

# **APPENDIX F**

## **BORING GEOPHYSICAL LOGGING FIELD MEASUREMENT PROCEDURES**

## 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 or equivalent, 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 P-S Logger and winch

The Suspension P-S Logger system, manufactured by OYO Corporation, or the Robertson Digital P-S Suspension Probe with the Robertson Micrologger2 are currently the only commercially available suspension logging systems. As shown in Figure 1, these systems 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 4 or 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 may be 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 uncased borehole must be between 10 and 20 cm in diameter, or 4 to 8 inches. A cased borehole may be as small as 3 inches, if properly grouted (see below) and the grout annulus does not exceed 1 inch.

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 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 seismograph has at least six channels (two simultaneous recording channels), each with at least a 12 bit 1024 sample record. Newer seismographs may have longer record lengths. The recorded data is displayed on a CRT or LCD display and possibly on paper tape output as six channels with a common time scale. Data is stored on digital media 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 data on the display 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. In the case of the Model 170, printed data is verified by the operator prior to moving the probe. In the case of the Robertson Micrologger2, storage on the hard disk should be verified from time-to-time, certainly before exiting the borehole.

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 are no longer required, since the Micrologger2 cannot generate them. However, data must be stored in at least 2 places prior to leaving the site
  - 3) List of record ID numbers (for data on digital media) and corresponding depth
  - 4) Diskettes, CDROM, or USB flash drives 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 in PSLOG, the picks are transferred to an Excel spreadsheet where Vs and Vp are calculated. The spreadsheet allows output for presentation in charts and tables.

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 Antony Mart Date 4/10/06

QA Review [Signature] Date 4/10/06

References:

1. "In Situ P and S Wave Velocity Measurement", Ohya, S. 1986. Proceedings of In-Situ '86, *Use of In-Situ Tests In Geotechnical Engineering*, an ASCE Specialty Conference sponsored by the Geotechnical Engineering Division of ASCE and co-sponsored by the Civil Engineering Dept of Virginia Tech.
2. Guidelines for Determining Design Basis Ground Motions, Report TR-102293, Electric Power Research Institute, Palo Alto, California, November 1993, Sections 7 and 8.
3. "Standard test Methods for Crosshole Seismic Testing", ASTM Standard D4428/D4428M-91, July 1991, Philadelphia, PA

