6190	0.48	21.5	390	1890	0.48
72.2	1250	6030	0.48	22.0	380	1840	0.48
73.8	1100	5820	0.48	22.5	330	1770	0.48
75.5	1280	6190	0.48	23.0	390	1890	0.48
77.1	1570	6750	0.47	23.5	480	2060	0.47
78.7	1710	7030	0.47	24.0	520	2140	0.47
80.4	1860	7580	0.47	24.5	570	2310	0.47
82.0	2110	7420	0.46	25.0	640	2260	0.46
83.7	2020	7420	0.46	25.5	620	2260	0.46
85.3	1990	7500	0.46	26.0	610	2290	0.46
85.3	1990	7670	0.46	26.0	610	2340	0.46
85.3	1980	7580	0.46	26.0	600	2310	0.46
86.9	2260	7760	0.45	26.5	690	2360	0.45
88.6	2250	7500	0.45	27.0	690	2290	0.45
90.2	2280	7940	0.46	27.5	700	2420	0.46
91.9	2360	8040	0.45	28.0	720	2450	0.45
93.5	2340	8330	0.46	28.5	710	2540	0.46
95.1	2580	8540	0.45	29.0	790	2600	0.45
96.8	3130	8880	0.43	29.5	950	2710	0.43
98.4	3250	8770	0.42	30.0	990	2670	0.42
100.1	2860	8540	0.44	30.5	870	2600	0.44
101.7	2850	8230	0.43	31.0	870	2510	0.43
103.4	2630	8330	0.44	31.5	800	2540	0.44
105.0	2660	8330	0.44	32.0	810	2540	0.44
106.6	2590	8230	0.45	32.5	790	2510	0.45
108.3	2530	7850	0.44	33.0	770	2390	0.44
109.9	2590	7940	0.44	33.5	790	2420	0.44
111.6	2250	8040	0.46	34.0	690	2450	0.46
113.2	2470	7850	0.44	34.5	750	2390	0.44
114.8	2390	7580	0.44	35.0	730	2310	0.44
116.5	2240	7940	0.46	35.5	680	2420	0.46
118.1	2120	7180	0.45	36.0	640	2190	0.45
119.8	2210	7580	0.45	36.5	670	2310	0.45
121.4	2250	7500	0.45	37.0	690	2290	0.45
123.0	2210	7580	0.45	37.5	670	2310	0.45
124.7	2150	7500	0.46	38.0	660	2290	0.46

TABLE 1 (cont.)
Summary of Compressional Wave Velocity, Shear Wave Velocity, and Poisson's Ratio Based on Receiver-to-Receiver Travel Time Data - Borehole B-2, Clinton NPP

American Units				Metric Units			
Depth at Midpoint Between Receivers	Velocity		Poisson's Ratio	Depth at Midpoint Between Receivers	Velocity		Poisson's Ratio
	V_s	V_p			V_s	V_p	
(ft)	(ft/s)	(ft/s)		(m)	(m/s)	(m/s)	
126.3	2210	7420	0.45	38.5	670	2260	0.45
128.0	2220	7260	0.45	39.0	680	2210	0.45
129.6	2060	7420	0.46	39.5	630	2260	0.46
131.2	2060	7340	0.46	40.0	630	2240	0.46
132.9	2140	7670	0.46	40.5	650	2340	0.46
134.5	2100	7260	0.45	41.0	640	2210	0.45
136.2	2160	7500	0.45	41.5	660	2290	0.45
137.8	2240	7180	0.45	42.0	680	2190	0.45
139.4	2140	7500	0.46	42.5	650	2290	0.46
141.1	2180	7760	0.46	43.0	660	2360	0.46
142.7	2370	8130	0.45	43.5	720	2480	0.45
144.4	2490	7760	0.44	44.0	760	2360	0.44
146.0	2450	7760	0.44	44.5	750	2360	0.44
147.6	2360	7760	0.45	45.0	720	2360	0.45
149.3	2350	7760	0.45	45.5	720	2360	0.45
150.9	2380	8230	0.45	46.0	720	2510	0.45
152.6	2430	7940	0.45	46.5	740	2420	0.45
154.2	2200	7760	0.46	47.0	670	2360	0.46
155.8	2280	7850	0.45	47.5	700	2390	0.45
157.5	2280	8130	0.46	48.0	700	2480	0.46
159.1	2350	7500	0.45	48.5	720	2290	0.45
160.8	2250	7670	0.45	49.0	690	2340	0.45
162.4	2200	7760	0.46	49.5	670	2360	0.46
164.0	1820	6620	0.46	50.0	560	2020	0.46
165.7	1420	6680	0.48	50.5	430	2040	0.48
167.3	1390	6250	0.47	51.0	420	1910	0.47
169.0	1450	6080	0.47	51.5	440	1850	0.47
170.6	1470	6140	0.47	52.0	450	1870	0.47
172.2	1650	6890	0.47	52.5	500	2100	0.47
173.9	1740	7260	0.47	53.0	530	2210	0.47
175.5	1630	7030	0.47	53.5	500	2140	0.47
177.2	1530	6680	0.47	54.0	470	2040	0.47
178.8	1540	6490	0.47	54.5	470	1980	0.47
180.5	1610	6680	0.47	55.0	490	2040	0.47
182.1	1790	6960	0.46	55.5	540	2120	0.46
183.7	2120	7420	0.46	56.0	650	2260	0.46
185.4	2470	8040	0.45	56.5	750	2450	0.45
187.0	2590	7940	0.44	57.0	790	2420	0.44
188.7	2670	7580	0.43	57.5	810	2310	0.43

TABLE 1 (cont.)
Summary of Compressional Wave Velocity, Shear Wave Velocity, and Poisson's Ratio Based on Receiver-to-Receiver Travel Time Data - Borehole B-2, Clinton NPP

American Units			
Depth at Midpoint Between Receivers	Velocity		Poisson's Ratio
	V_s	V_p	
(ft)	(ft/s)	(ft/s)	
190.3	2800	7940	0.43
191.9	2790	8230	0.44
193.6	2520	7500	0.44
195.2	2410	7580	0.44
196.9	2390	7940	0.45
198.5	2400	7850	0.45
200.1	2470	7850	0.44
201.8	2630	7760	0.44
203.4	2380	7420	0.44
205.1	2210	7500	0.45
206.7	2010	6960	0.45
208.3	1860	6890	0.46
210.0	1890	6960	0.46
211.6	1700	7420	0.47
213.3	1880	7180	0.46
214.9	2210	6820	0.44
216.5	2190	6890	0.44
218.2	2300	6620	0.43
219.8	2000	6430	0.45
221.5	1830	6430	0.46
223.1	1870	6490	0.45
224.7	1850	6750	0.46
226.4	1800	6550	0.46
228.0	1890	6750	0.46
229.7	1860	6680	0.46
231.3	1900	6820	0.46
232.9	1890	6890	0.46
234.6	1930	7340	0.46
236.2	2180	7110	0.45
237.9	2210	6430	0.43
239.5	1920	6620	0.45
241.1	1760	6030	0.45
242.8	1720	6030	0.46
244.4	1830	6820	0.46
246.1	2140	7420	0.45
247.7	2120	6820	0.45
249.3	1970	6430	0.45
251.0	1990	6820	0.45
252.6	2480	7260	0.43

Metric Units			
Depth at Midpoint Between Receivers	Velocity		Poisson's Ratio
	V_s	V_p	
(m)	(m/s)	(m/s)	
58.0	850	2420	0.43
58.5	850	2510	0.44
59.0	770	2290	0.44
59.5	730	2310	0.44
60.0	730	2420	0.45
60.5	730	2390	0.45
61.0	750	2390	0.44
61.5	800	2360	0.44
62.0	720	2260	0.44
62.5	670	2290	0.45
63.0	610	2120	0.45
63.5	570	2100	0.46
64.0	580	2120	0.46
64.5	520	2260	0.47
65.0	570	2190	0.46
65.5	670	2080	0.44
66.0	670	2100	0.44
66.5	700	2020	0.43
67.0	610	1960	0.45
67.5	560	1960	0.46
68.0	570	1980	0.45
68.5	560	2060	0.46
69.0	550	2000	0.46
69.5	570	2060	0.46
70.0	570	2040	0.46
70.5	580	2080	0.46
71.0	580	2100	0.46
71.5	590	2240	0.46
72.0	670	2170	0.45
72.5	670	1960	0.43
73.0	590	2020	0.45
73.5	540	1840	0.45
74.0	520	1840	0.46
74.5	560	2080	0.46
75.0	650	2260	0.45
75.5	650	2080	0.45
76.0	600	1960	0.45
76.5	610	2080	0.45
77.0	760	2210	0.43

TABLE 1 (cont.)
Summary of Compressional Wave Velocity, Shear Wave Velocity, and Poisson's Ratio Based on Receiver-to-Receiver Travel Time Data - Borehole B-2, Clinton NPP

American Units			
Depth at Midpoint Between Receivers	Velocity		Poisson's Ratio
	V_s	V_p	
(ft)	(ft/s)	(ft/s)	
254.3	2400	7180	0.44
255.9	2210	6960	0.44
257.6	2160	6820	0.44
259.2	1790	6310	0.46
260.8	1780	6250	0.46
262.5	1890	6750	0.46
264.1	1890	7180	0.46
265.8	1830	6890	0.46
267.4	1690	5490	0.45
269.0	1560	5270	0.45
270.7	1510	5720	0.46
272.3	1470	5490	0.46
274.0	1470	5970	0.47
275.6	1360	5870	0.47
277.2	1190	6370	0.48
278.9	1300	6680	0.48
280.5	1650	6680	0.47
282.2	1750	6680	0.46
283.8	2580	7180	0.43
285.4	2780	7110	0.41
287.1	2920	7580	0.41
288.7	2780	7110	0.41
290.4	3040	7030	0.38
292.0	3310	7940	0.39
293.6	3250	8130	0.41
295.3	3280	8130	0.40
296.9	3260	8130	0.40
298.6	3410	8440	0.40
300.2	3390	8230	0.40
301.8	3440	8130	0.39
303.5	3390	8040	0.39
305.1	3590	7850	0.37
306.8	3880	7940	0.34
308.4	3990	7670	0.31
310.0	4220	7940	0.30

Metric Units			
Depth at Midpoint Between Receivers	Velocity		Poisson's Ratio
	V_s	V_p	
(m)	(m/s)	(m/s)	
77.5	730	2190	0.44
78.0	670	2120	0.44
78.5	660	2080	0.44
79.0	550	1920	0.46
79.5	540	1910	0.46
80.0	580	2060	0.46
80.5	570	2190	0.46
81.0	560	2100	0.46
81.5	520	1670	0.45
82.0	480	1610	0.45
82.5	460	1740	0.46
83.0	450	1670	0.46
83.5	450	1820	0.47
84.0	410	1790	0.47
84.5	360	1940	0.48
85.0	400	2040	0.48
85.5	500	2040	0.47
86.0	530	2040	0.46
86.5	790	2190	0.43
87.0	850	2170	0.41
87.5	890	2310	0.41
88.0	850	2170	0.41
88.5	930	2140	0.38
89.0	1010	2420	0.39
89.5	990	2480	0.41
90.0	1000	2480	0.40
90.5	990	2480	0.40
91.0	1040	2570	0.40
91.5	1030	2510	0.40
92.0	1050	2480	0.39
92.5	1030	2450	0.39
93.0	1090	2390	0.37
93.5	1180	2420	0.34
94.0	1220	2340	0.31
94.5	1290	2420	0.30

