Report No. UT-03.18

DOWNHOLE SEISMIC ARRAY AT THE INTERSECTION OF I-15, I-80 AND SR-201, SALT LAKE CITY, UTAH

Prepared For:

Utah Department of Transportation Research and Development Division

Submitted By:

Brigham Young University
Department of Civil and Environmental Engineering

Authored By:

T. Leslie, Youd
David H. Briggs

2003

THIS PAGE LEFT BLANK INTENTIONALLY

UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

1. Report No. **UT-03.18**	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle: **Downhole Seismic Array at the Intersection of I-15, I-80 and SR-201, Salt Lake City, Utah**	**5. Report Date** **June 30, 2003**	
	6. Performing Organization Code	
7. Author(s) **T. Leslie Youd** **David H. Briggs**	**8. Performing Organization Report No.**	
9. Performing Organization Name and Address **Brigham Young University** **Department of Civil and Environmental Engineering** **Provo, Utah 84602**	**10. Work Unit No.**	
	11. Contract No.	
12. Sponsoring Agency Name and Address **Utah Department of Transportation** **4501 South 2700 West** **Salt Lake City, Utah 84119**	**13. Type of Report and Period Covered** Final Report, April 2002- July 2003	
	14. Sponsoring Agency Code 81FR0141	
15. Supplementary Notes **Clifton Farnsworth, UDOT Research Project Manager**		

16. Abstract

The purpose of this project was to install a downhole array of force-balance accelerometers (FBA's) at a free-field site near large bridge structures in the interchange between I-15, I-80, and Highway 201 in Salt Lake City, Utah. The street address for this site is near 600 West and 2200 South. The array includes four downhole FBA's installed at depths of 25 ft, 60 ft, 160 ft, and 390 ft (7.6 m, 18.3 m, 48.8 m, and 119 m), respectively. A surface FBA was previously installed near the downhole array. The downhole array was completed on April 18, 2003 and has been operational since that date. Seismic ground motions monitored by the downhole array are collected, processed and distributed by the University of Utah Seismograph Stations (UUSS). Maintenance for the array is provided under a UDOT interagency agreement with the US Geological Survey (USGS).

17. Key Words Earthquake, ground response, instrumentation, seismic wave propagation		**18. Distribution Statement**	
19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**

THIS PAGE LEFT BLANK INTENTIONALLY

CONTENTS

List of Figures

List of Tables

THIS PAGE LEFT BLANK INTENTIONALLY

Section 1

Introduction

The purpose of this project was to install a downhole array of force-balance accelerometers (FBA's) at a free-field site near large bridges in the interchange between I-15, I-80, and SR 201 in Salt Lake City, Utah. This site is referred to hereafter as the I-15 downhole array (I15DA). The street location of I15DA is near 600 West and 2200 South. The array includes four downhole FBA's installed at depths of 25 ft, 60 ft, 160 ft, and 390 ft (7.6 m, 18.3 m, 48.8, m and 119 m), respectively. A surface FBA was installed near the downhole array by Halling and Petty (2001) as part of a project to install FBA's on bridges in the nearby interchange. The downhole array was completed on April 18, 2003 and has been operational since that time. Seismic ground motions monitored by the downhole array, as well as motions monitored by the nearby structural and surface arrays, are collected, processed, and distributed by the University of Utah Seismograph Stations (UUSS). Maintenance for the array is provided under an interagency agreement between UDOT and the US Geological Survey (USGS).

The downhole array is needed to monitor the modifications (amplification or attenuation) of seismic waves as they propagate upward through soft sediments beneath the Salt Lake Valley. Such modifications are a major design consideration for bridges, buildings, and other major structures sited on deep soft sediments. These modifications, however, are poorly understood and not well predicted by engineers and earth scientists. Few records worldwide have been obtained from downhole arrays in soft sediments. These records are badly needed to provide real data for development and verification of ground motion modeling procedures.

In the lower parts of northern Utah valleys, the sediment profiles tend to be deep and composed of interlayered lacustrine and alluvial sands, silts and clays. These sediment profiles are different in character from other prominent deep soft-sediment areas, such as Mexico City, the margins of San Francisco Bay, and many Japanese coastal areas. For design of economical but safe structures in Utah, accurate estimates of ground motions are required for sites on deep soft sediments. Records for the I15DA will provide important benchmark data that will allow improved estimation of these ground motions.

To install the I15DA, boreholes were drilled, cased and fitted with FBA's at depths of 25 ft, 60 ft, 160 ft, and 390 ft (7.6 m, 18.3 m, 48.8 m, and 119 m). The array, now in operation, continuously monitors ground motions at the site. The intent is to monitor the propagation of waves generated by large earthquakes that infrequently strike the area. These earthquakes will generate motions at levels required for safe seismic design. Such strong motions will also strain the upper part of the sediment profile into the non-linear range, a level of strain that is important in the modeling of ground response on soft sites. Seismic waves generated by relatively small earthquakes, such as the July 8, 2001 earthquake near Magna (M=3.4), however, will also provide important information for assessing the character and properties of upwardly propagating waves.

The I15DA site was selected because: (1) the soft sediments are among the deepest in the valleys along the Wasatch front; (2) the nearby bridges are among the highest, longest and most important structures in the I-15 corridor; and (3) the superstructure of a nearby bridge has been instrumented by personnel from Utah State University (Halling and Petty, 2001). Thus, the installation of the downhole array complements the bridge instrumentation by allowing the monitoring of seismic waves as they propagate from deep within the geologic section, upward through the sediment profile and into the bridge superstructure.

Section 2

Location and Geologic Setting:

The I15DA site is located within the I-15/I-80/SR 201 interchange near 600 West and 2250 South as noted above. The location of I15DA is marked on Figure 2.1, a segment of a USGS topographic map of the area that was compiled prior to the I-15 reconstruction. Also marked on the topographic map is the location of a nearby 1,088-ft 332-m) deep borehole (Well Number 24) that was drilled and logged near the I15DA site. The log from that well is described later in this report.

Figure 2.2 is a post construction aerial photograph of the SR-201 ramps connecting to I-15 and I-80 which shows the location of I15DA and its proximity to nearby bridges and other features in the area. The site is on UDOT property west of 600 West, north of Andy Avenue, and located at about 2250 South.

Geologic Units

The following description of geologic units beneath the I15DA site is modified from a description by Bartlett and Farnsworth (2002) of geologic units beneath a similar site located near I-15 and 300 West in Salt Lake City. Depths and thicknesses of units noted below for the I15DA site were estimated from comparisons of logs from CPT SV-CS-11, near the I15DA site (Figure 2.3) and the log from CPT SS-RC-11 (not reproduced here) used by Bartlett and Farnsworth to interpret depths and thicknesses of geologic units beneath the 300 West site. Depths and thicknesses listed in the following text are given in both English and SI units because depths and other measures on the CPT log in Figure 2.3 are listed in SI units.

The upper 4 ft (1.3 m) of sediment beneath the I15DA site consists of fill placed during recent I-15 construction. The fill is underlain by Holocene alluvium to a depth of approximately 20 ft (6 m). The Holocene alluvium consists of alternating layers of sands,

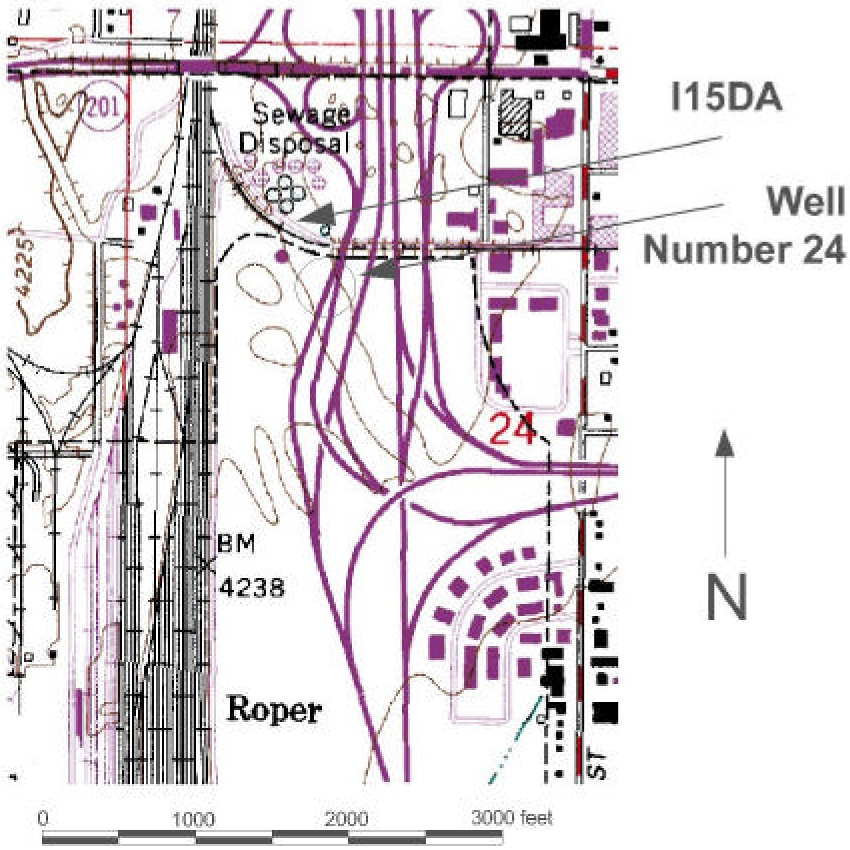


Figure 2.1. Topographic map of the I15DA area prior to the 1998-2002 reconstruction of I-15, showing locations of the I15DA site and Well Number 24, a nearby deep geologically logged well