## OYO SUSPENSION P-S VELOCITY LOGGING SETUP

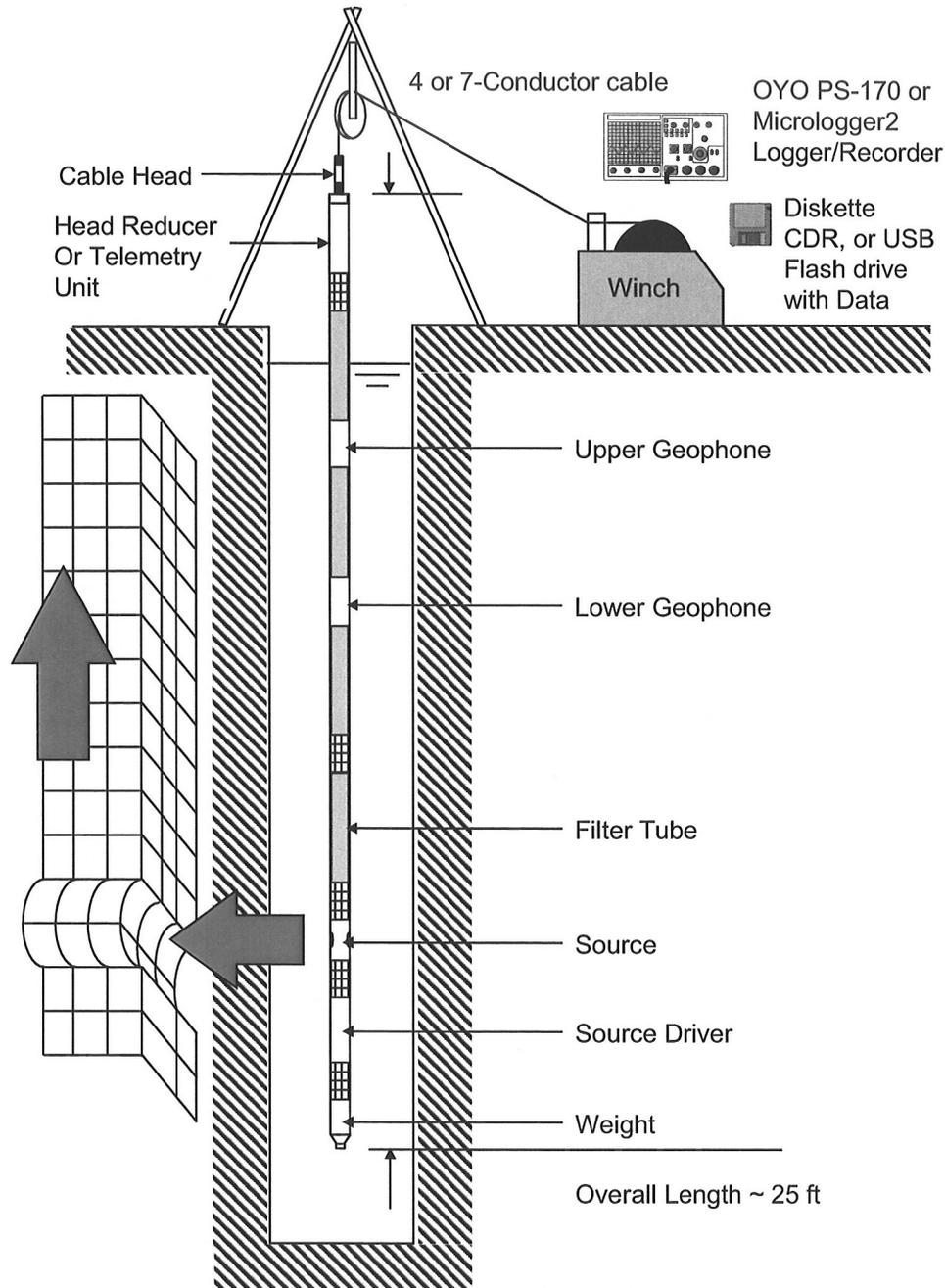


Figure 1. Suspension PS logging method setup

	Procedure for OYO P-S Suspension Seismic Velocity Logging	
	Rev 1.3 4/06/06	Page 6