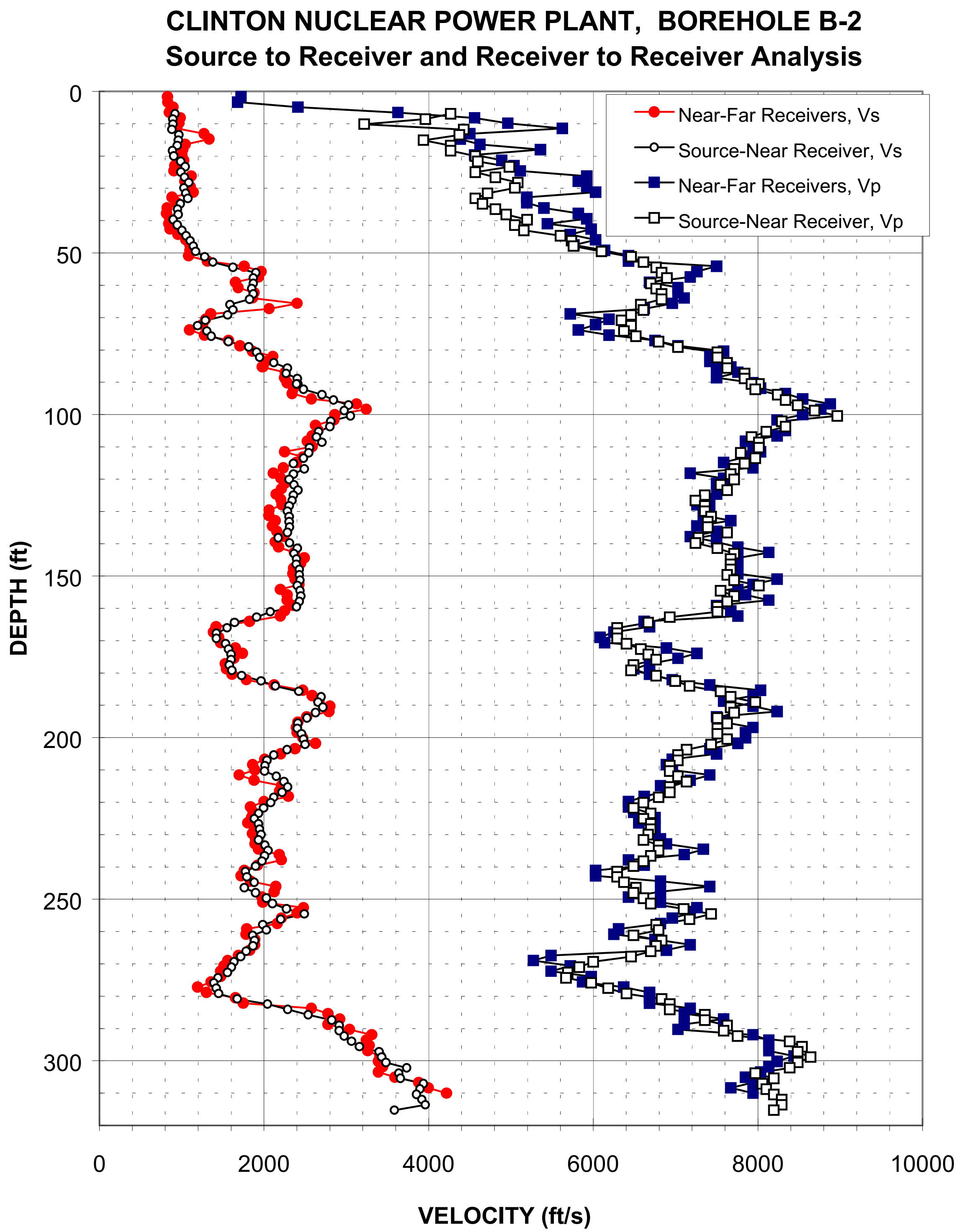


Figure 5: Borehole B-2, Suspension P and S_H-Wave R1-R2 and S-R1 Velocities

Table 2: Summary of Compressional Wave Velocity, Shear Wave Velocity, and Poisson's Ratio Based on Source-to-Receiver Travel Time Data - Borehole B-2, Clinton NPP

American Units				Metric Units			
Depth at Midpoint Between Source and Near Receiver	Velocity		Poisson's Ratio	Depth at Midpoint Between Source and Near Receiver	Velocity		Poisson's Ratio
	V_s	V_p			V_s	V_p	
(ft)	(ft/s)	(ft/s)		(m)	(m/s)	(m/s)	
6.9	920	4270	0.48	2.1	280	1300	0.48
8.6	890	3960	0.47	2.6	270	1210	0.47
10.2	900	3220	0.46	3.1	270	980	0.46
11.8	880	4430	0.48	3.6	270	1350	0.48
13.5	970	4370	0.47	4.1	290	1330	0.47
15.1	960	3940	0.47	4.6	290	1200	0.47
16.8	950	4270	0.47	5.1	290	1300	0.47
18.4	890	4270	0.48	5.6	270	1300	0.48
20.0	900	4570	0.48	6.1	280	1390	0.48
21.7	990	4600	0.48	6.6	300	1400	0.48
23.3	1040	4980	0.48	7.1	320	1520	0.48
25.0	990	4570	0.48	7.6	300	1390	0.48
26.6	1040	4810	0.48	8.1	320	1470	0.48
28.2	1090	5090	0.48	8.6	330	1550	0.48
29.9	1030	5050	0.48	9.1	310	1540	0.48
31.5	1050	4720	0.47	9.6	320	1440	0.47
33.2	1070	4570	0.47	10.1	330	1390	0.47
34.8	990	4660	0.48	10.6	300	1420	0.48
36.4	950	4810	0.48	11.1	290	1470	0.48
38.1	960	4940	0.48	11.6	290	1510	0.48
39.7	900	5200	0.48	12.1	270	1580	0.48
41.4	950	5050	0.48	12.6	290	1540	0.48
43.0	1010	5160	0.48	13.1	310	1570	0.48
44.6	1050	5600	0.48	13.6	320	1710	0.48
46.3	1100	5740	0.48	14.1	340	1750	0.48
47.9	1140	5760	0.48	14.6	350	1760	0.48
49.6	1170	6100	0.48	15.1	360	1860	0.48
51.2	1280	6460	0.48	15.6	390	1970	0.48
52.8	1380	6610	0.48	16.1	420	2010	0.48
54.5	1620	6760	0.47	16.6	490	2060	0.47
56.1	1900	6830	0.46	17.1	580	2080	0.46
57.8	1870	6890	0.46	17.6	570	2100	0.46
59.4	1870	6700	0.46	18.1	570	2040	0.46
61.0	1850	6760	0.46	18.6	560	2060	0.46
62.7	1870	6830	0.46	19.1	570	2080	0.46
64.3	1820	6830	0.46	19.6	560	2080	0.46
66.0	1590	6580	0.47	20.1	480	2000	0.47
67.6	1620	6610	0.47	20.6	490	2010	0.47
69.3	1560	6460	0.47	21.1	480	1970	0.47

TABLE 2 (cont.)
Summary of Compressional Wave Velocity, Shear Wave Velocity, and Poisson's Ratio Based on Source-to-Receiver Travel Time Data - Borehole B-2, Clinton NPP

American Units			
Depth at Midpoint Between Source and Near Receiver	Velocity		Poisson's Ratio
	V_s	V_p	
(ft)	(ft/s)	(ft/s)	
70.9	1290	6350	0.48
72.5	1190	6460	0.48
74.2	1310	6370	0.48
75.8	1360	6520	0.48
77.5	1570	6800	0.47
79.1	1820	7030	0.46
80.7	1910	7510	0.47
82.4	1950	7510	0.46
84.0	2120	7630	0.46
85.7	2280	7630	0.45
87.3	2270	7840	0.45
88.9	2410	7840	0.45
90.6	2400	7970	0.45
90.6	2410	8010	0.45
90.6	2400	7920	0.45
92.2	2480	7970	0.45
93.9	2710	8240	0.44
95.5	2850	8340	0.43
97.1	3030	8490	0.43
98.8	2980	8690	0.43
100.4	3050	8960	0.43
102.1	2810	8290	0.43
103.7	2800	8340	0.44
105.3	2670	8100	0.44
107.0	2640	7920	0.44
108.6	2710	8010	0.44
110.3	2550	8010	0.44
111.9	2540	7790	0.44
113.5	2480	7970	0.45
115.2	2360	7840	0.45
116.8	2490	7710	0.44
118.5	2360	7670	0.45
120.1	2310	7710	0.45
121.7	2370	7550	0.45
123.4	2410	7630	0.44
125.0	2360	7350	0.44
126.7	2340	7240	0.44
128.3	2310	7350	0.45
129.9	2280	7350	0.45

Metric Units			
Depth at Midpoint Between Source and Near Receiver	Velocity		Poisson's Ratio
	V_s	V_p	
(m)	(m/s)	(m/s)	
21.6	390	1930	0.48
22.1	360	1970	0.48
22.6	400	1940	0.48
23.1	420	1990	0.48
23.6	480	2070	0.47
24.1	550	2140	0.46
24.6	580	2290	0.47
25.1	590	2290	0.46
25.6	650	2320	0.46
26.1	700	2320	0.45
26.6	690	2390	0.45
27.1	730	2390	0.45
27.6	730	2430	0.45
27.6	730	2440	0.45
27.6	730	2410	0.45
28.1	760	2430	0.45
28.6	820	2510	0.44
29.1	870	2540	0.43
29.6	920	2590	0.43
30.1	910	2650	0.43
30.6	930	2730	0.43
31.1	860	2530	0.43
31.6	850	2540	0.44
32.1	810	2470	0.44
32.6	800	2410	0.44
33.1	820	2440	0.44
33.6	780	2440	0.44
34.1	770	2380	0.44
34.6	760	2430	0.45
35.1	720	2390	0.45
35.6	760	2350	0.44
36.1	720	2340	0.45
36.6	700	2350	0.45
37.1	720	2300	0.45
37.6	740	2320	0.44
38.1	720	2240	0.44
38.6	710	2210	0.44
39.1	700	2240	0.45
39.6	700	2240	0.45

TABLE 2 (cont.)
Summary of Compressional Wave Velocity, Shear Wave Velocity, and Poisson's Ratio Based on Source-to-Receiver Travel Time Data - Borehole B-2, Clinton NPP