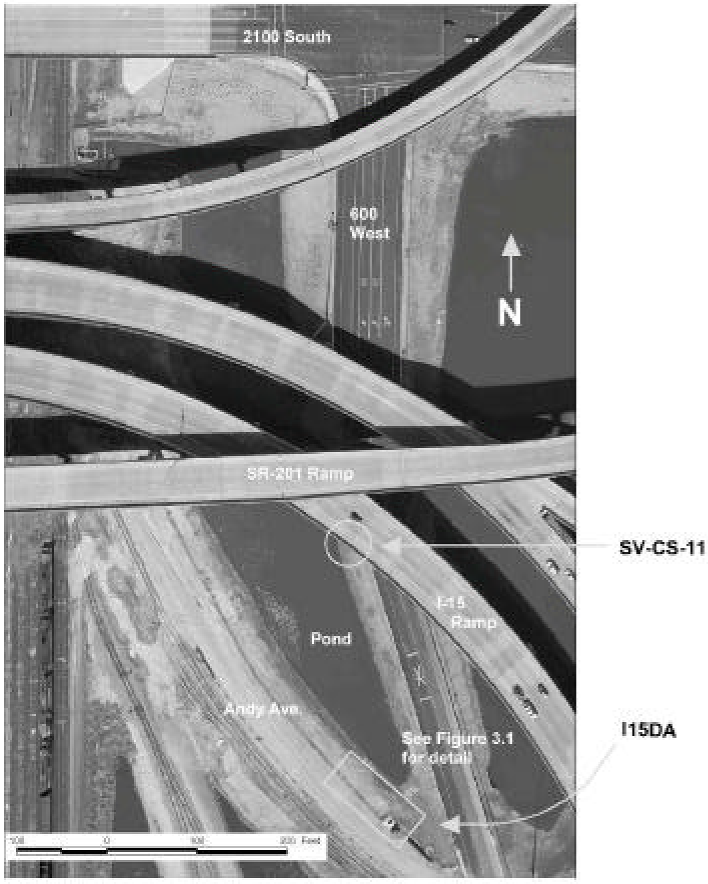
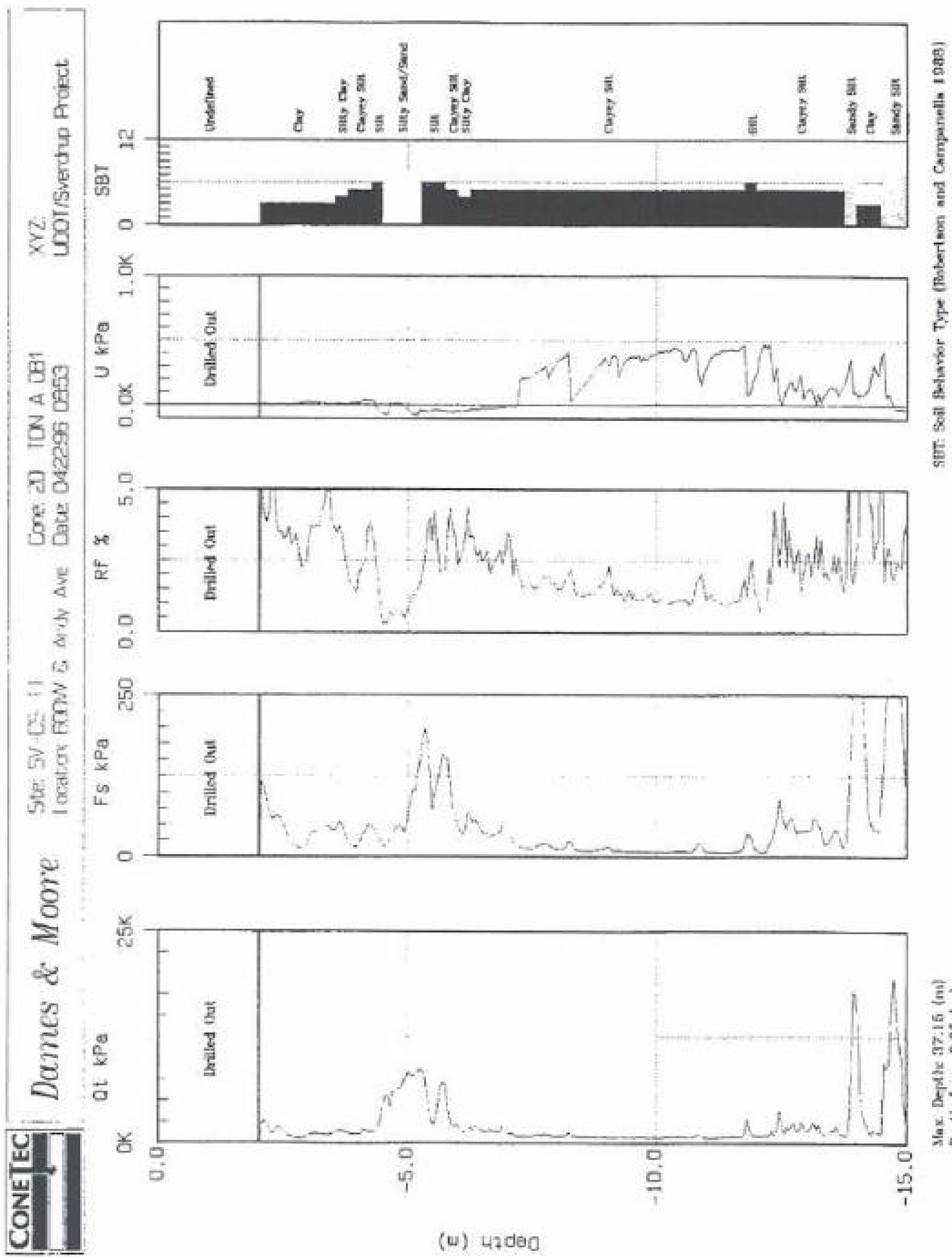
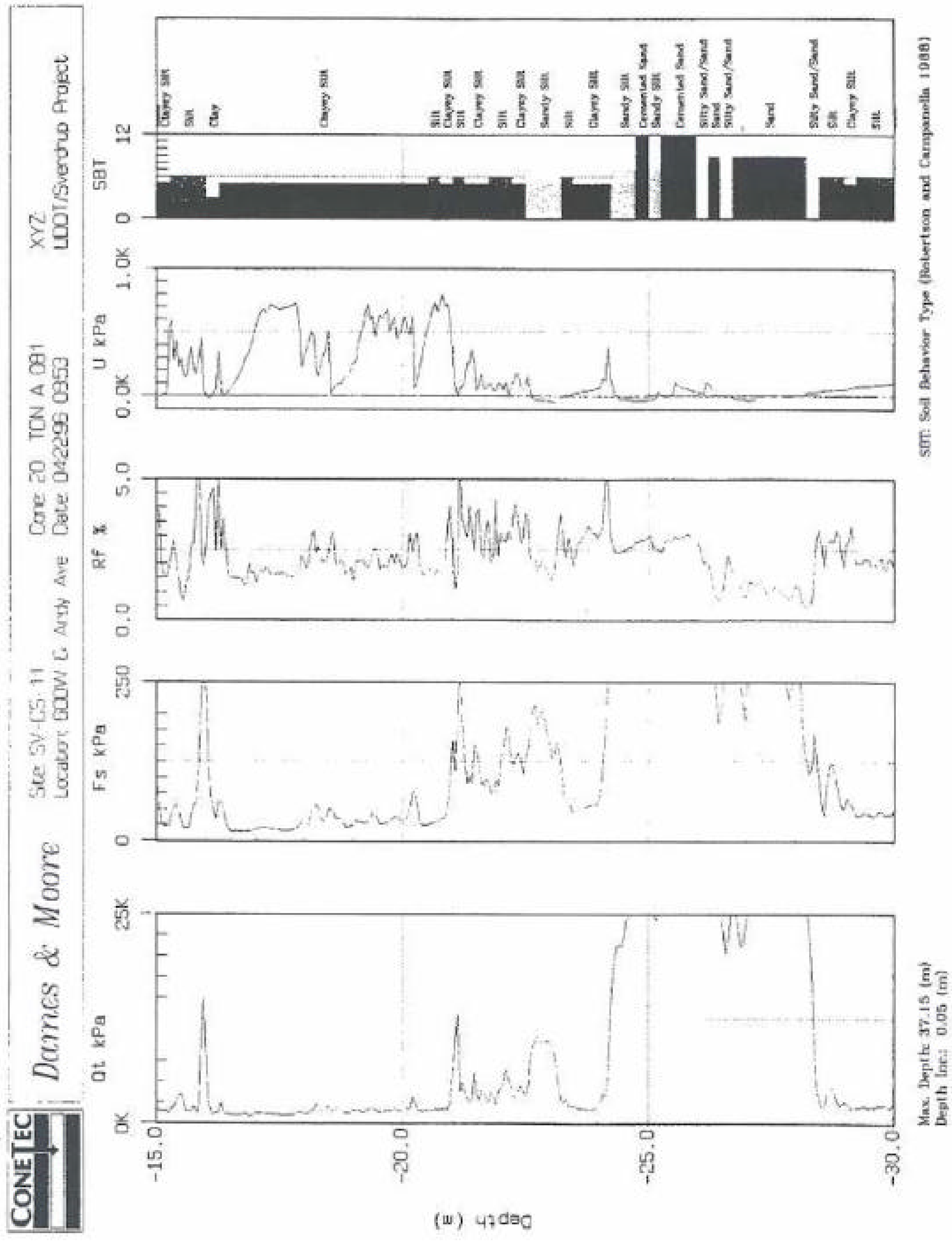


Figure 2.2. Arial photograph of ramps from SR-201 to I-15 (after reconstruction of the interchange) showing location of I15DDHA and its proximity to freeway bridges.

silts and clays transported into the area over the past 10,000 years by streams and rivers flowing from nearby canyons east of area in the Wasatch Mountains.

The Holocene alluvial deposits are underlain by about 50 ft (15 m) of soft, compressible sediment belonging to the Pleistocene Lake Bonneville depositional sequence. This unit extends to a depth of about 70 ft (21 m). The Lake Bonneville sediment consist of interbedded low plasticity clays (CL) and silts (ML) with lesser amounts of high plasticity clays (CH). Thin silty sand seams (SM) are common in the lower half of the unit. Lake Bonneville was a fresh water predecessor of the Great Salt


ConeTec
Dames & Moore
Site: SV-CS-11
Location: ROW & Andy Ave
Cone: 2D TON A 081
Date: 042296 0853
XYZ.
UDOT/Sverdrup Project
Qt kPa
Fs kPa
Rf %
U kPa
SBT
Drilled Out
Depth (m)
Max. Depth: 37.15 (m)
Depth Inc.: 0.05 (m)
SBT: Soil Behavior Type (Robertson and Campanella 1988)



CONETEC
Dames & Moore
Site SV-CS-11
Location: 600W & Andy Ave
Cone 20 TON A 081
Date 042296 0953
XYZ
UDOT/Sverdrup Project
Qt kPa
Fs kPa
Rf %
U kPa
SBT
Depth (m)
SBT: Soil Behavior Type (Robertson and Campanella 1988)
Max. Depth: 37.15 (m)
Depth Inc.: 0.05 (m)