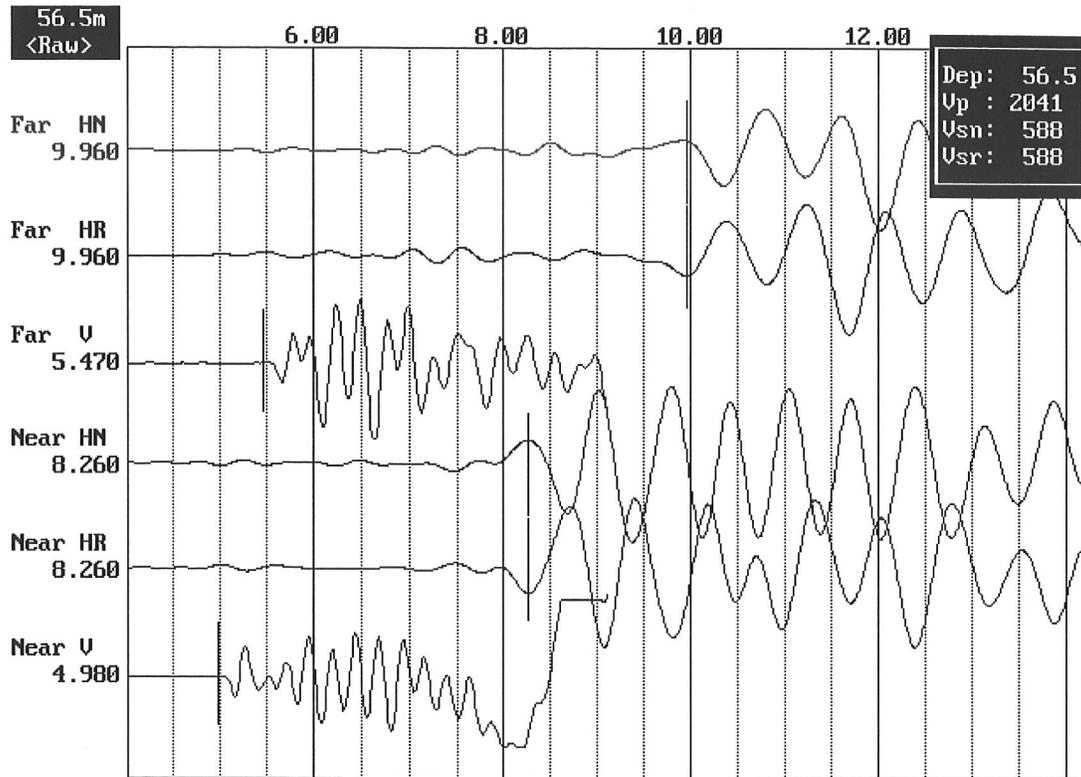


Figure 2. Sample suspension method waveform data showing horizontal normal and reversed (HR and HN), and vertical (V) waveforms received at the near (bottom 3 channels) and far (top 3 channels) geophones. The arrivals in milliseconds for each pick are shown on the left. The box in the upper right corner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