American Units			
Depth at Midpoint Between Source and Near Receiver	Velocity		Poisson's Ratio
	V_s	V_p	
(ft)	(ft/s)	(ft/s)	
131.6	2310	7430	0.45
133.2	2310	7390	0.45
134.9	2310	7390	0.45
136.5	2280	7630	0.45
138.1	2170	7280	0.45
139.8	2310	7240	0.44
141.4	2410	7510	0.44
143.1	2370	7710	0.45
144.7	2400	7670	0.45
146.4	2390	7670	0.45
148.0	2430	7670	0.44
149.6	2430	7630	0.44
151.3	2440	7710	0.44
152.9	2410	8010	0.45
154.6	2440	7550	0.44
156.2	2450	7710	0.44
157.8	2430	7630	0.44
159.5	2400	7510	0.44
161.1	2080	7510	0.46
162.8	1910	6930	0.46
164.4	1640	6670	0.47
166.0	1550	6290	0.47
167.7	1420	6290	0.47
169.3	1420	6290	0.47
171.0	1530	6400	0.47
172.6	1570	6580	0.47
174.2	1600	6670	0.47
175.9	1600	6760	0.47
177.5	1580	6490	0.47
179.2	1610	6460	0.47
180.8	1730	6760	0.47
182.4	1960	7000	0.46
184.1	2140	7170	0.45
185.7	2420	7550	0.44
187.4	2700	7670	0.43
189.0	2660	7970	0.44
190.6	2720	7670	0.43
192.3	2630	7710	0.43
193.9	2520	7510	0.44

Metric Units			
Depth at Midpoint Between Source and Near Receiver	Velocity		Poisson's Ratio
	V_s	V_p	
(m)	(m/s)	(m/s)	
40.1	700	2260	0.45
40.6	700	2250	0.45
41.1	700	2250	0.45
41.6	700	2320	0.45
42.1	660	2220	0.45
42.6	700	2210	0.44
43.1	730	2290	0.44
43.6	720	2350	0.45
44.1	730	2340	0.45
44.6	730	2340	0.45
45.1	740	2340	0.44
45.6	740	2320	0.44
46.1	740	2350	0.44
46.6	730	2440	0.45
47.1	740	2300	0.44
47.6	750	2350	0.44
48.1	740	2320	0.44
48.6	730	2290	0.44
49.1	630	2290	0.46
49.6	580	2110	0.46
50.1	500	2030	0.47
50.6	470	1920	0.47
51.1	430	1920	0.47
51.6	430	1920	0.47
52.1	470	1950	0.47
52.6	480	2000	0.47
53.1	490	2030	0.47
53.6	490	2060	0.47
54.1	480	1980	0.47
54.6	490	1970	0.47
55.1	530	2060	0.47
55.6	600	2130	0.46
56.1	650	2190	0.45
56.6	740	2300	0.44
57.1	820	2340	0.43
57.6	810	2430	0.44
58.1	830	2340	0.43
58.6	800	2350	0.43
59.1	770	2290	0.44

TABLE 2 (cont.)
Summary of Compressional Wave Velocity, Shear Wave Velocity, and Poisson's Ratio Based on Source-to-Receiver Travel Time Data - Borehole B-2, Clinton NPP

American Units				Metric Units			
Depth at Midpoint Between Source and Near Receiver	Velocity		Poisson's Ratio	Depth at Midpoint Between Source and Near Receiver	Velocity		Poisson's Ratio
	V_s	V_p			V_s	V_p	
(ft)	(ft/s)	(ft/s)		(m)	(m/s)	(m/s)	
195.6	2410	7630	0.44	59.6	730	2320	0.44
197.2	2410	7510	0.44	60.1	730	2290	0.44
198.8	2460	7510	0.44	60.6	750	2290	0.44
200.5	2480	7630	0.44	61.1	760	2320	0.44
202.1	2500	7430	0.44	61.6	760	2260	0.44
203.8	2280	7130	0.44	62.1	690	2170	0.44
205.4	2120	7030	0.45	62.6	650	2140	0.45
207.0	2040	7030	0.45	63.1	620	2140	0.45
208.7	2010	6930	0.45	63.6	610	2110	0.45
210.3	2010	6930	0.45	64.1	610	2110	0.45
212.0	2150	7030	0.45	64.6	660	2140	0.45
213.6	2240	7130	0.45	65.1	680	2170	0.45
215.2	2290	6930	0.44	65.6	700	2110	0.44
216.9	2220	6930	0.44	66.1	680	2110	0.44
218.5	2120	6800	0.45	66.6	650	2070	0.45
220.2	2080	6610	0.44	67.1	630	2010	0.44
221.8	2000	6490	0.45	67.6	610	1980	0.45
223.5	1940	6700	0.45	68.1	590	2040	0.45
225.1	1880	6610	0.46	68.6	570	2010	0.46
226.7	1930	6700	0.45	69.1	590	2040	0.45
228.4	1950	6700	0.45	69.6	590	2040	0.45
230.0	1960	6670	0.45	70.1	600	2030	0.45
231.7	1930	6610	0.45	70.6	590	2010	0.45
233.3	2010	6800	0.45	71.1	610	2070	0.45
234.9	2050	6800	0.45	71.6	620	2070	0.45
236.6	2010	6700	0.45	72.1	610	2040	0.45
238.2	1980	6610	0.45	72.6	600	2010	0.45
239.9	1900	6490	0.45	73.1	580	1980	0.45
241.5	1770	6290	0.46	73.6	540	1920	0.46
243.1	1790	6290	0.46	74.1	550	1920	0.46
244.8	1880	6370	0.45	74.6	570	1940	0.45
246.4	1760	6520	0.46	75.1	540	1990	0.46
248.1	1900	6490	0.45	75.6	580	1980	0.45
249.7	2030	6610	0.45	76.1	620	2010	0.45
251.3	2100	6700	0.45	76.6	640	2040	0.45
253.0	2270	7100	0.44	77.1	690	2160	0.44
254.6	2490	7430	0.44	77.6	760	2260	0.44
256.3	2210	7170	0.45	78.1	670	2190	0.45
257.9	1990	6760	0.45	78.6	610	2060	0.45

TABLE 2 (cont.)
Summary of Compressional Wave Velocity, Shear Wave Velocity, and Poisson's Ratio Based on Source-to-Receiver Travel Time Data - Borehole B-2, Clinton NPP

American Units				Metric Units			
Depth at Midpoint Between Source and Near Receiver	Velocity		Poisson's Ratio	Depth at Midpoint Between Source and Near Receiver	Velocity		Poisson's Ratio
	V_s	V_p			V_s	V_p	
(ft)	(ft/s)	(ft/s)		(m)	(m/s)	(m/s)	
259.5	2030	6800	0.45	79.1	620	2070	0.45
261.2	1860	6490	0.45	79.6	570	1980	0.45
262.8	1890	6830	0.46	80.1	580	2080	0.46
264.5	1870	6760	0.46	80.6	570	2060	0.46
266.1	1780	6700	0.46	81.1	540	2040	0.46
267.7	1720	6460	0.46	81.6	520	1970	0.46
269.4	1640	6000	0.46	82.1	500	1830	0.46
271.0	1610	5830	0.46	82.6	490	1780	0.46
272.7	1560	5690	0.46	83.1	470	1730	0.46
274.3	1440	5670	0.47	83.6	440	1730	0.47
275.9	1390	5980	0.47	84.1	420	1820	0.47
277.6	1420	6180	0.47	84.6	430	1880	0.47
279.2	1450	6400	0.47	85.1	440	1950	0.47
280.9	1680	6830	0.47	85.6	510	2080	0.47
282.5	2040	6930	0.45	86.1	620	2110	0.45
284.1	2290	6930	0.44	86.6	700	2110	0.44
285.8	2540	7350	0.43	87.1	770	2240	0.43
287.4	2820	7350	0.41	87.6	860	2240	0.41
289.1	2910	7630	0.41	88.1	890	2320	0.41
290.7	2910	7590	0.41	88.6	890	2310	0.41
292.3	2980	7750	0.41	89.1	910	2360	0.41
294.0	3060	8390	0.42	89.6	930	2560	0.42
295.6	3160	8540	0.42	90.1	960	2600	0.42
297.3	3400	8490	0.40	90.6	1040	2590	0.40
298.9	3430	8640	0.41	91.1	1050	2630	0.41
300.6	3480	8490	0.40	91.6	1060	2590	0.40
302.2	3730	8390	0.38	92.1	1140	2560	0.38
303.8	3640	7970	0.37	92.6	1110	2430	0.37
305.5	3660	8190	0.38	93.1	1120	2500	0.38
307.1	3940	8060	0.34	93.6	1200	2460	0.34
308.8	3900	8100	0.35	94.1	1190	2470	0.35
310.4	3850	8190	0.36	94.6	1170	2500	0.36
312.0	3920	8290	0.36	95.1	1190	2530	0.36
313.7	3960	8290	0.35	95.6	1210	2530	0.35
315.3	3590	8190	0.38	96.1	1090	2500	0.38

EXHIBIT A

PROCEDURE FOR
OYO P-S SUSPENSION SEISMIC
VELOCITY LOGGING

PROCEDURE FOR

OYO P-S SUSPENSION SEISMIC VELOCITY LOGGING

Background

This procedure describes a method for measuring shear and compressional wave velocities in soil and rock. The OYO P-S Suspension Method is applied by generating shear and compressional waves in a borehole using the OYO P-S Suspension Logger borehole tool and measuring the travel time between two receiver geophones or hydrophones located in the same tool.

Objective

The outcome of this procedure is a plot and table of P and S_H wave velocity versus depth for each borehole. Standard analysis is performed on receiver to receiver data. Data is presented in report format, with ASCII data files and digital records transmitted on diskette.

Instrumentation

1. OYO Model 170 Digital Logging Recorder or equivalent
2. OYO P-S Suspension Logger probe, including two sets horizontal and vertical geophones, seismic source, and power supply for the source and receivers
3. Winch and winch controller, with logging cable
4. Batteries to operate OYO 170 and winch

The Model 170 Suspension P-S Logging system, manufactured by OYO Corporation, is currently the only commercially available suspension system. As shown in Figure 1, the System consists of a borehole probe suspended by a cable and a recording/control electronics package on the surface.

The suspension system probe consists of a combined reversible polarity solenoid horizontal shear-wave generator (S_H) and compressional-wave generator (P), joined to two biaxial geophones by a flexible isolation cylinder. The separation of the two geophones is one meter, allowing average wave velocity in the region between the

geophones to be determined by inversion of the wave travel time between the two geophones. The total length of the probe is approximately 7 meters; the center point of the geophones is approximately 5 meters above the bottom end of the probe.

The probe receives control signals from, and sends the amplified geophone signals to, the instrumentation package on the surface via an armored 7 conductor cable. The cable is wound onto the drum of a winch and is used to support the probe. Cable travel is measured by a rotary encoder to provide probe depth data.

The entire probe is suspended by the cable and centered in the borehole by nylon "whiskers." Therefore, source motion is not coupled directly to the borehole walls; rather, the source motion creates a horizontally propagating pressure wave in the fluid filling the borehole and surrounding the source. This pressure wave produces a horizontal displacement of the soil forming the wall of the borehole. This displacement propagates up and down the borehole wall, in turn causing a pressure wave to be generated in the fluid surrounding the geophones as the soil displacement wave passes their location.

Environmental Conditions

The OYO P-S Suspension Logging Method can be used in either cased or uncased boreholes. For best results, the borehole must be between 10 and 20 cm in diameter, or 4 to 8 inches.

Uncased boreholes are preferred because the effects of the casing and grouting are removed. It is recommended that the borehole be drilled using the rotary mud method. This method does little damage to the borehole wall, and the drilling fluid coats and seals the borehole wall reducing fluid loss and wall collapse. The borehole fluid is required for the logging, and must be well circulated prior to logging.