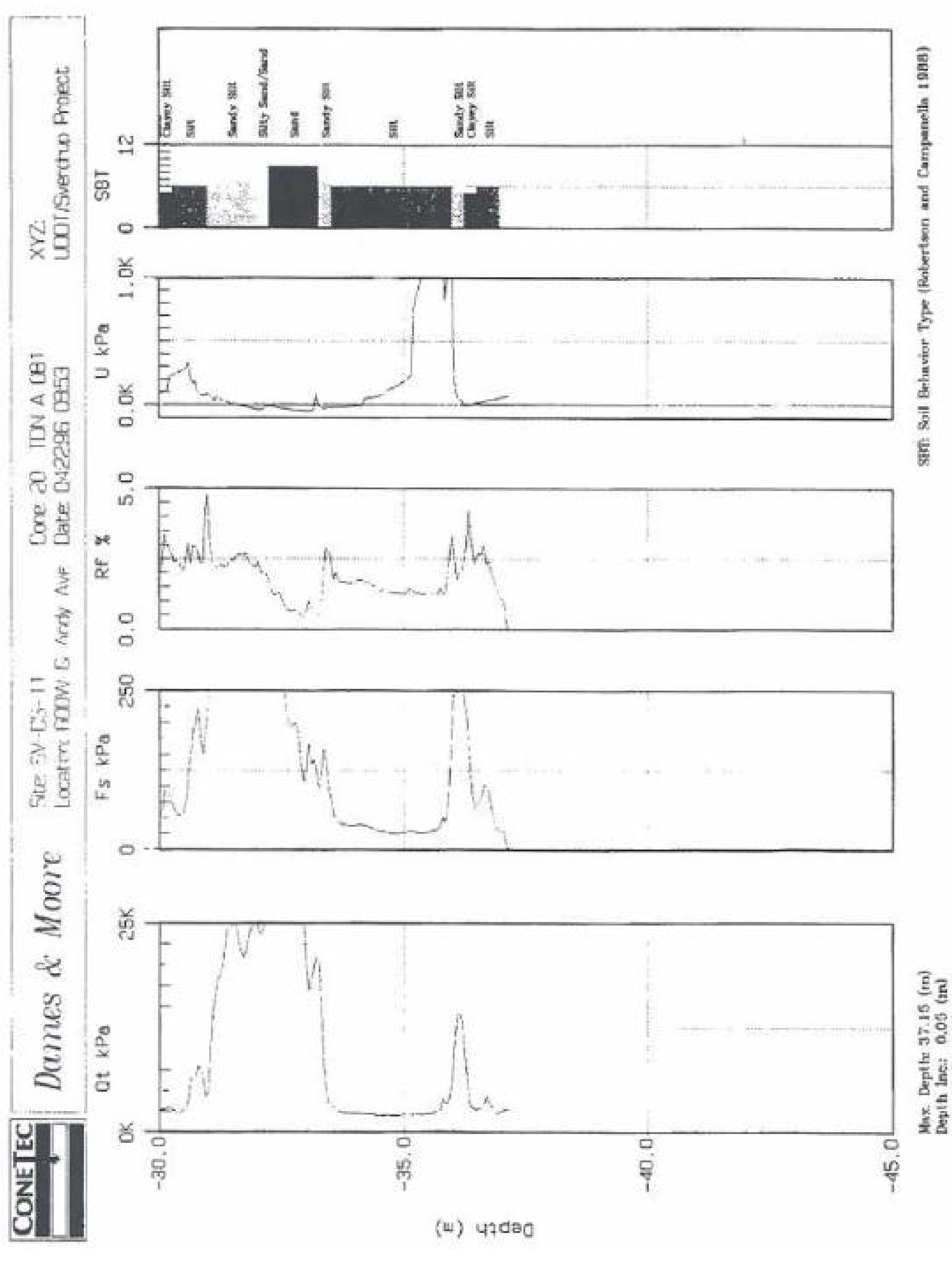


Figure 2.3. Cone penetration (CPT) log in three parts with soil stratigraphy interpreted by ConeTec from sounding CPT SV-SS-1; that sounding was located about 100 ft (30 m) north of I15DA and was installed during the I-15 reconstruction (log courtesy of ConeTec, Dames and Moore, and UDOT)

Lake that occupied the western part of the Great Basin from about 30,000 years ago to about 10,000 years ago.

Beneath the Lake Bonneville deposit, is a 40-ft (12-m) thick sequence of interbedded alluvium and lake deposits composed of alternating layers of clay, silt and sand. These deposits probably comprise lower Lake Bonneville sediment interbedded with Pleistocene alluvium. The base of this unit is at depth of about 110 ft (33 m).

Underlying the interbedded deposits is a layer of lacustrine sediment with a thickness greater than 10 ft (3 m). This sediment is part of the Cutler Dam Lake depositional sequence and is composed primarily of silt with smaller layers of silty clay and sandy silt. The Cutler Dam Lake was a predecessor to Lake Bonneville and occupied the Great Basin during mid Pleistocene time, more than 30,000 year ago.

<u>Geotechnical Profile beneath I15DA</u>

Because soil sampling and testing were not included in the site work to install the boreholes, casing and FBA's (only cuttings were collected and logged during the drilling operation), logs from nearby boreholes and CPT soundings were collected and complied to develop a geotechnical profile for the site. In addition geophysical probes were lowered into the deepest borehole (400 ft (122 m) deep) to collect geophysical data from sediment surrounding the hole. Those measurements were interpreted to provide additional information. .

Geotechnical Information

Several sources of information were used to compile a geotechnical profile for I15DA. These sources include (1) a deep borehole (Well 24) drilled in the 1980's at a locality about 600 ft (183 m) southeast of I15DA; (2) cuttings collected from the circulated drilling fluid during the boring of the 400-ft (122 m) hole; (3) geophysical data collected during logging of the 400 ft (122 m) hole; and (4) the log of CPT SV-CS-11 (Figure 2.3). Each of these sources of information is considered in the following text.

Well 24

The deepest borehole in the vicinity of I15DA is Well Number 24, a 1,088-ft (332-m) deep water well located in the central part of the Salt Lake Valley. That well is located about 600 ft ((180 m) southeast of I15DA (location noted on Figure 2.1). The log from Well Number 24 was collected, compiled and published by the Utah Geological Survey (Case, 1985). A redrafted version of the log is provided in Figure 2.4. Well 24 is one of several deep wells that were logged in the Salt Lake and nearby valleys to develop deep sediment profiles for the region. Although generalized, in that only thick layers are delineated, this log provides valuable information on the general sediment stratigraphy of the area. The sediment stratigraphy at Well 24 should be very similar to that beneath I15DA.

The log for Well 24 indicates that the sediment profile to a depth of 1,088 ft (332 m) is composed primarily of various strata of clay with significant granular layers composed of sand, gravel or conglomerate at depths of 150 ft, 540 ft, 700 ft, 830 ft to 970 ft, and 1,050 ft (46 m, 165 m, 213 m, 253 m, 296 m and 320 m). In the upper 150 ft (46 m) the sediments classify as clays with various colors and consistencies. In the interval between 150 ft and 300 ft (46 m and 91 m), the sediment log indicates various granular layers composed of conglomerate, interlayered clays and course sands, cemented sand, and cemented gravel. Between 300 ft and 400 ft (91 m and 122 m), the depth of the deepest hole in I15DA, the sediment is classified as clay. Undoubtedly, many thin granular layers were interspersed within the thicker clay units, but were too thin to be noted by the compliers of this generalized log.

Cuttings from the 400-ft (122-m) deep borehole in the I15DA

An attempt was made to log the 400-ft (122-m) deep borehole in the I15DA using cuttings separated from the circulated drilling fluid, but difficulties in maintaining a continuous flow of fluid during the drilling process precluded accurate logging of these cuttings. At times the borehole became plugged with clayey sediment or clay balls, requiring the driller to stop the drilling process and flush the hole. Thus our sampling of cuttings was somewhat irregular and the depth from which the cuttings originated was sometimes difficult to determine. Also cuttings from some layers, particularly the more granular layers, may have been mixed with the clay and not detected.

We had planned to retrieve split spoon samples at 50 ft (15 m) depth intervals, but due to the drilling difficulty and our concern that the hole might collapse during sampling operations, the soil sampling segment was omitted from the work plan. The cost savings gained from omitting the tube samples was used to enhance geophysical logging of the hole.

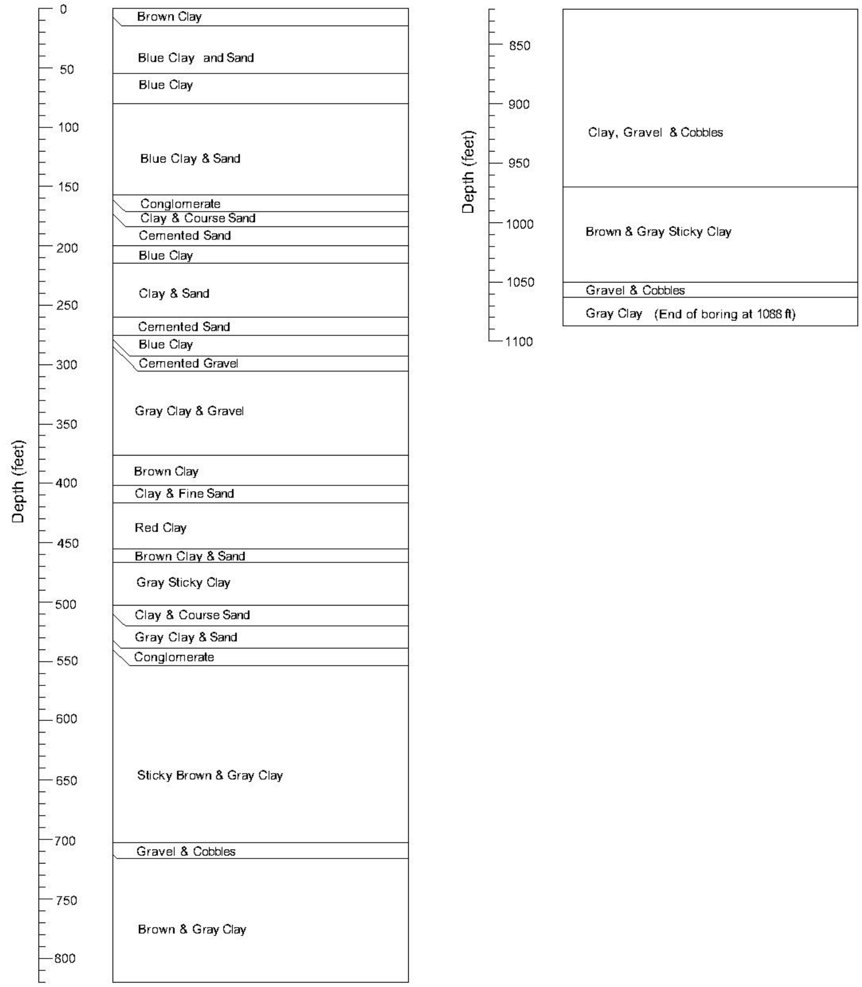


Figure 2.4. Sediment stratigraphy reported from Well Number 24 located about 600 ft (183 m) southeast of the I15DA site (Case, 1985)

The borehole log developed from the collected cuttings is reproduced in Figure 2.5. This log is consistent with the log from Well 25 reproduced in Figure 2.4. The log indicates clayey sediment to a depth of 150 ft (46 m). Below 150 ft (46 m), the cuttings indicate that the sediment is composed of clay or clayey sands with layers of varying shades of color. Some gravel was also encountered in the cuttings from depths between 200 ft and 250 ft (61 m and 76 m). As noted above, some granular layers may have been missed due to irregular drilling and mixing of sediment with the many clay balls that formed and were expelled in the drilling fluid.

Stratigraphic Log Interpreted from Geophysical Data

A lithologic log (Figure 2.6) was interpreted from resistivity and gamma radiation measurements taken during the geophysical survey of the hole. The resistivity and gamma-radiation logs are included in Appendix 1 (report from GeoVision Geophysical Services, Inc. (2003)). The geophysical measurements to a depth of 250 ft (76 m) were made in the uncased borehole on August 12, 2002. Unfortunately a minor blockage in the hole prevented lowering of the geophysical probe below the 250 ft (76 m) depth level on that date.