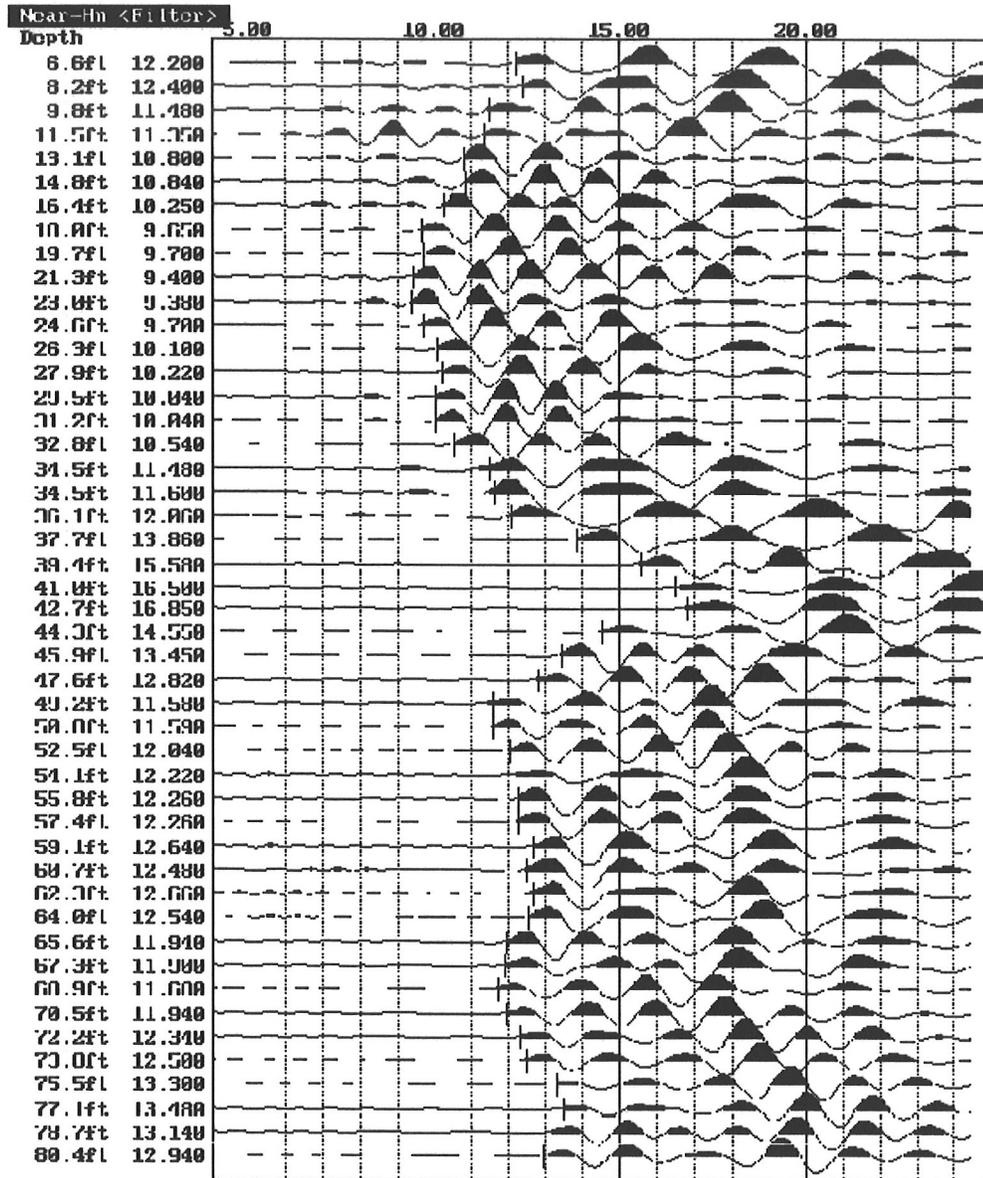


Figure 3. Sample composite waveform plot for normal shear waves received at the near geophone in a single borehole



## P-S SUSPENSION VELOCITY FIELD LOG

SITE: \_\_\_\_\_ DATE: \_\_\_\_\_

CLIENT: \_\_\_\_\_ JOB: \_\_\_\_\_

AUTHOR: \_\_\_\_\_ PAGE 1 OF \_\_\_\_\_

CONTACT: \_\_\_\_\_ OFFICE PHONE: \_\_\_\_\_

PHONE: \_\_\_\_\_

CONTACT: \_\_\_\_\_ OFFICE PHONE: \_\_\_\_\_

PHONE: \_\_\_\_\_

CONTACT: \_\_\_\_\_ PHONE: \_\_\_\_\_

PHONE: \_\_\_\_\_

CONTACT: \_\_\_\_\_ PHONE: \_\_\_\_\_

PHONE: \_\_\_\_\_

DRILLER: \_\_\_\_\_ PHONE: \_\_\_\_\_

COMPANY: \_\_\_\_\_ PHONE: \_\_\_\_\_

DIRECTIONS TO SITE: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

GENERAL SITE CONDITIONS/LOCATION: \_\_\_\_\_  
\_\_\_\_\_

EA#: \_\_\_\_\_  
BOREHOLE DESIGNATION: \_\_\_\_\_ LOCATION: \_\_\_\_\_

COUNTY: \_\_\_\_\_ RANGE: \_\_\_\_\_ TOWNSHIP: \_\_\_\_\_ SECTION: \_\_\_\_\_

BOREHOLE CONSTRUCTION: CASED \_\_\_\_\_ UNCASSED \_\_\_\_\_

DIAMETERS AND DEPTH RANGES: \_\_\_\_\_ 0 TO \_\_\_\_\_; \_\_\_\_\_, \_\_\_\_\_ TO \_\_\_\_\_

BOREHOLE TOTAL DEPTH AS DRILLED: \_\_\_\_\_

CONDUCTOR CASING?: YES \_\_\_\_\_ DEPTH TO BOTTOM OF CASING \_\_\_\_\_; NO \_\_\_\_\_

DEPTH TO BEDROCK: \_\_\_\_\_ DEPTH TO WATER TABLE: \_\_\_\_\_

BOREHOLE FLUID: WATER \_\_\_\_\_; FRESH WATER MUD \_\_\_\_\_; SALT WATER MUD \_\_\_\_\_;