If the borehole must be cased, the casing must be PVC and properly installed and grouted. Any voids in the grout will cause problems with the data. Likewise, large grout bulbs used to fill cavities will also cause problems. The grout must be set before testing. This means the grouting must take place at least 48 hours before testing.

For borehole casing, applicable preparation procedures are presented in ASTM Standard D4428/D4428M-91 Section 4.1 (see ASTM website for copy).

Calibration

Calibration of the Model 170 digital recorder is required. Calibration is limited to the timing accuracy of the recorder. GEOVision's Seismograph Calibration Procedure or equivalent should be used. Calibration must be performed on an annual basis.

Measurement Procedure

The entire probe is lowered into the borehole to a specific measurement depth by the winch. A measurement sequence is then initiated by the operator from the instrumentation package control panel. No further operator intervention is then needed to complete the measurement sequence described below.

The system electronics activates the SH-wave source in one direction and records the output of the two horizontally oriented geophone axes which are situated parallel to the axis of motion of the source. The source is then activated in the opposite direction, and the horizontal output signals are again recorded, producing a SH-wave record of polarity opposite to the previous record. The source is finally actuated in the first direction again, and the responses of the vertical geophone axes to the resultant P-wave are recorded during this sampling.

The data from each geophone during each source activation is recorded as a different channel on the recording system. The Model 170 has six channels (two simultaneous recording channels), each with a 12 bit 1024 sample record. The recorded data is displayed on a CRT display and on paper tape output as six channels with a common time scale. Data is stored on 3.5-inch floppy diskettes for further processing. Up to 8 sampling sequences can be stacked (averaged) to improve the signal to noise ratio of the signals.

Review of the displayed data on the CRT or paper tape allows the operator to set the gains, filters, delay time, pulse length (energy), sample rate, and stacking number in order to optimize the quality of the data before recording. Final printed data is verified by the operator prior to moving the probe.

Typical depth spacing for measurements is 1.0 meters, or 3.3 feet. Alternative spacing is 0.5 meter, or 1.6 feet.

Required Field Records

1) Field log for each borehole showing
    a) Borehole identification
    b) Date of test
    c) Tester or data recorder
    d) Description of measurement
    e) Any deviations from test plan and action taken as a result
    f) QA Review

2) Paper output records for each measurement as backup showing depth and ID number

3) List of record ID numbers (for data on diskette) and corresponding depth

4) Diskettes with backup copies of data on hard disk, labeled with borehole designation, record ID numbers, date, and tester name.

An example Field Log is attached to this procedure.

Analysis

Following completion of field work, the recorded digital records are processed by computer using the OYO Corporation software program PSLOG and interactively analyzed by an experienced geophysicist to produce plots and tables of P and S_H wave velocity versus depth.

The digital time series records from each depth are transferred to a personal computer for analysis. Figure 2 shows a sample of the data from a single depth. These digital records are analyzed to locate the first minima on the vertical axis records, indicating the arrival of P-wave energy. The difference in travel time between these arrivals is used to calculate the P-wave velocity for that 1-meter interval. When observable, P-wave arrivals on the horizontal axis records are used to verify the velocities determined from the vertical axis data. In addition, the soil velocity calculated from the travel time from source to first receiver is compared to the velocity derived from the travel time between receivers.

The digital records are studied to establish the presence of clear SH-wave pulses, as indicated by the presence of opposite polarity pulses on each pair of horizontal records. Ideally, the SH-wave signals from the 'normal' and 'reverse' source pulses are very nearly inverted images of each other. Digital FFT – IFFT lowpass filtering are used to remove the higher frequency P-wave signal from the SH-wave signal.

The first maxima are picked for the 'normal' signals and the first minima are picked for the 'reverse' signals. The absolute arrival time of the 'normal' and 'reverse' signals may vary by +/- 0.2 milliseconds, due to differences in actuation time of the solenoid source caused by constant mechanical bias in the source or by borehole inclination. This variation does not affect the velocity determinations, as the differential time is measured between arrivals of waves created by the same source actuation. The final velocity value is the average of the values obtained from the 'normal' and 'reverse' source actuations.

In Figure 2, the time difference over the 1-meter interval of 1.70 millisecond is equivalent to a SH-wave velocity of 588 m/sec. Whenever possible, time differences are determined from several phase points on the S_H -wave pulse trains to verify the data obtained from the first arrival of the S_H -wave pulse. In addition, the soil velocity

calculated from the travel time from source to first receiver is compared to the velocity derived from the travel time between receivers.

Figure 3 is a sample composite plot of the far normal horizontal geophone records for a range of depths. This plot shows the waveforms at each depth, clearly showing the S-wave arrivals. This display format is used during analysis to observe trends in velocity with changing depth.

Once the proper picks are entered, PSLOG automatically calculates both V_s and V_p for each depth. The program allows spreadsheet output for presentation in either charts or tables or both.

Standard analysis is performed on receiver 1 to receiver 2 data, with separate analysis performed on source to receiver data as a quality assurance procedure.

Registered Geophysicist______________________________Date 6/20/00

QA Review______________________________Date 6/20/00

References:

1. Guidelines for Determining Design Basis Ground Motions, Report TR-102293, Electric Power Research Institute, Palo Alto, California, November 1993, Sections 7 and 8.

2. The P-S Velocity Logging Method, R.L. Nigbor and T. Imai, XIII ICSMFE, 1994, New Delhi, India / XIII CIMSTF, 1994, New Delhi, India

3. "Standard test Methods for Crosshole Seismic Testing", ASTM Standard D4428/D4428M-91, July 1991, Philadelphia, PA