The stratigraphic interpretation of geophysical data presented in Figure 2.6 was made by David Briggs with appreciated assistance from Dr John McBride, BYU Department of Geology, Mr David Alderks, graduate student, BYU Department of Geology, and Mr Robert Steller, Geophysist, GeoVision Geophysical Services, Inc. The basic theory in constructing this log is that clay-rich layers, which have low permeability and allow little water transmission though the sediment, should be characterized by low resistivity and high gamma radiation emission. Conversely, granular layers, which allow water to more freely percolate, should be characterized by high resistivity and low gamma radiation emission. By comparing resitivity and gamma radiation emission

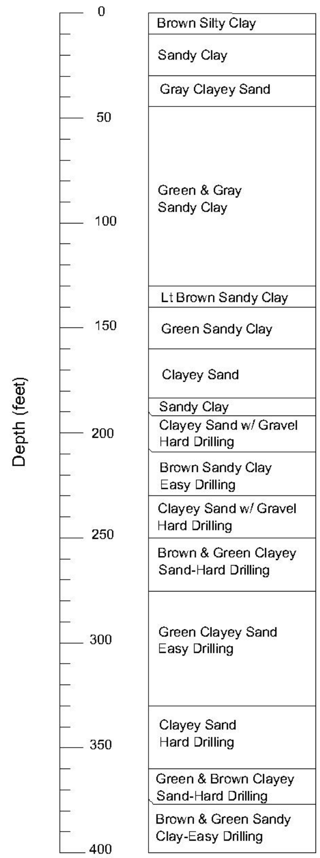


Figure 2.5. Lithologic log of 400-ft (122 m) deep hole in I15DA compiled by David Briggs from sediment cuttings extracted from the drilling fluid

patterns in the geophysical logs (Appendix 1, page 45), sediment layers were delineated and assigned either as fine-grained (clays) or coarse grained (sands).

The lithologic log interpreted from resistivity and gamma radiation measurements indicates that clay is the major sediment type in the profile, but that there are also many relatively thick sand layers dispersed through out the sediment stratigraphy. Thus, the interpreted lithologic log plotted in Figure 2.6 indicates much more granular sediment in the profile than is indicated by either the log from Well 24 (Figure 2.4) or the log estimated from sediment cuttings (Figure 2.5). The log in Figure 2.6, however, is only approximate, because of uncertain interpretation of geophysical data and the lack of intact samples of sediment to confirm our interpretations.

Interpreted Stratigraphy from CPT Sounding SV-CS-11

CPT Sounding SV-CS-11 was installed about 100 ft (30 m) north of I15DA during the reconstruction of I-15. That log, along with an interpreted soil profile using the procedure published by Robertson and Wride (1998), is reproduced in Figure 2.3. This CPT sounding was extended to a depth of 120 ft (37 m), far short of the depth of the 400-ft (122 m) borehole in the I15DA. This sounding, however, provides information on the penetration resistance and the general character of near-surface sediment layers which have great influence on the propagation of seismic waves as they approach the ground surface.

The interpreted soil types noted on Figure 2.3 indicate that nearly all of the sediment in the upper 120 ft (37 m) beneath the I15DA is fine-grained silty clay, clayey silt or silt, with a few interspersed coarse-grained layers 2-ft to 4-ft (0.6-m to 1.1-m) thick at depths of 16 ft (5 m), 50 ft (15 m), 75 ft (23 m), 82 ft (25 m), 87 ft (26 m), and 104 ft (32 m). The depths of these granular layers roughly correlate with the granular layers noted on the lithologic log interpreted from geophysical measurements (Figure 2.6), but the thicknesses of the granular layers are much thinner on the CPT log.

A synthesis of the three logs discussed in this section, giving our best estimate of the soil profile beneath I15DA, is plotted along on both Figures 2.9 (seismic velocity log) and 3.2 (sediment cross section with locations and depths of installed PVC casings).

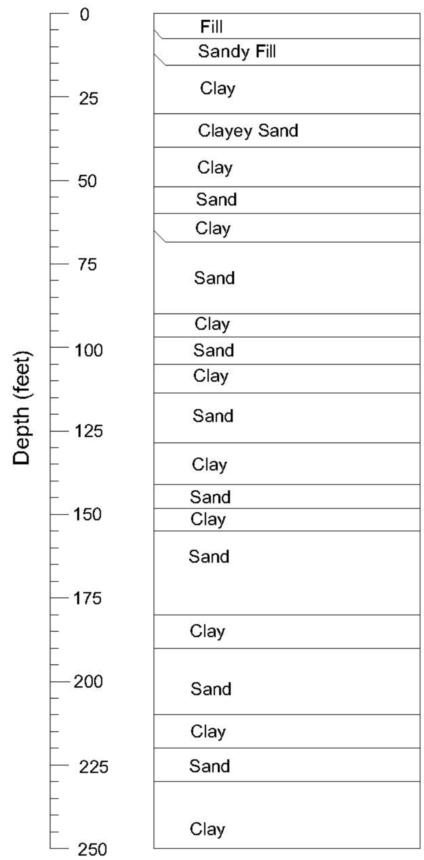


Figure 2.6. Lithologic log interpreted from resistitivity and gamma radiation logs prepared by GeoVision Geophysical Services, Inc (Appendix 1); lithology interpretation is by David Briggs, with assistance from Dr. John McBride, David Alderks, and Robert Steller

Seismic Velocity Logs

OYO Suspension Logger

During the I15DA site investigation, seismic velocities (both compression (P-wave) and shear (S-wave)) velocities were measured with an OYO in-hole suspension logger and by cross-hole velocity measurements between the 160 ft (49 m) and 400 ft (122 m) deep PVC casings. The suspension logging was performed by Robert Steller, GeoVision Geophysical Services, and the cross hole logging was performed by Dr James Bay, Utah State University. A schematic diagram of the OYO suspension probe, along with the supporting tripod and winch, is reproduced in Figure 2.7. The seismic velocity logging was conducted by lowering the probe to the bottom of the borehole with the tripod and winch system. The probe was then withdrawn from the hole in 1.6 ft (0.5 m) increments. Seismic velocity measurements were made at each increment. To make a measurement, the source element was excited electronically to generate a pulse of seismic energy containing both P-waves and S-waves. These waves propagated outward from the source into the soil surrounding sediment and upward to the receivers. First arrivals of both P- and S-waves were sensed by two receivers (the lower receiver, R1, and an upper receiver, R2). Distances between the source and the two receivers are noted on Figure 2.7. Three calculations of P-wave and S-wave velocities were made for each test depth. These calculations are based on the distances from (1) the source to R1, (2) the source to R2; and (3) from R1 to R2. Thus, the velocity plots in the GeoVision report (page A-2, Appendix 1), contain three different lines, one for each of these calculated velocities. The velocities were calculated by dividing the distance between the source and the receivers or between the receivers by the appropriate increment of travel time.

The velocities were logged on two different dates. The upper 250 ft (76 m) of the sediment profile was logged on August 12, 2002 in the open, uncased 400-ft (122 –m) deep borehole. Because of the obstruction in the hole at the 250 ft (76 m) depth, the probe could not be lowered below that point at that time. Later, on April 15, 2003, the logging of the lower 150 ft (46 m) of the hole was completed by lowering the OYO suspension logger into the cased borehole. The borehole casing had little effect on the velocity measurements as indicated by near identical calculated velocities in an overlap zone between 220 ft and 250 ft (67 m and 76 m). Thus no degradation of velocity data occurred as a consequence logging the lower 150 ft (46 m) from within the cased hole. (On the other hand, the casing interfered with the measurement of resistivity and gamma radiation emission. Thus, these geophysical measurements were not made in the lower 150 ft (46 m) of the hole.)

The incremental P-wave and S-wave velocities determined from measurements between receivers R1 and R2 are plotted on Figure 2.9. These velocities indicate generally monotonic increases of both P-wave and S-wave velocity with depth, with many local deviations from the general trend. Measured P-wave velocities are rather erratic in the upper 70 ft (21 m) of the profile with values ranging between about 2,000 and 5,000 ft/sec (600 m/sec and 1,500 m/sec). This variability and the fact that the measured velocities are mostly less than those for liquid water (4,800 ft/sec (1,460 m/sec)) indicate that the sediments above 70 ft (21 m) may contain air or gas in the voids and are not fully saturated. Decomposition of minor amounts of organic matter in the sediment may be a source for gas in the voids. Even minor amounts of air or gas can lead to measured P-wave velocities less than 4,800 ft/sec (1,460 m/sec). The variability of P-wave velocities above 70 ft (21 m) indicates considerable local variation in the degree of saturation or the amount of air in the voids.

Below 70 ft (21 m), the measured P-wave velocities are less erratic and uniformly greater than 4,800 ft/sec (1,460 m/sec), indicating that the sediment below that level is saturated. These velocities increase from about 5,000 ft/sec (1,525 m/sec) at 70 ft (21 m) to about 6,000 ft/sec (1,830 m/sec) at a depth of 160 ft (49 m). Between depths of 160 ft