OTHER: \_\_\_\_\_

DEPTH TO BOREHOLE FLUID: \_\_\_\_\_ TIME SINCE LAST CIRCULATION: \_\_\_\_\_



SITE: \_\_\_\_\_ DATE: \_\_\_\_\_  
CLIENT: \_\_\_\_\_ JOB: \_\_\_\_\_  
AUTHOR: \_\_\_\_\_ PAGE 2 OF \_\_\_\_\_

LOGGING CREW: \_\_\_\_\_  
VEHICLE(S) USED AND MILEAGE: \_\_\_\_\_  
MOBILIZED FROM: \_\_\_\_\_ DEPARTURE TIME: \_\_\_\_\_  
ARRIVED ON SITE: \_\_\_\_\_  
STANDBY TIME: \_\_\_\_\_ CAUSE: \_\_\_\_\_  
LOGGING STARTED: \_\_\_\_\_ LOGGING COMPLETED: \_\_\_\_\_  
STANDBY TIME: \_\_\_\_\_ CAUSE: \_\_\_\_\_  
LOGGING STARTED: \_\_\_\_\_ LOGGING COMPLETED: \_\_\_\_\_  
DEMOBILIZED TO: \_\_\_\_\_ ARRIVAL TIME: \_\_\_\_\_  
ADDITIONAL DEMOB TIME: \_\_\_\_\_ REASON: \_\_\_\_\_

BATTERIES CHANGED BEFORE LOGGING: YES \_\_\_\_\_; NO \_\_\_\_\_; STORED WITH NEW \_\_\_\_\_  
WINCH                      COMPROBE                       GREY                       OYO                       RG                       OTH   
INSTRUMENT              OYO 12004               15014               19029                       RG 160023               160024   
RECEIVER S/N              12008               20042               26066               11001               23053

MAINTENANCE PERFORMED ON SITE: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

EQUIPMENT PROBLEMS OR FAILURES: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

SUGGESTIONS, ADDITIONS, CHANGES: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

COMMENTS: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

## GEOVISION SUSPENSION LOGGING FIELD NOTES

SITE: \_\_\_\_\_ DATE: \_\_\_\_\_  
 CLIENT: \_\_\_\_\_ JOB: \_\_\_\_\_  
 AUTHOR: \_\_\_\_\_ PAGE \_\_\_\_\_ OF \_\_\_\_\_

DEPTH METERS	DEPTH FEET	UNFILTERED FILE NO.	FILTERED FILE NO.	COMMENTS CASING, WATER, ROCK, ETC
0.5	1.64			
1.0	3.28			
1.5	4.92			
2.0	6.56			
2.5	8.20			
3.0	9.84			
3.5	11.48			
4.0	13.12			
4.5	14.76			
5.0	16.40			
5.5	18.04			
6.0	19.69			
6.5	21.33			
7.0	22.97			
7.5	24.61			
8.0	26.25			
8.5	27.89			
9.0	29.53			
9.5	31.17			
10.0	32.81			
10.5	34.45			
11.0	36.09			
11.5	37.73			
12.0	39.37			
12.5	41.01			
13.0	42.65			
13.5	44.29			
14.0	45.93			
14.5	47.57			
15.0	49.21			
15.5	50.85			
16.0	52.49			
16.5	54.13			
17.0	55.77			
17.5	57.41			
18.0	59.06			

## GEOVISION SUSPENSION LOGGING FIELD NOTES

SITE: \_\_\_\_\_ DATE: \_\_\_\_\_  
 CLIENT: \_\_\_\_\_ JOB: \_\_\_\_\_  
 AUTHOR: \_\_\_\_\_ PAGE \_\_\_\_\_ OF \_\_\_\_\_