OYO SUSPENSION P-S VELOCITY LOGGING SETUP

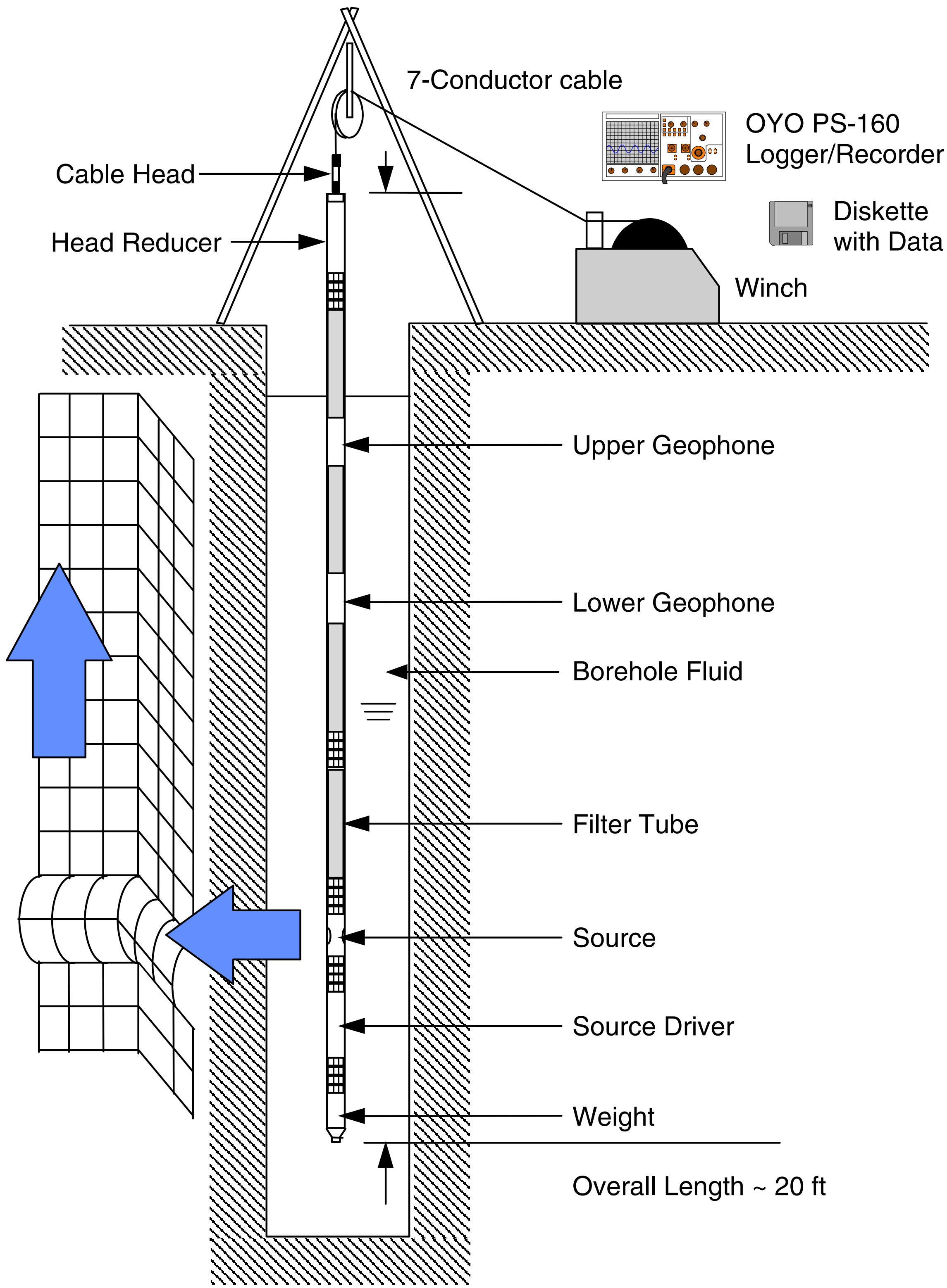


Figure 1. Suspension PS logging method setup

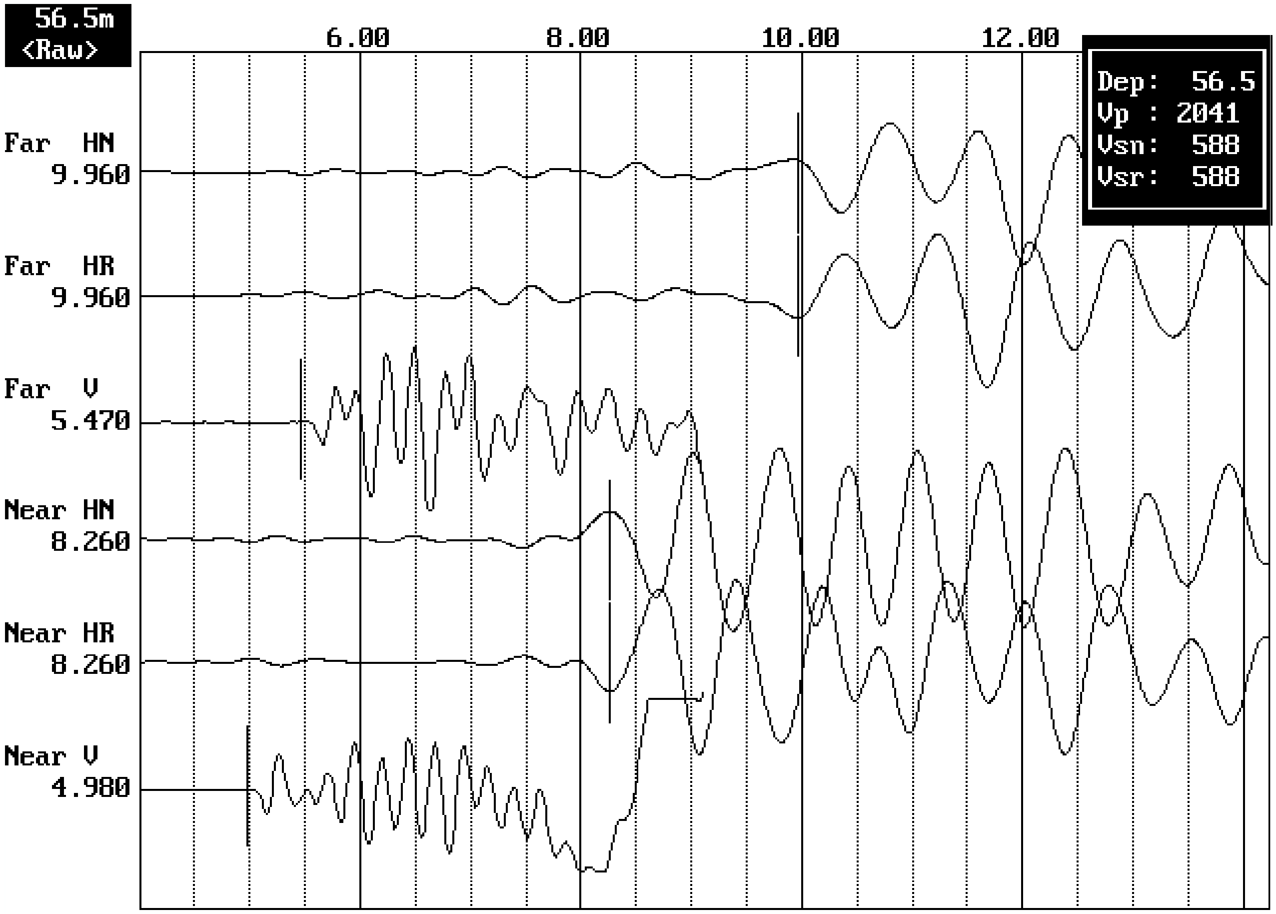


Figure 2. Sample suspension method waveform data showing horizontal normal and reversed (HR and HN), and vertical (V) waveforms received at the near (bottom 3 channels) and far (top 3 channels) geophones. The arrivals in milliseconds for each pick are shown on the left. The box in the upper right corner shows the depth in the borehole and the velocities calculated based on the picks.

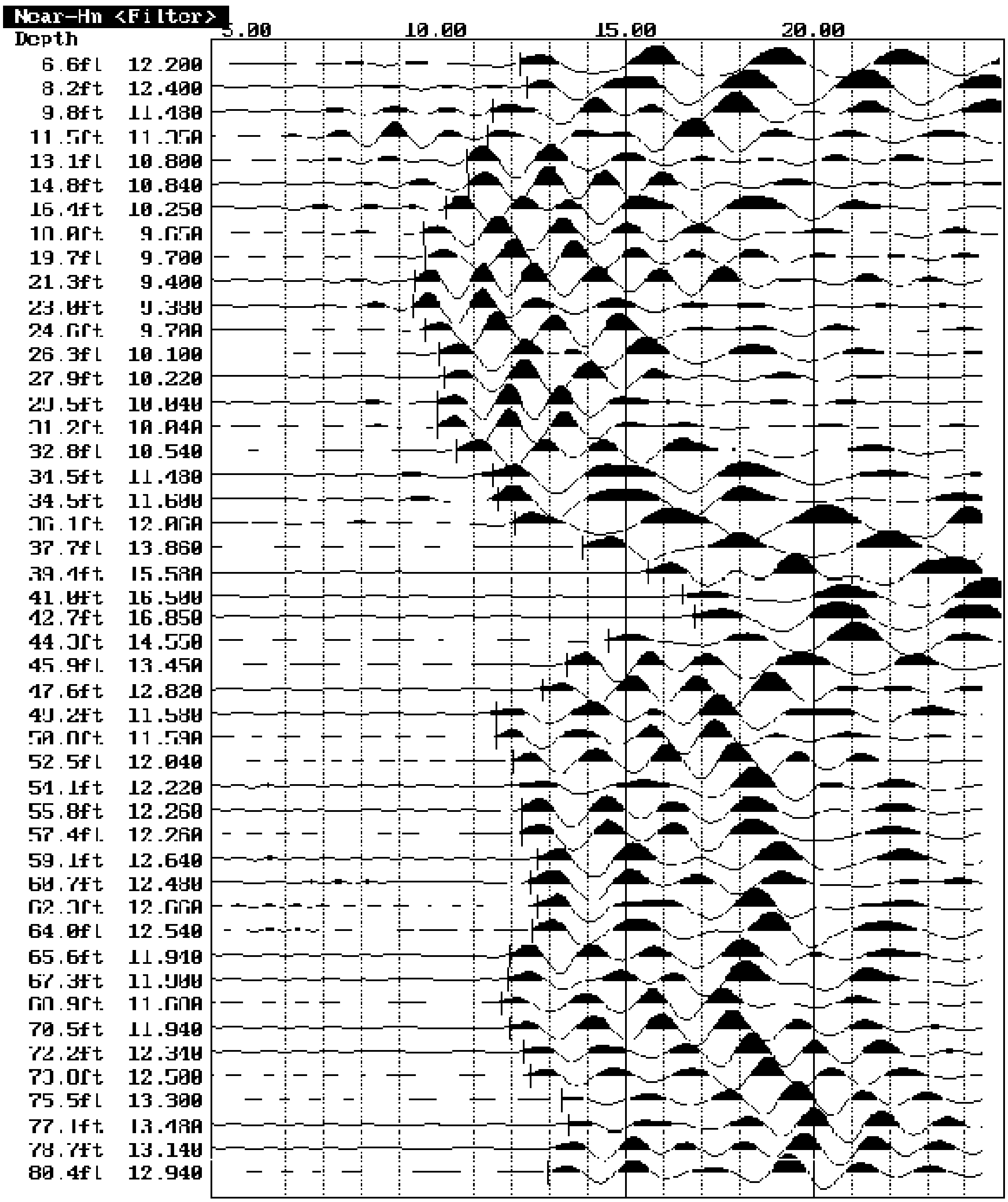


Figure 3. Sample composite waveform plot for normal shear waves received at the near geophone in a single borehole

EXHIBIT B

OYO 170 VELOCITY LOGGING SYSTEM

NIST TRACEABLE CALIBRATION PROCEDURE AND CALIBRATION RECORDS

CALIBRATION PROCEDURE FOR

GEOVision SEISMIC RECORDER/LOGGER

Reviewed 02/16/1999

Objective

The timing/sampling accuracy of seismic recorders or data loggers is required for several GEOVision field procedures including Seismic Refraction, Downhole Seismic Velocity Logging, and P-S Suspension Logging. This procedure describes the method for measuring the timing accuracy of a seismic data logger, such as the OYO Model 170 or the Geometrics Strataview. The objective of this procedure is to verify that the timing accuracy of the recorder is accurate to within 1%.

Frequency of Calibration

The calibration of each GEOVision seismic data logger is twelve (12) months. In the case of rented seismic data loggers, calibration must be performed prior to use.

Test Equipment Required

The following equipment is required. Item #2 must have current NIST traceable calibration.

1. Function generator, Krohn Hite 5400B or equivalent
2. Frequency counter, HP 5315A or equivalent
3. Test cables, from item 1 to item 2, and from item 1 to subject data logger.

Procedure

This procedure is designed to be performed using the accompanying Seismograph Calibration Data Sheet with the same revision number. All data must be entered and the procedure signed by the technician performing the test.

1. Record all identification data on the form provided.
2. Connect function generator to data logger (such as OYO Model 170) using test cable
3. Connect the function generator to the frequency counter using test cable.

4. Set up generator to produce a 100.0 Hz, 0.25 volt (amplitude is approximate, modify as necessary to yield less than full scale waveforms on logger display) peak square wave or sine wave. Verify frequency using the counter and initial space on the data sheet.
5. Initialize data logger and record a data record of at least 0.1 second using a 100 microsecond sample period.
6. Measure the recorded square wave frequency by measuring the duration of 9 cycles of data. This measurement can be made using the data logger display device, or by printing out a paper tape. If a paper tape can be printed, the resulting printout must be attached to this procedure. Record the data in the space provided.
7. Repeat steps 5 and 6 three more times using separate files.

Criteria

The duration for 9 cycles in any file must be 90.0 milliseconds plus or minus 0.9 milliseconds, corresponding to an average frequency for the nine cycles of 100.0 Hz plus or minus 1 Hz (obtained by dividing 9 cycles by the duration in milliseconds).

If the results are outside this range, the data logger must be marked with a GEOVision REJECT tag until it can be repaired and retested.

If results are acceptable affix label indicating the initials of the person performing the calibration, the date of calibration, and the due date for the next calibration (12 months).

Procedure Approval

Approved by:

JOHN G. DIEHL	VP
Name	Title
[signature]	2/16/99
Signature	Date

Client Approval (if required):

Name	Title
Signature	Date

GEOVision
geophysical services
a division of Blackhawk GeoServices

SEISMOGRAPH CALIBRATION DATA SHEET REV 7/11/02

INSTRUMENT DATA

SYSTEM MFR: OYO
SERIAL NO.: 19029
BY: R. STELLER

MODEL NO.: 3331 A
CALIBRATION DATE: 7/11/02
DUE DATE: 7/11/03

COUNTER MFR: TENMA
SERIAL NO.: MB0000 6378
BY: MICROPRECISION CAL

MODEL NO.: 72-5085
CALIBRATION DATE: 2/25/02
DUE DATE: 2/25/03

FCTN GEN MFR: TENMA
SERIAL NO.: MB0000 6378
BY: MICROPRECISION CAL

MODEL NO.: 72-5085
CALIBRATION DATE: 2/25/02
DUE DATE: 2/25/03

SYSTEM SETTINGS:

GAIN: 10
FILTER: 20 KHZ
RANGE: 100 MSEC
DELAY: 0
STACK: 1 (STD) 1
PULSE: 1.6 MSEC
DISPLAY: VARIABLE
SYSTEM: DATE = CORRECT DATE & TIME 7/11/02 1:15 PM

PROCEDURE:

SET FREQUENCY TO 100.0HZ SQUAREWAVE WITH AMPLITUDE APPROXIMATELY 0.25 VOLT PEAK. RECORD BOTH ON DISKETTE AND PAPER TAPE. ANALYZE AND PRINT WAVEFORMS FROM ANALYSIS UTILITY. ATTACH PAPER COPIES OF PRINTOUT AND PAPER TAPES TO THIS FORM. AVERAGE FREQUENCY MUST BE BETWEEN 99.0 AND 101.0 HZ.