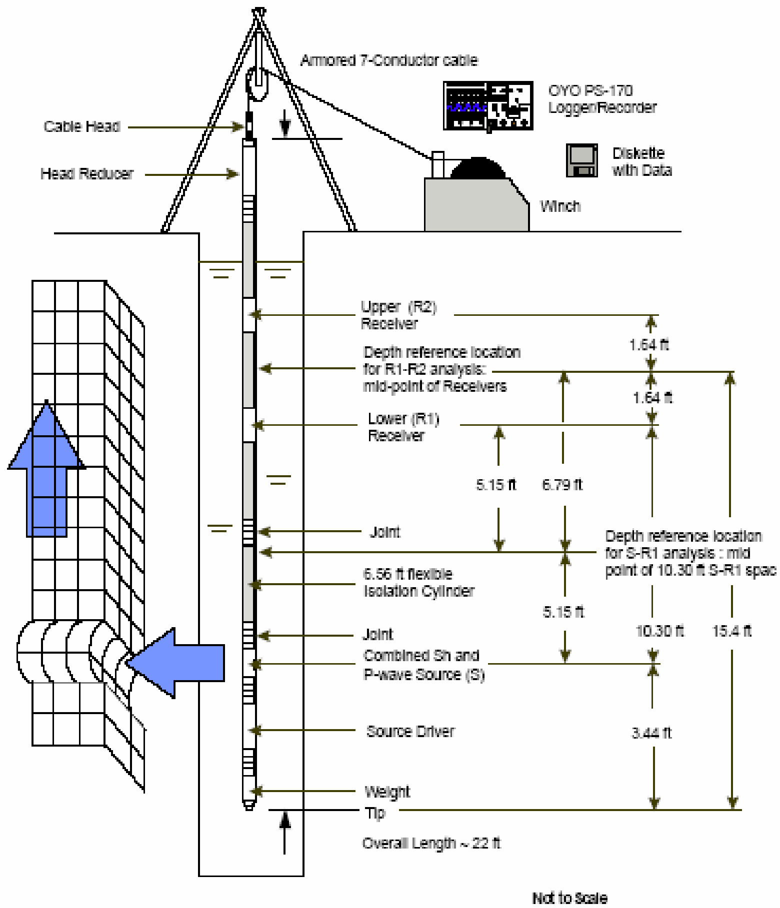
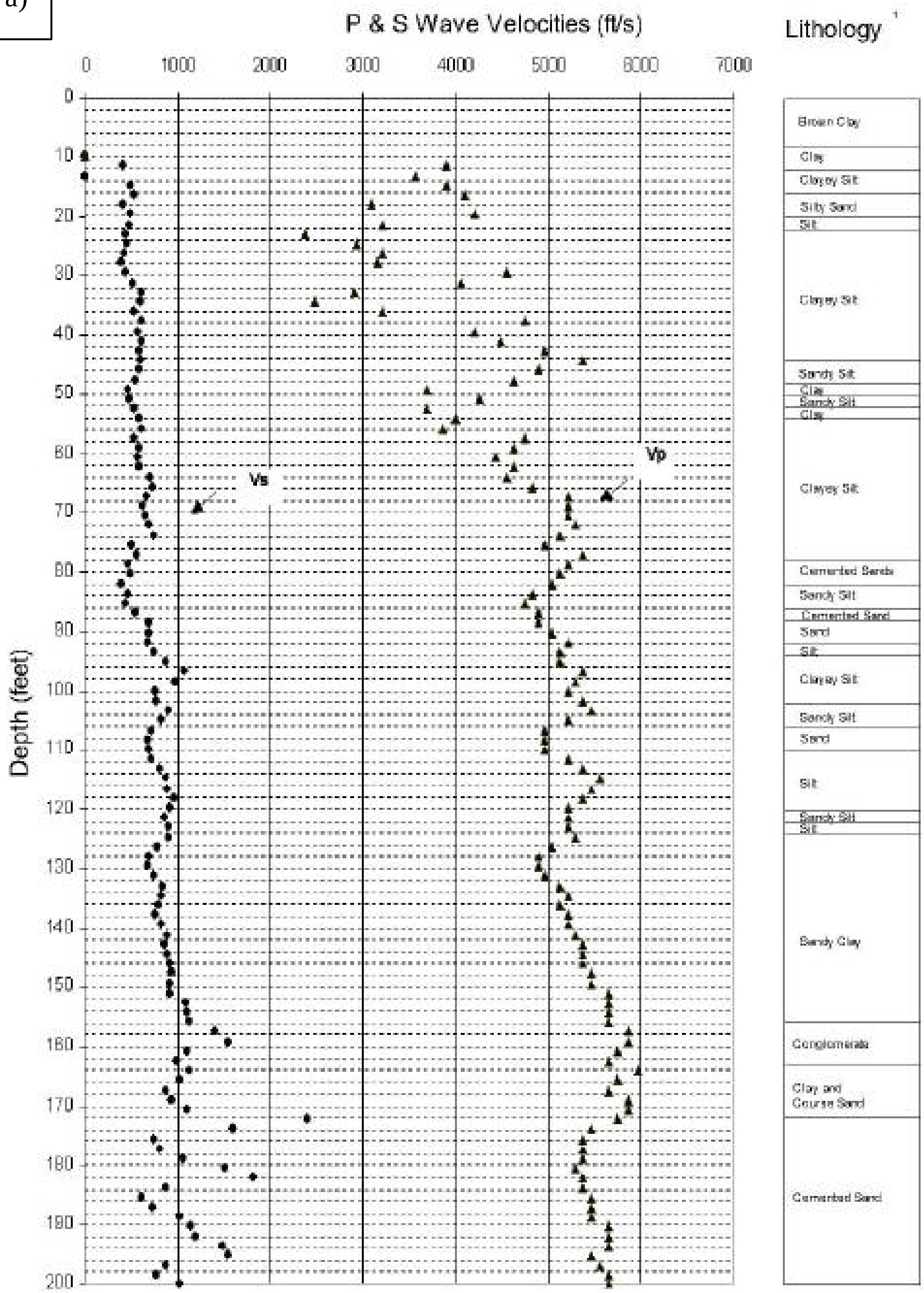


Figure 2.7. Diagram and dimensions of OYO probe used to log P-wave and S-wave velocities in the 400-ft (122 m) deep casing at I15DA (GeoVision Geophysical Services, 2003)

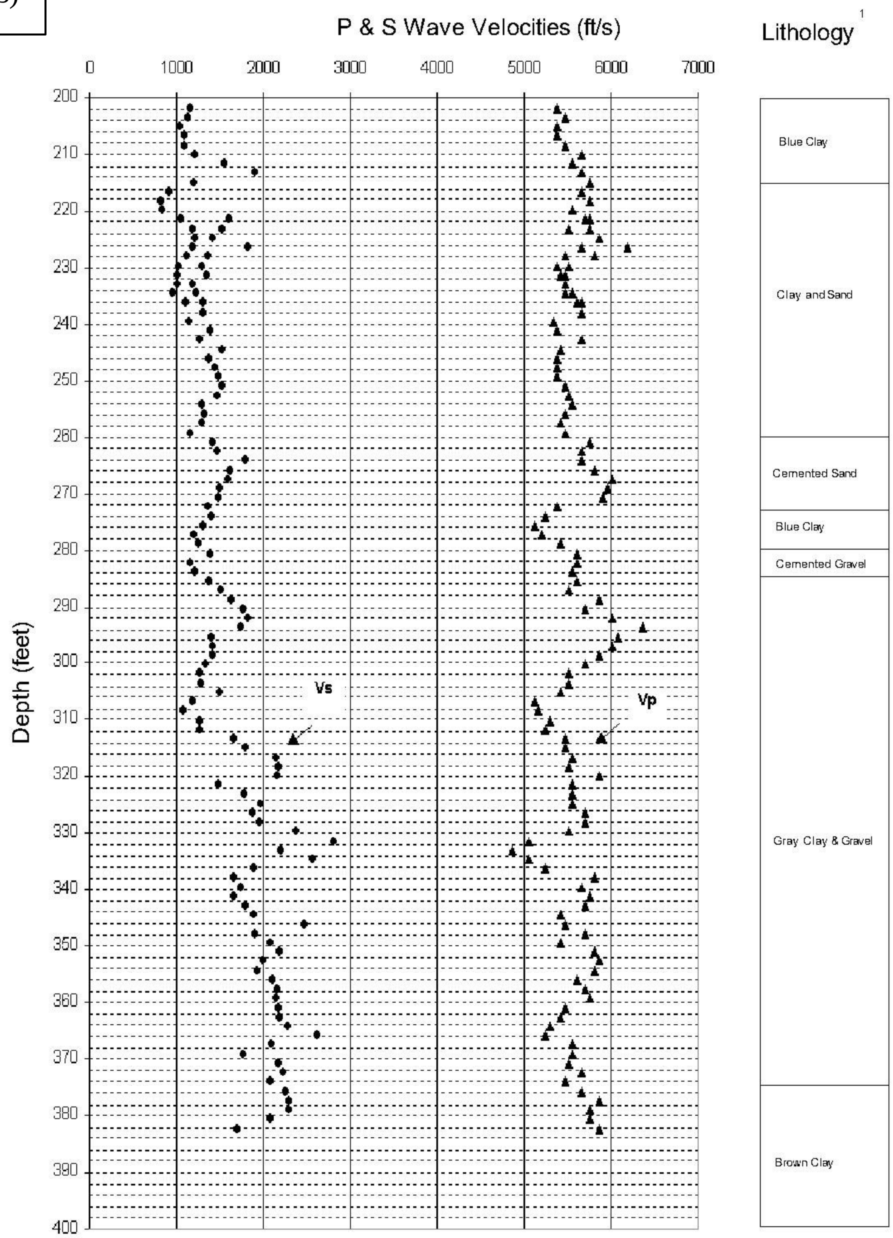
and 385 ft (490m and 117 m), the maximum depth of the velocity log, P-wave velocities consistently plot between 5,000 ft/sec and 6,000 ft/sec (1,525 m/sec and 1,830 m/sec), but with many local variations. These local variations indicate a layered sediment profile.

a)



[1] Composite log interpreted by David Briggs from Well Number 24, Cuttings from I15DA 400 ft hole and CPT SV-CS-11

b)



[1] Composite log interpreted by David Briggs from Well Number 24, Cuttings from I15DA 400 ft hole and CPT SV-CS-11

Figure 2.8. I15DA compression and shear wave velocity logs from 400 ft (122 m) borehole at I15DA; (a) logs from 10 ft to 200 ft (3 m to 61 m) depth; (b) logs from 200 ft to 400 ft (61 m to 122 m) depth (data courtesy of GeoVision Geophysical Services, Inc. Geotechnical Log compiled by David Briggs)

S-wave velocities increase from about 400 ft/sec (120 m/sec) at a depth of 10 ft (3 m) to 1,000 ft/sec (300 m/sec) at a depth of 150 ft (46 m). These relatively low S-wave velocities indicate that the sediment is very soft near the ground surface, but increase in stiffness to moderately stiff sediment at a depth of 150 ft (46 m). The S-wave velocity remains nearly constant at about 1,000 ft/sec (300 m/sec) between 150 ft to 220 ft (46 m to 67 m), but with much local scatter. That scatter is typical of sediments with alternating layers of higher velocity granular layers and lower velocity fine grained layers. Below 220 ft (67 m), the S-wave velocity slowly increases with depth to a value of about 2,300 ft/sec (700 m/sec) at 385 ft (117 m), the bottom of the log. The many local variations of velocity in this region again indicate alternating layers of stiffer and softer sediment. The velocity of 2,300 ft/sec (700 m/sec) at the base of the profile indicates very stiff sediment.

Cross-hole Tests

Measured velocities from cross-hole seismic tests, performed by Dr. James Bay, Utah State University, are plotted on Figure 2.9; the data are listed in Appendix 3. Velocities calculated from the cross-hole tests are compared in Figure 2.10 with those determined from the OYO suspension logger. The S-wave velocities are generally consistent but in several layers the cross-hole velocities are slightly and consistently greater than the OYO velocities.

In the upper 90 ft (27 m) of the soil column, the cross-hole P-wave velocities are consistently greater than the OYO P-wave velocities. The cross-hole velocities are also consistently above 4,800 ft/sec (1,460 m/sec) except for a zone between 25 ft and 35 ft (7.6 m and 10.7 m) deep. Thus, the cross hole velocities indicate that the sediment is saturated below a depth of 10 ft, except for the zone noted above. Below a depth of 90 ft (30 m), P-wave velocities from the two test procedures are generally consistent and consistently above 4,800 ft/sec (1,460 m/sec).