DEPTH METERS	DEPTH FEET	UNFILTERED FILE NO.	FILTERED FILE NO.	COMMENTS CASING, WATER, ROCK, ETC
18.5	60.70			
19.0	62.34			
19.5	63.98			
20.0	65.62			
20.5	67.26			
21.0	68.90			
21.5	70.54			
22.0	72.18			
22.5	73.82			
23.0	75.46			
23.5	77.10			
24.0	78.74			
24.5	80.38			
25.0	82.02			
25.5	83.66			
26.0	85.30			
26.5	86.94			
27.0	88.58			
27.5	90.22			
28.0	91.86			
28.5	93.50			
29.0	95.14			
29.5	96.78			
30.0	98.43			
30.5	100.07			
31.0	101.71			
31.5	103.35			
32.0	104.99			
32.5	106.63			
33.0	108.27			
33.5	109.91			
34.0	111.55			
34.5	113.19			
35.0	114.83			
35.5	116.47			
36.0	118.11			

## GEOVISION SUSPENSION LOGGING FIELD NOTES

SITE: \_\_\_\_\_ DATE: \_\_\_\_\_  
 CLIENT: \_\_\_\_\_ JOB: \_\_\_\_\_  
 AUTHOR: \_\_\_\_\_ PAGE \_\_\_\_\_ OF \_\_\_\_\_

DEPTH METERS	DEPTH FEET	UNFILTERED FILE NO.	FILTERED FILE NO.	COMMENTS CASING, WATER, ROCK, ETC
36.5	119.75			
37.0	121.39			
37.5	123.03			
38.0	124.67			
38.5	126.31			
39.0	127.95			
39.5	129.59			
40.0	131.23			
40.5	132.87			
41.0	134.51			
41.5	136.15			
42.0	137.80			
42.5	139.44			
43.0	141.08			
43.5	142.72			
44.0	144.36			
44.5	146.00			
45.0	147.64			
45.5	149.28			
46.0	150.92			
46.5	152.56			
47.0	154.20			
47.5	155.84			
48.0	157.48			
48.5	159.12			
49.0	160.76			
49.5	162.40			
50.0	164.04			
50.5	165.68			
51.0	167.32			
51.5	168.96			
52.0	170.60			
52.5	172.24			
53.0	173.88			
53.5	175.52			
54.0	177.17			

## GEOVISION SUSPENSION LOGGING FIELD NOTES

SITE: \_\_\_\_\_ DATE: \_\_\_\_\_  
 CLIENT: \_\_\_\_\_ JOB: \_\_\_\_\_  
 AUTHOR: \_\_\_\_\_ PAGE \_\_\_\_\_ OF \_\_\_\_\_

DEPTH METERS	DEPTH FEET	UNFILTERED FILE NO.	FILTERED FILE NO.	COMMENTS CASING, WATER, ROCK, ETC
54.5	178.81			
55.0	180.45			
55.5	182.09			
56.0	183.73			
56.5	185.37			
57.0	187.01			
57.5	188.65			
58.0	190.29			
58.5	191.93			
59.0	193.57			
59.5	195.21			
60.0	196.85			
60.5	198.49			
61.0	200.13			
61.5	201.77			
62.0	203.41			
62.5	205.05			
63.0	206.69			
63.5	208.33			
64.0	209.97			
64.5	211.61			
65.0	213.25			
65.5	214.90			
66.0	216.54			
66.5	218.18			
67.0	219.82			
67.5	221.46			
68.0	223.10			
68.5	224.74			
69.0	226.38			
69.5	228.02			
70.0	229.66			
70.5	231.30			
71.0	232.94			
71.5	234.58			
72.0	236.22			