AS FOUND 100.0 AS LEFT 100.0

WAVEFORM	FILE NO	FREQUENCY	TIME FOR 9 CYCLES Hn	TIME FOR 9 CYCLES Hr	TIME FOR 9 CYCLES V	AVERAGE FREQ.
SQUARE	001	100.0	90.0	90.0	90.0	100.0
SQUARE	002	100.0	90.0	90.0	90.0	100.0
SINE	003	100.0	90.0	90.1	90.0	100.0
SINE	004	100.0	90.0	90.0	90.1	100.0

CALIBRATED BY: ROBERT STELLER 7/11/02 [signature]
NAME DATE SIGNATURE

REV2

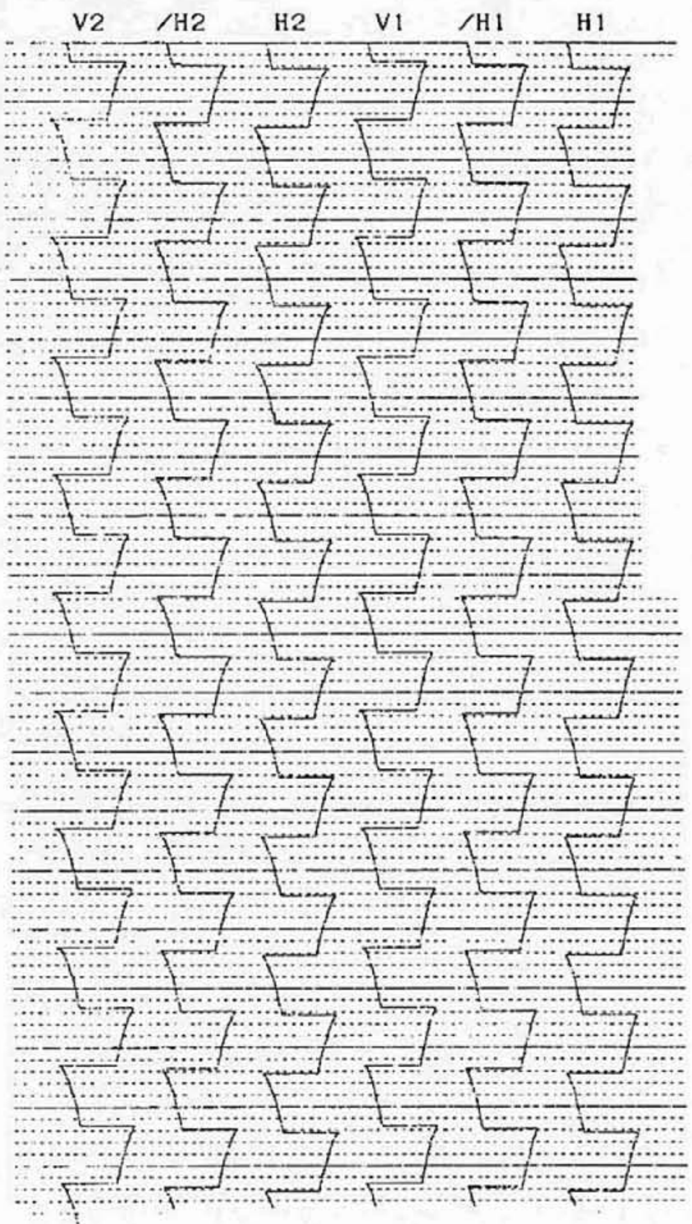
Suspension 170 4.25

S/N 19029

ID_NO. : 001
HOLE NO. : 0
DEPTH : 0.0 [m]
DATE : 11/07/02 01:16:04 PM
H-SAMPLE RATE: 100 [μSEC]
V-SAMPLE RATE: 100 [μSEC]
PULSE WIDTH : 1.6 [mSEC]
DELAY TIME : 0 [mSEC]

	H1	/H1	V1	H2	/H2	V2
GAIN	:X 10	X 10	X 10	X 10	X 10	X 10
LCF [Hz]	: 5	5	5	5	5	5
HCF [Hz]	: 20K	20K	20K	20K	20K	20K
STACK	: 1	1	1	1	1	1

TRACE SIZE : 1
H-TIME SCALE: 1.00 [mSEC/LINE]
V-TIME SCALE: 1.00 [mSEC/LINE]



C

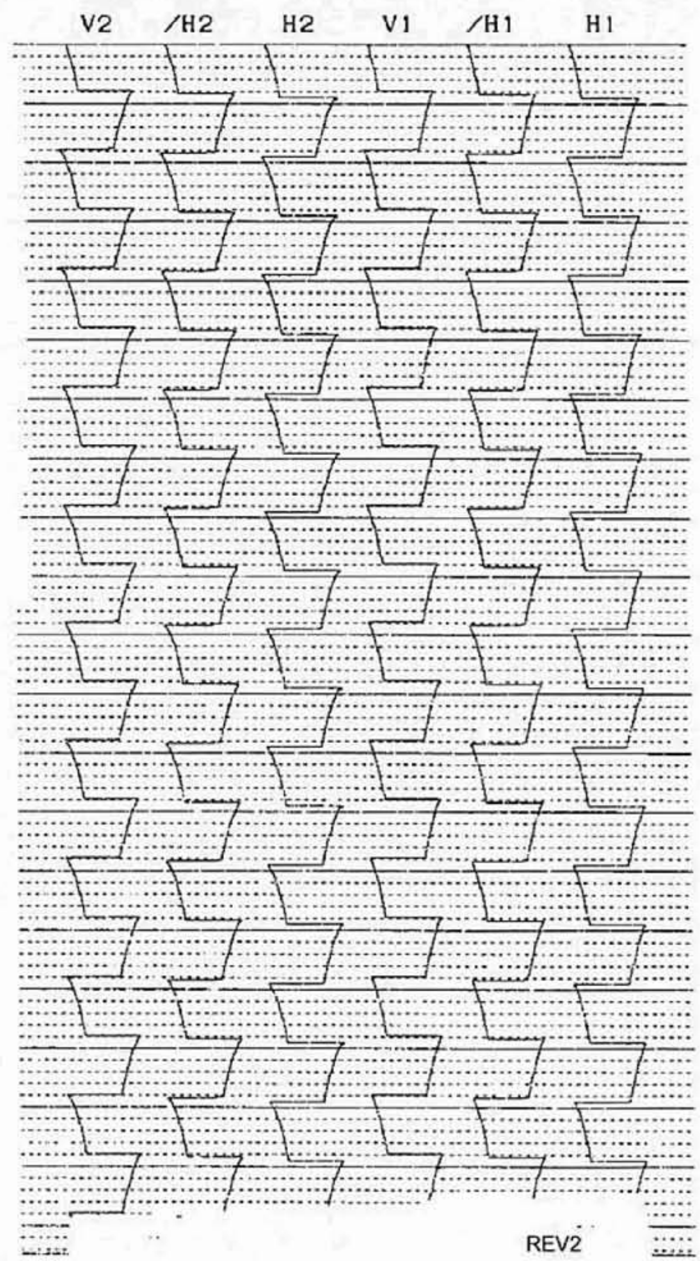
Suspension 170 4.25

S/N 19029

ID_NO. : 002
HOLE NO. : 0
DEPTH : 0.0 [m]
DATE : 11/07/02 01:16:54 PM
H-SAMPLE RATE: 100 [μSEC]
V-SAMPLE RATE: 100 [μSEC]
PULSE WIDTH : 1.6 [mSEC]
DELAY TIME : 0 [mSEC]

	H1	/H1	V1	H2	/H2	V2
GAIN	:X 10	X 10	X 10	X 10	X 10	X 10
LCF [Hz]	: 5	5	5	5	5	5
HCF [Hz]	: 20K	20K	20K	20K	20K	20K
STACK	: 1	1	1	1	1	1

TRACE SIZE : 1
H-TIME SCALE: 1.00 [mSEC/LINE]
V-TIME SCALE: 1.00 [mSEC/LINE]



REV2

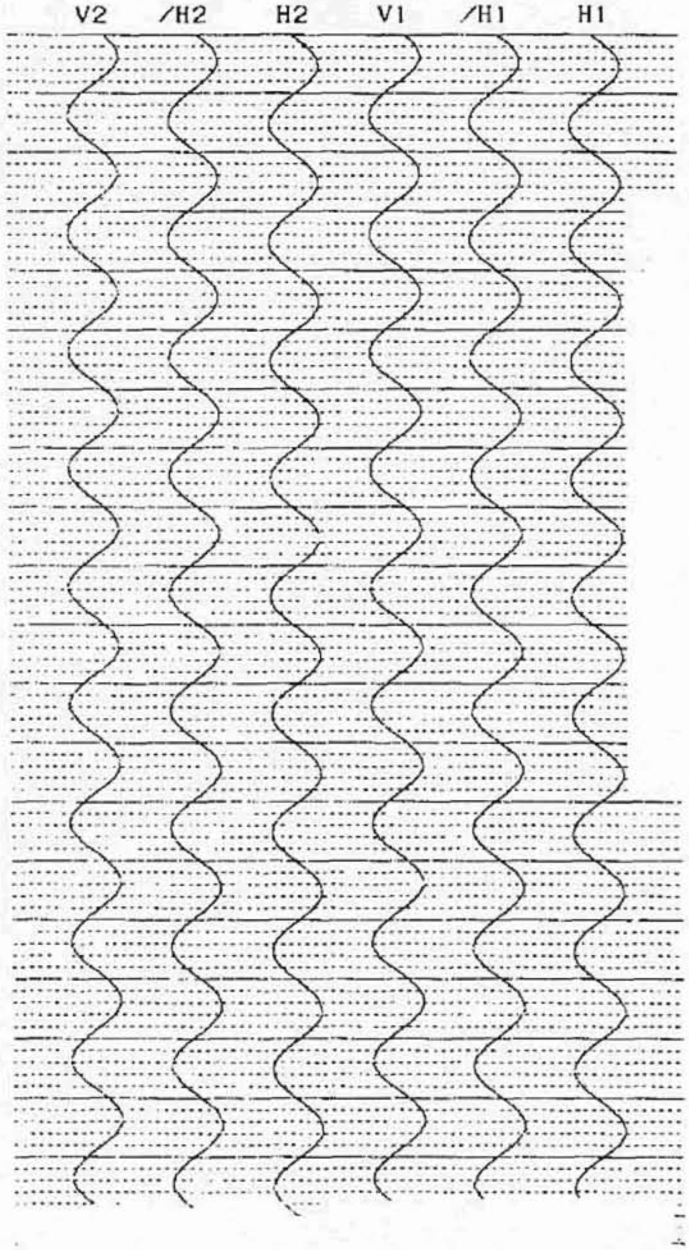
Suspension 110 4.25

ID_NO.   : 003   S/N 19029
HOLE NO.   :   0
DEPTH   :   0.0 [m]
DATE   : 11/07/02 01:17:47 PM
H-SAMPLE RATE: 100 [µSEC]
V-SAMPLE RATE: 100 [µSEC]
PULSE WIDTH   : 1.6 [mSEC]
DELAY TIME   :   0 [mSEC]

	H1	/H1	V1	H2	/H2	V2
GAIN	:X 10	X 10	X 10	X 10	X 10	X 10
LCF [Hz]	: 5	5	5	5	5	5
HCF [Hz]	: 20K	20K	20K	20K	20K	20K
STACK	: 1	1	1	1	1	1

TRACE SIZE   : 1
H-TIME SCALE: 1.00 [mSEC/LINE]
V-TIME SCALE: 1.00 [mSEC/LINE]