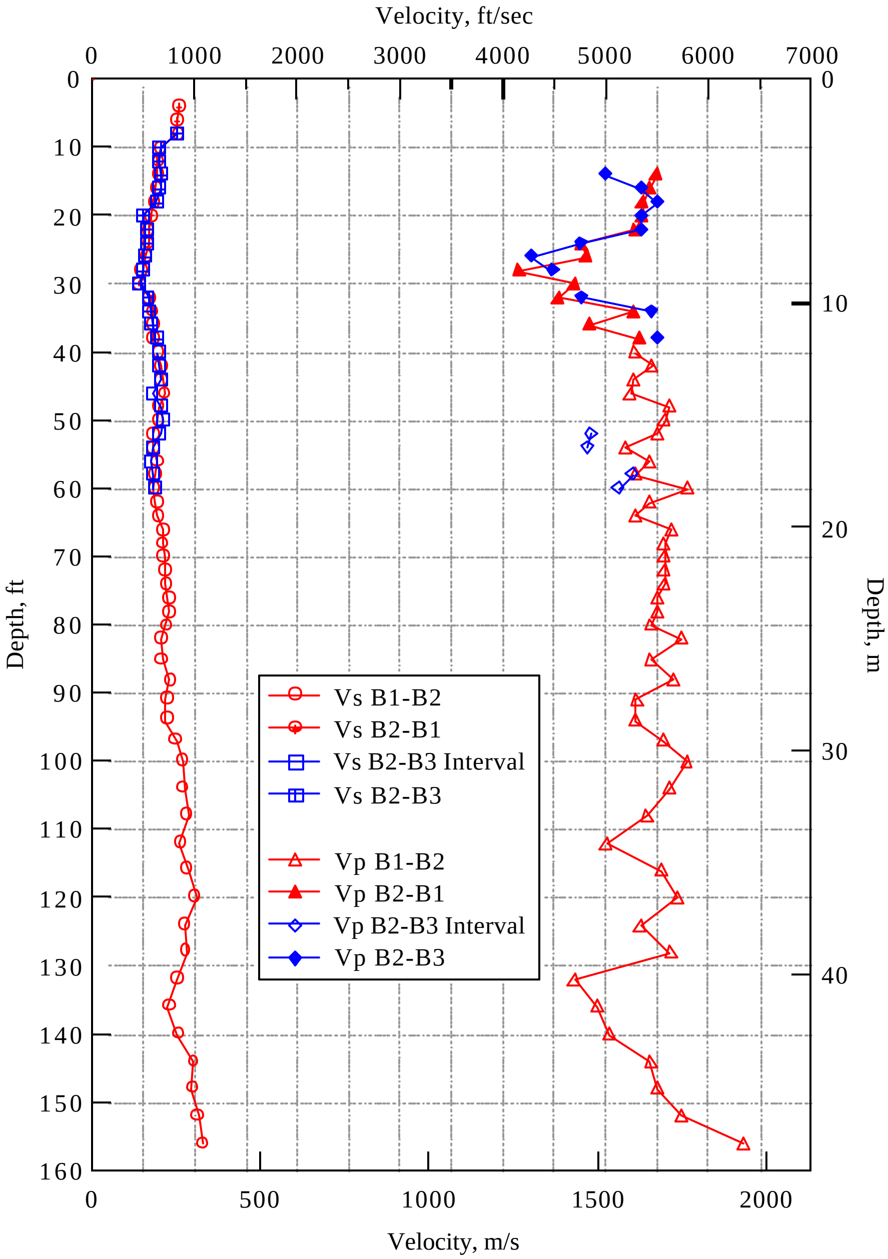


Figure 2.9. Seismic velocities from cross-hole tests at I15DA (J. A. Bay, Utah State University)

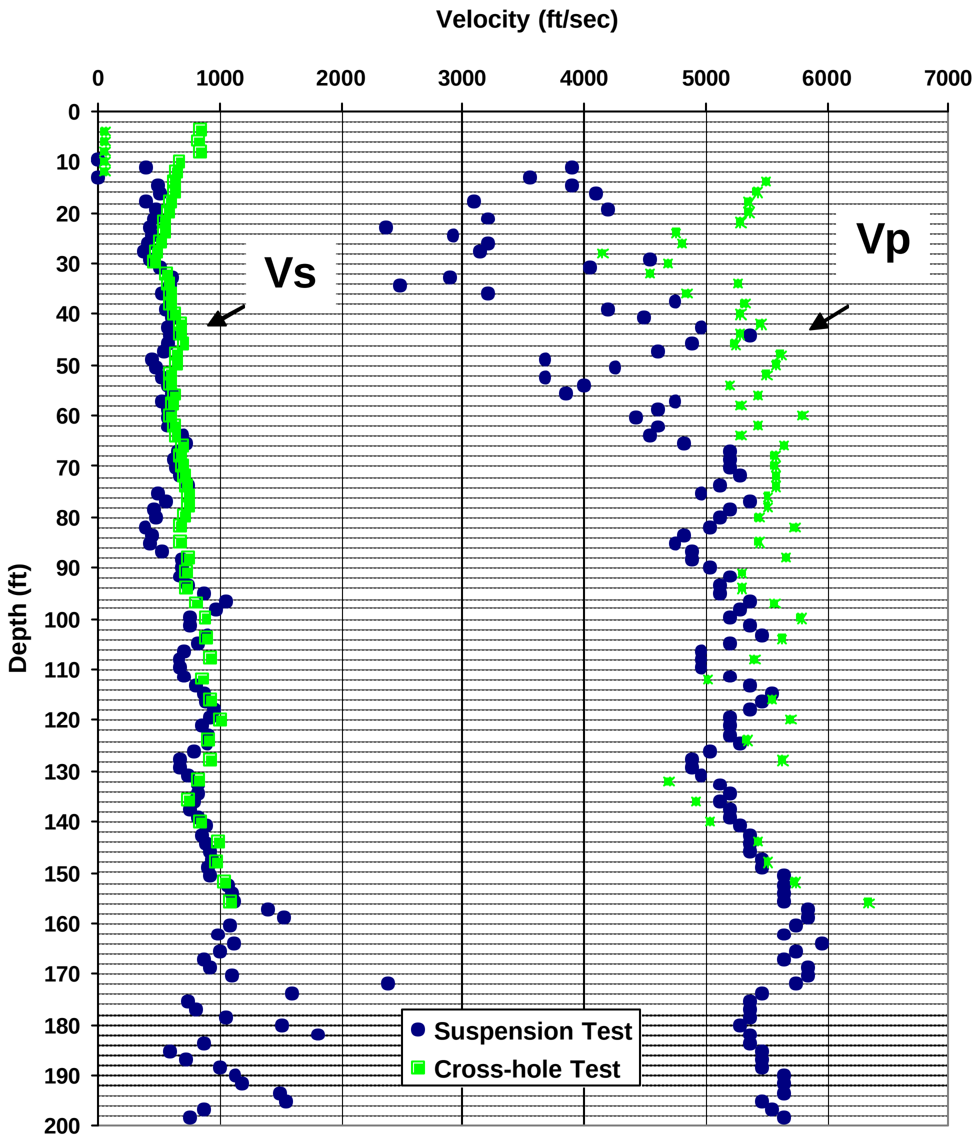


Figure 2.10. Comparison of seismic velocities measured with cross-hole and OYO suspension tests

Section 3

Installation of Equipment

Drilling of Holes

A subcontract was let to Layne GeoConstruction, Salt Lake City, Utah, to drill and case the required bore holes for the downhole array. Rotary drilling with circulated drilling fluid was specified for the drilling operation. The driller used an 8-inch diameter tricone drill bit with NW drill rod as the primary drilling tool. A 1-ft (0.30m) diameter steel casing was installed in the upper 8 ft (2.4 m) of the holes to prevent dry surface materials from collapsing into the hole. This casing was removed after the hole was completed.

The drilling operation commenced on July 31, 2002 and was completed on August 8, 2002. A log of drilling progress over these 9 days is contained in Appendix 4. The location of the boreholes is shown in Figure 3.1.

In the initial stages of drilling, progress was interrupted by several equipment break downs, and in the latter stages, drilling was interrupted by mud balls obstructing the 400-ft (122-m) hole. Removal of these mud balls required a day to remove the mud balls, reconstitute the drilling fluid and clean the hole.

The drilling fluid was composed of bentonite and water. Cuttings generated at the bit-level during the drilling operation were removed by the upward flow of the circulated fluid. At the ground surface, the drilling fluid flowed into a large settlement tub where the heavier particles were allowed to settle prior to recirculating the fluid down the hole.

The drilling of the 25 ft, 60 ft and 160 ft (7.6 m, 18.3 m, and 48.8 m) holes went rather smoothly with only a few minor glitches. The drilling of the 400 ft (122 m) hole was much more difficult, with several hard layers below 160 ft (48.8 m) that slowed drilling progress for hours at a time. As mentioned previously, mudballs formed in the hole below 160 ft (48.8 m) which plugged the hole, requiring drilling interruption while the hole was flushed. In particular, a day of mud ball removal and recirculation of drilling fluid was required after reaching the 400 ft (122 m) depth. This flushing was required to clean the hole sufficiently to lower the geophysical probes into the hole and to install the PVC casing. Even with this cleaning, the geophysical probes could not be lowered below a depth of 250 ft (76 m) due to an obstruction. However, the 4-in PVC casing was lowered into the hole to the full depth of 400 ft (122 m) with out major difficulty.

Installation of Casing

Once a hole was completed the drill rod and drill bit were retrieved from the hole and the settlement tub and other equipment removed from the drill-hole site. A 4-in diameter PVC casing was then pushed downward into the open borehole. The casing was installed in 20-ft (6-m) long increments, coupled together on site via threaded pipe ends. Schedule 40 casing was installed in the 25 ft and 60 ft (7.6 m and 18.3 m) holes. Schedule 80 casing was installed in the 160 ft and 400 ft (48.8 m and 122 m) holes. The PVC casings were filled with water, drafted from a nearby pond, as they were pushed downward to reduce the buoyancy.

After the casing was installed, a 1-in diameter PVC pipe or “tremmy-pipe” was pushed down the annulus between the casing and the intact ground to the bottom of the hole. The 4-in-diameter casing was then raised a few feet off the bottom. A moderately thick grout mixture, composed of 1 bag of bentonite to 5 bags of cement mixed with

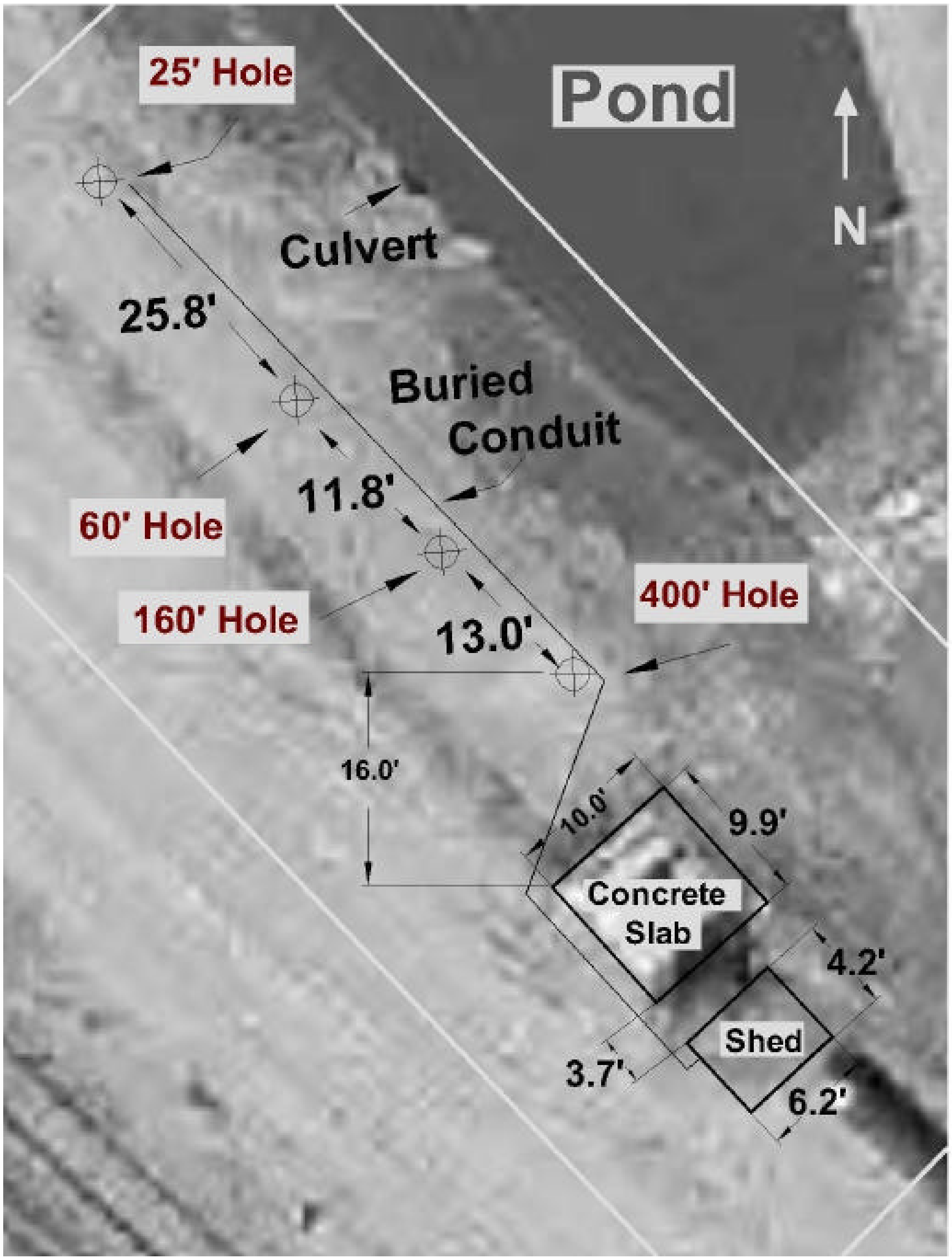


Figure 3.1. Layout of I15DA site showing borehole locations, distances and shed that houses data acquisition systems and other electronics at the site