## GEOVISION SUSPENSION LOGGING FIELD NOTES

SITE: \_\_\_\_\_ DATE: \_\_\_\_\_  
 CLIENT: \_\_\_\_\_ JOB: \_\_\_\_\_  
 AUTHOR: \_\_\_\_\_ PAGE \_\_\_\_\_ OF \_\_\_\_\_

DEPTH METERS	DEPTH FEET	UNFILTERED FILE NO.	FILTERED FILE NO.	COMMENTS CASING, WATER, ROCK, ETC
72.5	237.86			
73.0	239.50			
73.5	241.14			
74.0	242.78			
74.5	244.42			
75.0	246.06			
75.5	247.70			
76.0	249.34			
76.5	250.98			
77.0	252.62			
77.5	254.27			
78.0	255.91			
78.5	257.55			
79.0	259.19			
79.5	260.83			
80.0	262.47			
80.5	264.11			
81.0	265.75			
81.5	267.39			
82.0	269.03			
82.5	270.67			
83.0	272.31			
83.5	273.95			
84.0	275.59			
84.5	277.23			
85.0	278.87			
85.5	280.51			
86.0	282.15			
86.5	283.79			
87.0	285.43			
87.5	287.07			
88.0	288.71			
88.5	290.35			
89.0	291.99			
89.5	293.64			
90.0	295.28			

## GEOVISION SUSPENSION LOGGING FIELD NOTES

SITE: \_\_\_\_\_ DATE: \_\_\_\_\_  
 CLIENT: \_\_\_\_\_ JOB: \_\_\_\_\_  
 AUTHOR: \_\_\_\_\_ PAGE \_\_\_\_\_ OF \_\_\_\_\_

DEPTH METERS	DEPTH FEET	UNFILTERED FILE NO.	FILTERED FILE NO.	COMMENTS CASING, WATER, ROCK, ETC
90.5	296.92			
91.0	298.56			
91.5	300.20			
92.0	301.84			
92.5	303.48			
93.0	305.12			
93.5	306.76			
94.0	308.40			
94.5	310.04			
95.0	311.68			
95.5	313.32			
96.0	314.96			
96.5	316.60			
97.0	318.24			
97.5	319.88			
98.0	321.52			
98.5	323.16			
99.0	324.80			
99.5	326.44			
100.0	328.08			
100.5	329.72			
101.0	331.36			
101.5	333.01			
102.0	334.65			
102.5	336.29			
103.0	337.93			
103.5	339.57			
104.0	341.21			
104.5	342.85			
105.0	344.49			
105.5	346.13			
106.0	347.77			
106.5	349.41			
107.0	351.05			
107.5	352.69			
108.0	354.33			

## GEOVISION SUSPENSION LOGGING FIELD NOTES

SITE: \_\_\_\_\_ DATE: \_\_\_\_\_  
 CLIENT: \_\_\_\_\_ JOB: \_\_\_\_\_  
 AUTHOR: \_\_\_\_\_ PAGE \_\_\_\_\_ OF \_\_\_\_\_

DEPTH METERS	DEPTH FEET	UNFILTERED FILE NO.	FILTERED FILE NO.	COMMENTS CASING, WATER, ROCK, ETC
108.5	355.97			
109.0	357.61			
109.5	359.25			
110.0	360.89			
110.5	362.53			
111.0	364.17			
111.5	365.81			
112.0	367.45			
112.5	369.09			
113.0	370.73			
113.5	372.38			
114.0	374.02			
114.5	375.66			
115.0	377.30			
115.5	378.94			
116.0	380.58			
116.5	382.22			
117.0	383.86			
117.5	385.50			
118.0	387.14			
118.5	388.78			
119.0	390.42			
119.5	392.06			
120.0	393.70			
120.5	395.34			
121.0	396.98			
121.5	398.62			
122.0	400.26			
122.5	401.90			
123.0	403.54			
123.5	405.18			
124.0	406.82			
124.5	408.46			
125.0	410.10			
125.5	411.75			
126.0	413.39			