V2   /H2   H2   V1   /H1   H1



C

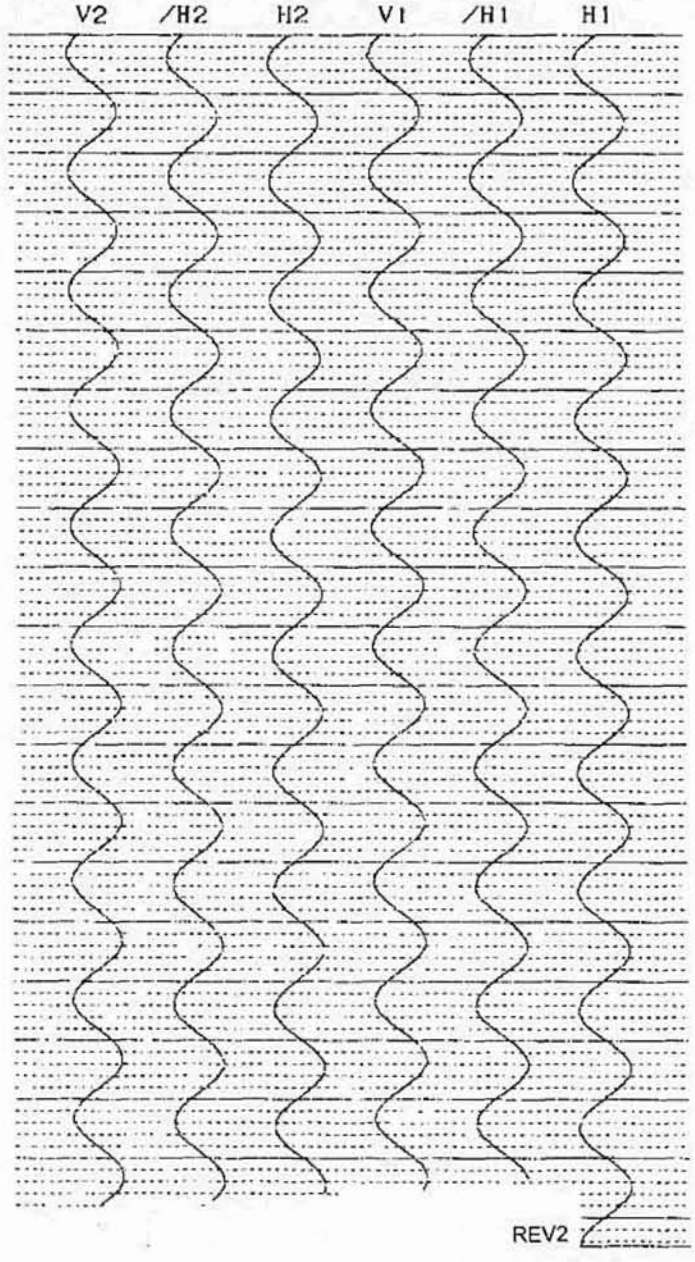
Suspension 110 4.25

ID_NO.   : 004   S/N 19029
HOLE NO.   :   0
DEPTH   :   0.0 [m]
DATE   : 11/07/02 01:18:15 PM
H-SAMPLE RATE: 100 [µSEC]
V-SAMPLE RATE: 100 [µSEC]
PULSE WIDTH   : 1.6 [mSEC]
DELAY TIME   :   0 [mSEC]

	H1	/H1	V1	H2	/H2	V2
GAIN	:X 10	X 10	X 10	X 10	X 10	X 10
LCF [Hz]	: 5	5	5	5	5	5
HCF [Hz]	: 20K	20K	20K	20K	20K	20K
STACK	: 1	1	1	1	1	1

TRACE SIZE   : 1
H-TIME SCALE: 1.00 [mSEC/LINE]
V-TIME SCALE: 1.00 [mSEC/LINE]

V2   /H2   H2   V1   /H1   H1



REV2

MICRO PRECISION CALIBRATION INC.
11562 Knott Street, Ste. 3, Garden Grove, CA 92841
Ph. 714-901-5659 Fax: 714-901-5649

Calibration Report

Customer: GEOVISION Corona CA 92882

Account: 15214

Instrument: BB9414 Digital Universal Test Center

Mfg: Tenma	Model: 72-5085	Serial #: MB00006378
Size:	Resltn:	Location:

Cust Ctrl:	Dept:	P.O.: 2236-020220-2
Job Number: L16939	Report Number: 115406	Report Date: 022502

Work Performed: Inspected, cleaned, and calibrated. Page 1 of 1

Parts Replaced: None

Received Condition: In tolerance Returned Condition: In tolerance

Function Tested	
Multimeter	Function Generator cont'
AC/DC Volts & Current	Amplitude
Resistance & Capacitance	Sine wave distortion& flatness
Power Supply	Square wave symmetry, rise & fall time
Voltage	Triangle wave linearity
Current	TTL rise & fall time, output level
Ripple	
Frequency Counter	
Frequency range & Accuracy	
Input Sensitivity	
Function Generator	
Frequency	

Ctrl #	Manufacture, Model #, & Description of standards used for calibration	Due Date	Traceability
L8100	L8100 Wavetek 4800A Multifunction Calibr	031202	35951031201
L1600	L1600 Hewlett Packard 34401A Multimeter	040502	97906
T1100	T1100 Hewlett Packard 53131A Counter	060402	100795
P5300	P5300 Tektronix THS710 Oscilloscope w/DMM	022003	114723
X4350	X4350 Hewlett Packard 8903A Audio Analyzer	053102	99604

Services provided conform to ANSI/NCSL Z540-1-1994 (Formerly Mil-Std 45662A) and ISO 10012-1:1992
All work performed complies with MPC Quality System QM 540-94, Rev 1e.

Environmental: 72 Deg F / 42% Rh

Uncertainty: Accuracy Ratio > 4:1

Cal Procedure: Manufacture Man

Technician: ERIC BRADLEY

Test Date: 022502

Cycle: 12

Due Date: 022503

Quality Approval: QC 3

Form Cert 2-25-02 REV2

GEOVision
geophysical services
a division of Blackhawk GeoServices

SEISMOGRAPH CALIBRATION DATA SHEET REV 7/11/02

INSTRUMENT DATA

SYSTEM MFR: OYO — MODEL NO.: 3331 A
SERIAL NO.: 19029 — CALIBRATION DATE: 9/4/02
BY: R. STELLER — DUE DATE: 9/4/03

COUNTER MFR: TENMA — MODEL NO.: 72 - 5085
SERIAL NO.: MB0000 6378 — CALIBRATION DATE: 2/25/02
BY: MICROPRECISION CAL — DUE DATE: 2/25/03

FCTN GEN MFR: TENMA — MODEL NO.: 72 - 5085
SERIAL NO.: MB0000 6378 — CALIBRATION DATE: 2/25/02
BY: MICROPRECISION CAL — DUE DATE: 2/25/03

SYSTEM SETTINGS:

GAIN: 10
FILTER: 20 KHz
RANGE: 100 MSEC
DELAY: 0
STACK: 1 (STD) 1
PULSE: 1.6 MSEC
DISPLAY: VARIABLE
SYSTEM: DATE = CORRECT DATE & TIME 9/4/02 11:54 AM

PROCEDURE:

SET FREQUENCY TO 100.0HZ SQUAREWAVE WITH AMPLITUDE APPROXIMATELY 0.25 VOLT PEAK. RECORD BOTH ON DISKETTE AND PAPER TAPE. ANALYZE AND PRINT WAVEFORMS FROM ANALYSIS UTILITY. ATTACH PAPER COPIES OF PRINTOUT AND PAPER TAPES TO THIS FORM. AVERAGE FREQUENCY MUST BE BETWEEN 99.0 AND 101.0 HZ.

AS FOUND 100.0 — AS LEFT 100.0

WAVEFORM	FILE NO	FREQUENCY	TIME FOR 9 CYCLES Hn	TIME FOR 9 CYCLES Hr	TIME FOR 9 CYCLES V	AVERAGE FREQ.
SQUARE	201	100.0	90.0	90.0	90.0	100.0
SQUARE	202	100.0	90.0	90.0	90.0	100.0
SINE	203	100.0	90.0	90.0	90.0	100.0
SINE	204	100.0	90.0	90.0	90.1	100.0

CALIBRATED BY: ROBERT STELLER (NAME) 9/4/02 (DATE) [signature] (SIGNATURE)

REV2

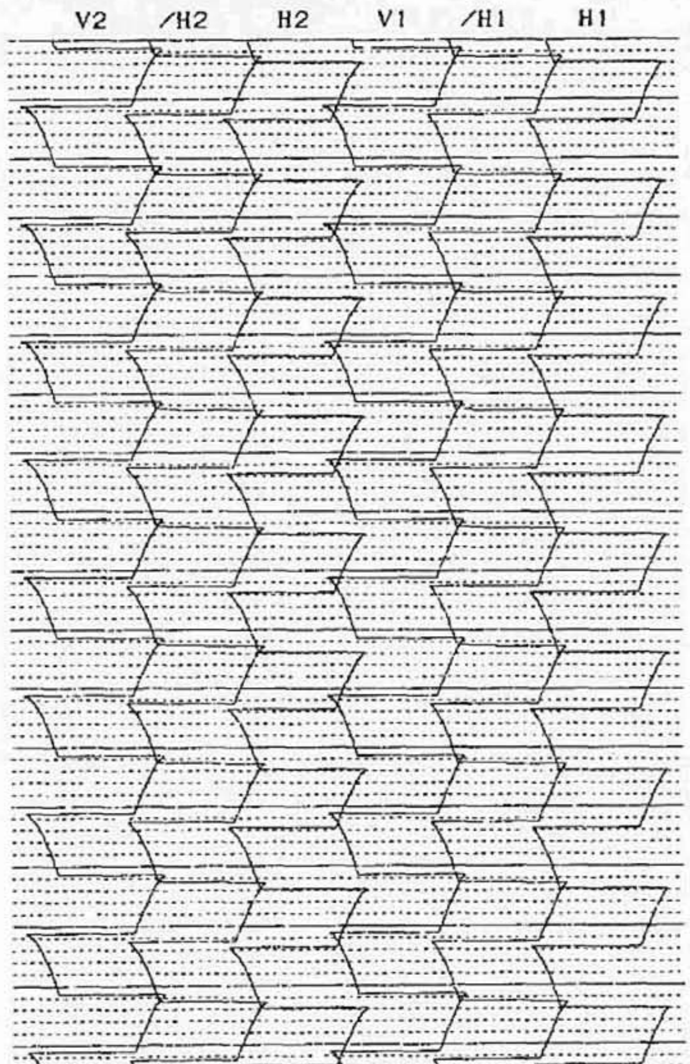
C

Suspension 170 4.25

ID_NO. : 201 S/N 19029
HOLE NO. : 0
DEPTH : 0.0 [m]
DATE : 04/09/02 11:56:57 AM
H-SAMPLE RATE: 100 [μSEC]
V-SAMPLE RATE: 100 [μSEC]
PULSE WIDTH : 1.6 [mSEC]
DELAY TIME : 0 [mSEC]

		H1	/H1	V1	H2	/H2	V2
GAIN	:	X 10	X 10	X 10	X 10	X 10	X 10
LCF [Hz]	:	5	5	5	5	5	5
HCF [Hz]	:	20K	20K	20K	20K	20K	20K
STACK	:	1	1	1	1	1	1

TRACE SIZE : 1
H-TIME SCALE: 1.00 [mSEC/LINE]
V-TIME SCALE: 1.00 [mSEC/LINE]



REV2

OYO

Suspension 1.. ..