water, was then pumped down the tremmy pipe to fill the bottom of the hole and the annular space around the casing. After filling the hole with grout, the casing was pressed down to the bottom of the hole with some raising and lowering in the process to assure that the base of the casing was surrounded with well mixed grout.

The drill rig was then driven away from the hole. Several bags of cement or bentonite were then balanced on a flat piece of timber placed on top of the casing to prevent buoyant rise of the casing. This ballast was left on the casing for a minimum of 24 hr to hold the casing in place while the grout had set.

After the grout had set, the ballast was removed and the casing was cut off a few inches above ground surface and capped with a removable cap. The capped casing was then protected temporarily by installing a plastic well-head box over the casing. This box remained in place until the final installation of FBA's in April, 2003.

Strong Ground Motion Instrumentation

All of the force balance accelerometers (FBA's) installed in the I15DA are standard, off-the-shelf units produced by Kinemetrics, Inc., Pasadena, California. Two types of downhole FBA's were installed. The shallower three FBA's are "Shallow Borehole EpiSensor (SBEPI)" FBA's. The manufacture's specifications for these and other FBA's purchased from Kinemetrics, Inc., are included in Appendix 2. The SBEPI consists of three EpiSensor FBA modules stacked and mounted orthogonally in a cylindrical stainless steel tube 2.625 in (66.68 mm) in diameter and 10.00 in (254 mm) length. The units have a full-scale recording range of ± 2.0g and a useable bandwidth from DC to 200 Hz.

The FBA in the 400 ft (122 m) casing is a Kinematics Model FBA ES-DH triaxial downhole accelerometer package designed especially for deep borehole installations. The unit consists of three EpiSensor force balance accelerometer modules stacked and mounted orthogonally in a stainless steel tube 3.00 in (76.2 mm) in diameter and 18.75 in (476 mm) in length. The internal accelerometers are the same as those contained in the Shallow EpiSensor package.

The FBA's are connected to a 12 channel Kinemetrics K2 data acquisition system through waterproof electrical cables. Each of the three component accelerometers (four FBA's times 3 modules each) connects to one of the 12 channels in the K2 unit. The K2 has an internal GPS clock for accurate timing of recorded data. The K2 has a dynamic range of approximately 114 db and 24 bit output capability. The data is stored in a DOS file system that allows cards to be read directly by a PC. The FBA's are continuously powered, but the K2 data logger only stores data during significant shaking events. The unit is set to trigger when one of the downhole accelerometers senses an acceleration of 0.01 g or greater. Upon triggering, the K2 stores data from each accelerometer for a period of 15 sec before triggering until 30 sec following the last sensed acceleration greater than 0.01 g. After significant earthquakes, the stored data will be downloaded by UUSS or USGS technicians visiting the site into a computer file for processing and distribution. .

Installation of FBA's

The Kinematics equipment was delivered to Brigham Young University in late March, 2003 and installed during the period of April 16-18, 2003. Robert Steller, GeoVision Geophysical Services, Inc., assisted with the installation of FBA's in the cased boreholes, and Marion Salsman and Walter Youngblood, USGS, connected the FBA's to the K2 data acquisition system, calibrated the FBA's, and tested the completed and operating system. The operating system was placed in service on April 18, 2003.

The Shallow EpiSensor units were installed in the shallower casings (25ft, 60 ft, and 160 ft) (7.6 m, 18.3 m, and 48.8 m) and the HypoSensor unit was installed in the 400 ft (122 m) casing. Prior to installation, each FBA canister was fitted with a borehole centering device. The package was then lowered down the casing until the FBA rested on the bottom of the casing or hardened cement paste in the case of the deep HypoSensor. The FBA was then oriented using one of the procedures noted in the following paragraph. This orientation assures the north arrow imprinted on the stainless steel canister is indeed pointing northward. Once oriented, the FBA canister was wedged into the bottom of the casing by pouring uniformly-sized aquarium gravel down the casing to form a dense gravel pack around the instrument.

For the 25 ft (7.6 m) hole, the water in the casing was pumped out and the FBA canister illuminated by a light directed down the hole. The arrow on the canister was oriented by twisting the electrical cable from the top of the hole until the arrow on the canister pointed northward. A magnetic compass at ground surface was used as reference for this orientation. Once the FBA was oriented, the coarse aquarium gravelwas poured down the hole to wedge the FBA package into surrounding casing. This procedure has been used by Mr Steller to install many FBA's. In those instances, however, Mr Steller used spherical glass beads rather than aquarium gravel as a wedging material. However, because glass beads were not readily available, the rounded aquarium gravel was substituted. The aquarium gravel has the same beneficial characteristics as the glass beads of settling into particulate structure at near 100 percent relative density. .

To assure that the aquarium gravel formed a dense pack around the FBA canisters, several tests were conducted with the aquarium gravel. The tests were conducted by pouring aquarium gravel into a transparent section of 4-in diameter casing. The casing was then tapped to further compact the gravel with the settlement of the gravel pack visually monitored. In these tests, the tapping casing caused insignificant settlement of the test gravel pack, indicating that the poured gravel settled into a dense configuration. The aquarium gravel has the advantages over glass beads of a greater specific gravity and slightly greater angular angularity. The greater density and angularity of the particles caused increased tightness and interlocking of packed particles.

The aquarium gravel use in the Shallow Episensor installations is uniformly graded with particle sizes between 5 mm and 7 mm diameter. Sufficient gravel was poured down the hole to fill the annulus around the FBA canister and cover the canister by a few inches. With this amount of gravel, the canister can be easily extracted from the gravel pack by pulling on the electrical cable. Because the FBA's have a long (several tens of years) service life, it is unlikely that a unit will fail and require removal and replacement. However, if needed, the installation is such that FBA's can be removed and reinstalled. In doing so, however, the original gravel packs may need to be flushed out of the casing.

For installation the 60 ft and 160 ft (18.3 and 48.8 m) casings, an electronic compass was temporarily fixed to the top of the FBA canister prior to lowering the package down the casing. Once on FBA was at the bottom of the hole, the package was oriented with the aid of the attached compass. Again orientation was performed by twisting the electrical cable while noting the orientation of the compass on a PC. When the package was oriented with the north arrow pointing northward, a pre-measured charge of aquarium gravel was poured down the PVC casing. Only enough gravel was used to fill the annulus around the FBA canister plus cover the canister by an inch or so. Once the FBA was fixed in place at the bottom of the casing, compressed air was blown down a small plastic tube attached to the compass. This air jettisoned the compass from the FBA canister and the compass retrieved using the airline as a hoisting cable.

The compass was easily jettisoned and retrieved from the 60 ft (18.3 m) casing. However, a high air pressure was required to jettison the compass from the FBA canister in the 160 ft (48.8 m) casing. Fortunately, the airline connections held and the compass was successfully retrieved. The difficulty, however, indicates that160 ft (48.8 m) is near the depth limit for this device.

A scaled cross section of the sediment layers and the locations and depths of the three shallower casings is sketched in Figure 3.2. This diagram indicates the relationship of the positions of the FBA's wedged into the bottoms of the casings relative to the sediment stratigraphy at the site.

A diagram of the installed FBA canister in the 160 ft (48.8 m) casing, with dimensions and other details of the packing around the instrument, is given in Figure 3.3.

Because of the depth of the 400 ft (122 m) hole, a more robust and more expensive HypoSensor FBA package was installed. For several reasons, the installation procedure for this package was different from that used for the shallower units. Details of the installed unit are sketched in Figure 3.4

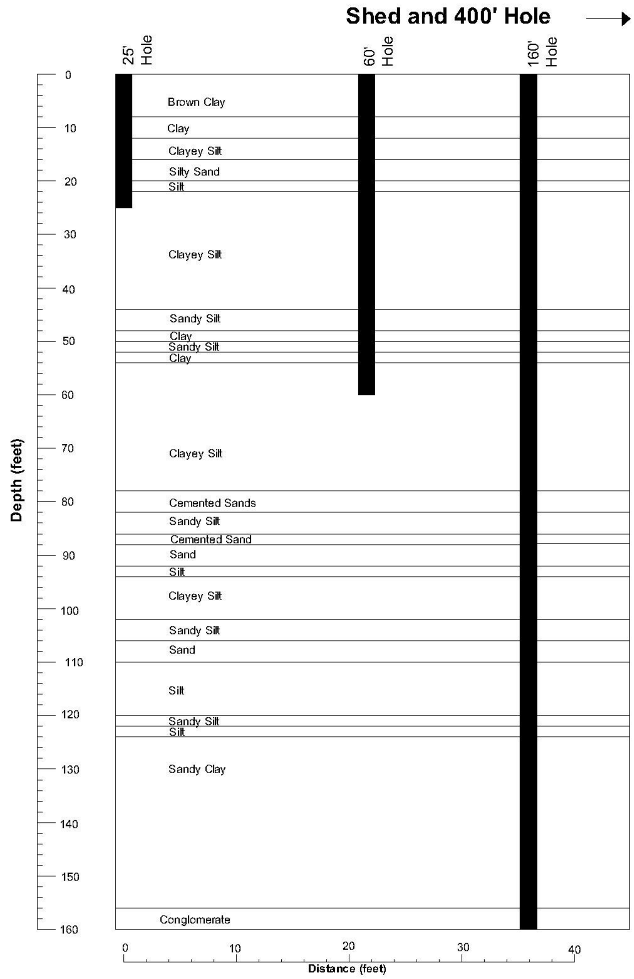


Figure 3.2 Cross section of sediment layers with positions of 25 ft, 60 ft and 160 ft (7.6 m, 18.3 m, and 48.8 m) casings marked

Because of the depth of the 400 ft (122 m) hole, use of an external compass was not feasible for orienting the FBA canister. Thus, the HypoSensor unit was ordered with a built-in electronic compass. That compass was used to orient the FBA canister and may be used in the future to recheck the orientation if such a need should arise.