ID_NO. : 202 S/N 19029

HOLE NO. : 0

DEPTH : 0.0 [m]

DATE : 04/09/02 11:57:32 AM

H-SAMPLE RATE: 100 [μSEC]

V-SAMPLE RATE: 100 [μSEC]

PULSE WIDTH : 1.6 [mSEC]

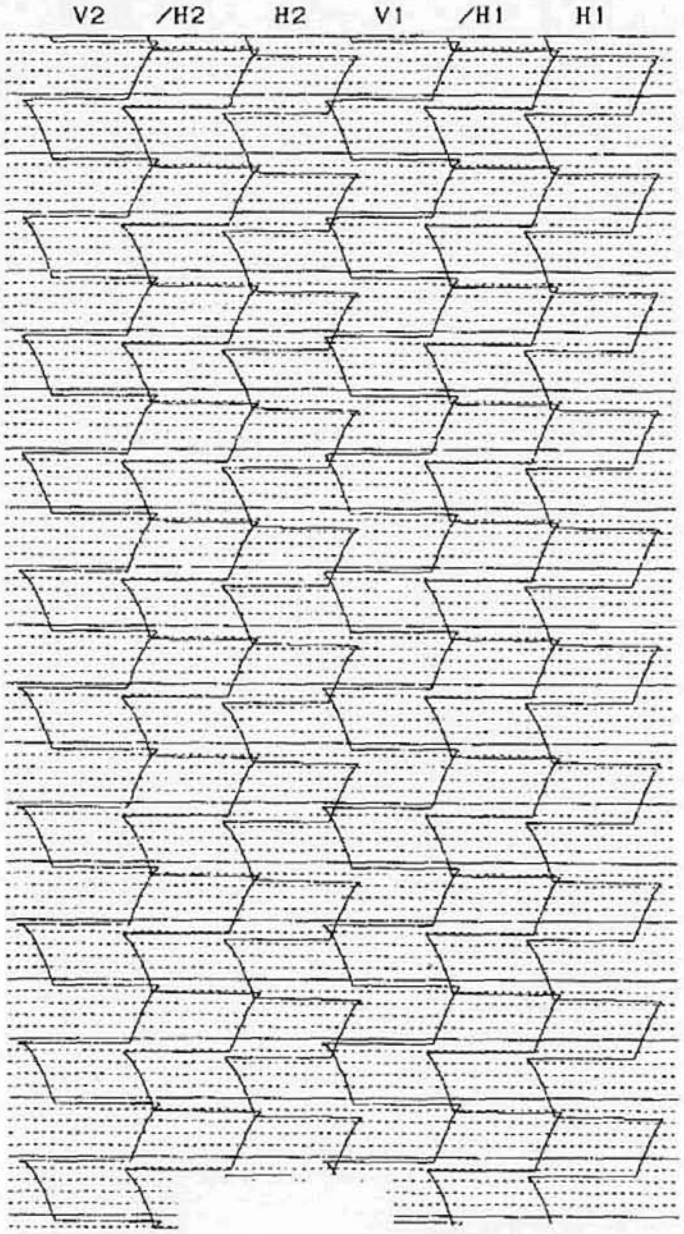
DELAY TIME : 0 [mSEC]

	H1	/H1	V1	H2	/H2	V2
GAIN	:X 10	X 10	X 10	X 10	X 10	X 10
LCF[Hz]	: 5	5	5	5	5	5
HCF[Hz]	: 20K	20K	20K	20K	20K	20K
STACK	: 1	1	1	1	1	1

TRACE SIZE : 1

H-TIME SCALE: 1.00 [mSEC/LINE]

V-TIME SCALE: 1.00 [mSEC/LINE]



REV2

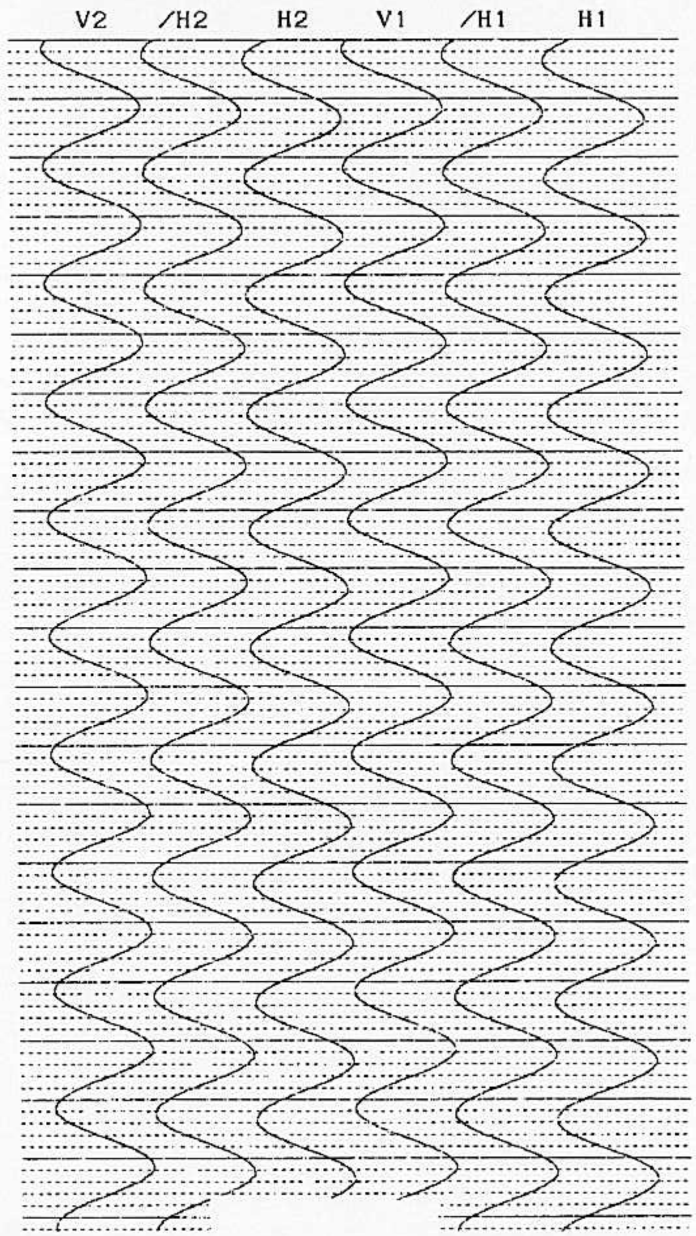
OYO

Suspension I/U 4.25

ID_NO. : 203 S/N 19029
HOLE NO. : 0
DEPTH : 0.0 [m]
DATE : 04/09/02 11:58:54 AM
H-SAMPLE RATE: 100 [μSEC]
V-SAMPLE RATE: 100 [μSEC]
PULSE WIDTH : 1.6 [mSEC]
DELAY TIME : 0 [mSEC]

	H1	/H1	V1	H2	/H2	V2
GAIN :	X 10	X 10	X 10	X 10	X 10	X 10
LCF [Hz] :	5	5	5	5	5	5
HCF [Hz] :	20K	20K	20K	20K	20K	20K
STACK :	1	1	1	1	1	1

TRACE SIZE : 1
H-TIME SCALE: 1.00 [mSEC/LINE]
V-TIME SCALE: 1.00 [mSEC/LINE]



REV2

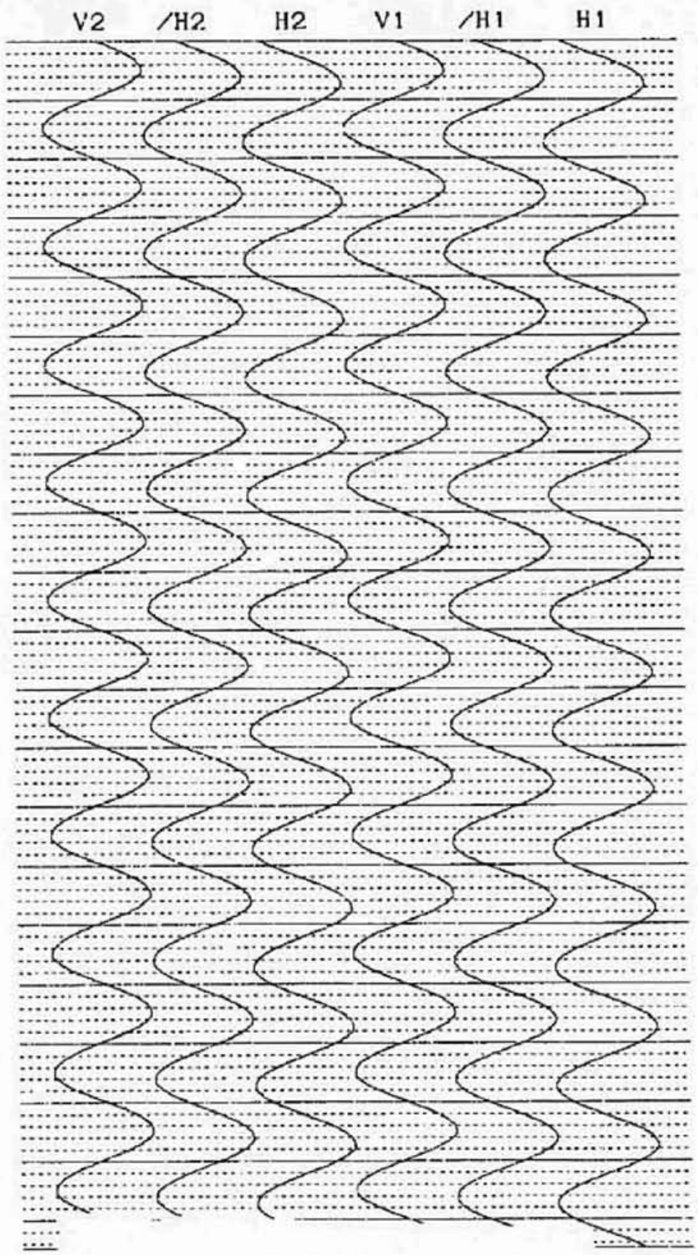
OYO

Suspension : .

ID_NO. : 204 S/N 19029
HOLE NO. : 0
DEPTH : 0.0 [m]
DATE : 04/09/02 11:59:24 AM
H-SAMPLE RATE: 100 [μSEC]
V-SAMPLE RATE: 100 [μSEC]
PULSE WIDTH : 1.6 [mSEC]
DELAY TIME : 0 [mSEC]

	H1	/H1	V1	H2	/H2	V2
GAIN	X 10	X 10	X 10	X 10	X 10	X 10
LCF [Hz]	5	5	5	5	5	5
HCF [Hz]	20K	20K	20K	20K	20K	20K
STACK	1	1	1	1	1	1

TRACE SIZE : 1
H-TIME SCALE: 1.00 [mSEC/LINE]
V-TIME SCALE: 1.00 [mSEC/LINE]



REV2