.

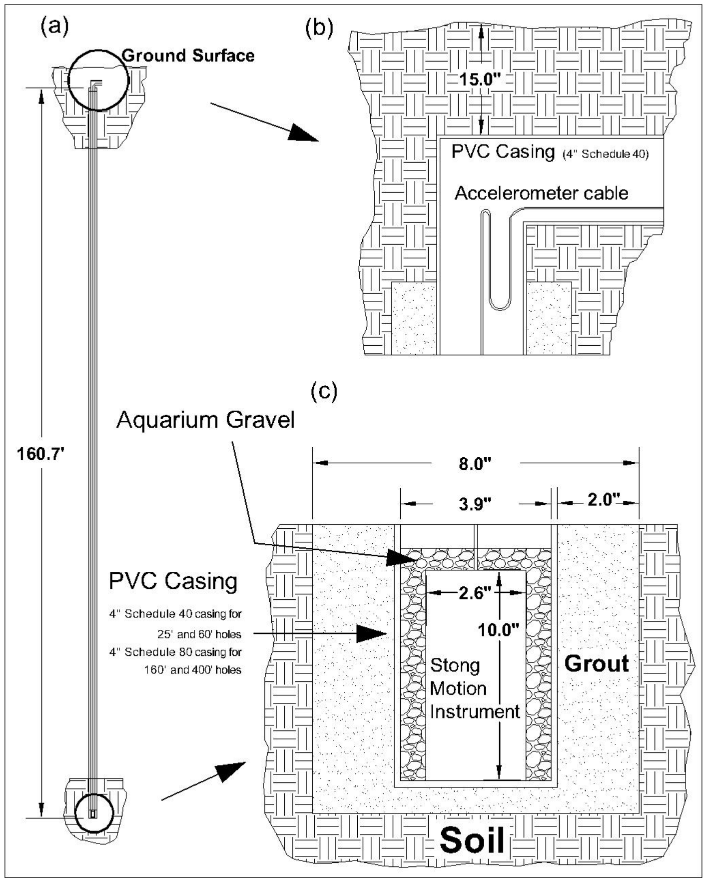


Figure 3.3. Diagram of 160 ft (48.8 m) deep FBA with detail of drill hole, grout, PVC casing, and gravel pack around FBA canister

As noted previously, water was drafted from the pond north of I15DA to fill the PVC casings. This water was sufficiently clean, for the shallower casings, that insignificant amounts of sediment settled on the base of the casing. This lack of sediment was confirmed by bouncing the FBA canister off the bottom of the installed casing and sensing by hand the hard impact of the canister. However, when the FBA canister was lowered to the bottom of the 400-ft (122-m), casing, the canister stopped 4 ft (1.2 m) short of the bottom of the casing on a cushioned surface. Thus, we estimate that about 4 ft (1.2 m) of sediment had accumulated in the bottom of this casing. To provide a firm base, the FBA canister was removed from the casing and about 35 pounds (156 N) of dry-pack concrete mix was shoveled into the casing. This mixture of gravel, sand and cement was allowed to precipitate to the bottom of the water column and accumulate on top of the soft sediment at the bottom of the casing. The accumulated concrete mix was then allowed to set and harden overnight. When the FBA canister again lowered down the 400 ft (122 m) casing, the canister hit a hard bottom at a depth of about 390 ft (119 m). With a hard bottom in place, the canister was oriented and locked into position by pouring a premeasured charge of aquarium gravel into the casing. Figure 3.4 is a diagram of the set canister in the bottom of the 400-ft (122-m) casing. To check the configuration of the precipitated concrete mix, we dropped a small charge of concrete mix into a one-liter hydrometer cylinder and measured the thicknesses of the segregated components of the mix. Based on this experiment, we estimate that there is 4 ft (1.2 m) of soft sediment in the base of the casing overlain by about 3.5 ft (1.1 m) of segregated gravel, 0.5 ft (0.15 m) of sand, and 2 ft (0.6 m) of hardened cement paste. Even though about 10 ft (3 m) of the hole was lost to provide this installation, we believe the FBA canister is rigidly fixed at a depth of 390 ft (119 m) in the 400 ft (122 m) casing. .

Because the annulus between the HypoSensor canister and the casing is narrower than that for the Shallow Episensor instruments, a finer grained aquarium gravel was used in the gravel pack for this instrument. The particle sizes in this gravel range from 4 mm to 5 mm.

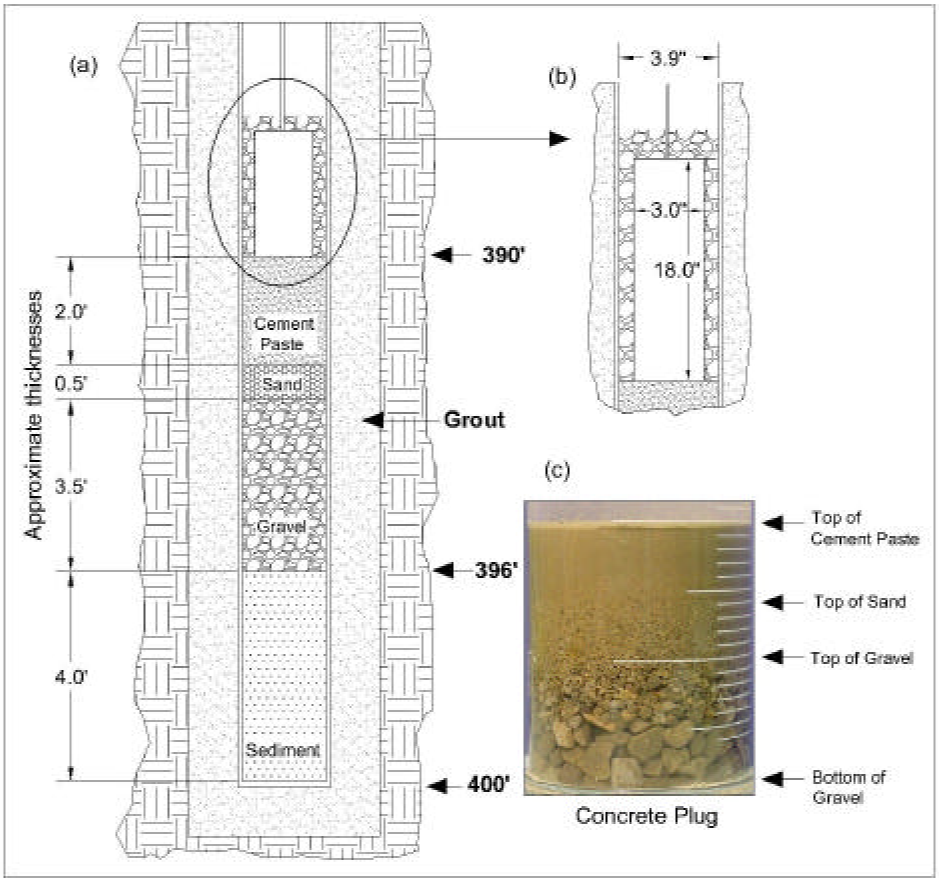


Figure 3.4. (a) Detail of casing, sediment plug, segregated and hardened concrete mix, and gravel pack around FBA canister wedged into the 400 ft (122 m)PVC casing; (b) dimensions of canister and gravel pack; (c) segregated concrete mix from test in a hydrometer cylinder

Section 4

<u>Connection of FBA's to Data Acquisition System</u>

Prior to installing the FBA's, a trench 1.5 ft (0.45 m) deep was dug parallel to the alignment of the PVC casings for burial of the electrical cables from the FBA's to the instrument shed. This trench, which was dug with a trenching machine, extended to the foundation of the instrument shed. After the trench was dug, short extensions were dug by hand to connect trench to the casing well heads. These extensions were dug sufficiently deep to allow the PVC casings to be cut off about 1.0 ft (0.3 m) below ground surface. After cutting off the PVC well heads, the latitudes and longitudes of the tops of the casings were carefully measured with a survey-grade GPS unit. Later, ground surface elevations were measured with a survey level above each casing. Those locations and elevations are listed in Table 4.1.

Table 4.1 I15DA Instrument depths, GPS Coordinates, and elevations

Casing: depth (ft)	Instrument depth (ft)	GPS coordinates	Elevation at top of ground (ft)
1: 25	25	N 40°43'23.53"	4232.8
		W 111°54'26.84"	
2: 60	59.7	N 40°43'23.43"	4233.4
		W 111°54'26.05"	
3: 160	160.8	N 40°43'23.36"	4233.9
		W 111°54'25.98"	
4: 400	393	N 40°43'23.48"	4234.1
		W 111°54'45.97"	

Electrical cables 130 ft to 360 ft (40 m and 110 m) long were bonded at the factory onto each of the Shallow EpiSensor FBA's. A 460-ft(140-m)-long cable on a spool came with the HypoSensor FBA. That cable is fitted with a waterproof connector for field attachment to that FBA .

After wedging the FBA's in the bottoms of the PVC casings, the cable from the instrument was stretched out near the pond where the cable was away from foot and vehicular traffic. After all of the FBA's were installed and the cables stretched out, 4-in diameter PVC Pipe was placed in the excavated trench and connected to the well heads with elbows and tees. The electrical cables were then pulled through the protective conduit. The PVC pipe segments and connectors in the conduit line were slipped together without gluing. A flexible coupling was also installed in the conduit near each well head. If parts of the conduit should ever need to be removed, the flexible coupling can be easily detached and the conduit pieces disassembled without cutting of the PCV pipe.

During assembly of the PVC conduit, a loop of electrical cable approximately 3 ft (0.9 m) long was formed and fitted into the top of each casing to provide slack and to assure that the pulling of the cables through the PVC conduit did not accidentally pull on an FBA. Figure 4.1 shows the top of a PVC casing after installation of the FBA, with the loop of cable in the casing and the tail of the cable extending away from the hole. Figure 4.2 shows installed PVC conduit over a wellhead with a driven fence post to mark the location of the wellhead. Figure 4.3 shows an installed section of the PVC conduit with cables from three FBA's extending out of the partially assembled conduit line.

At the edge of the instrument shed, a riser conduit fabricated of exterior-grade gray PVC electrical-conduit, was attached to the underground white PVC pipe and attached to the wall of the shed. Figure 4.4 shows the completed subsurface PVC conduit, in the process of being buried, and the vertical gray weather resistant electrical conduit temporarily placed against the wall. When finished, this riser extended from the buried white PVC to an external connection box mounted on the wall of the shed. This box was required because one of electrical cables was too short to reach the K2 data acquisition system in the shed. Gray conduit extended upward from the connection box to a grommet that provides a weatherproof entrance for the cables into the shed. Once in the shed, the cables were strung around the roofline and then down to the K2 unit. A grounded lightning protection box is installed within the shed to protect the K2 and FBA's in case of a lightening strike.

Figure 4.1. Exposed top of 25-ft (7.6 m) casing after installation of FBA; note loop of cable in the casing to provide slack and assure that later operations did not accidentally pull on the cable and lift the FBA from the bottom of the casing

Once the conduit was installed with the cables entering the instrument shed, Marion Salsman and Walter Youngblood, USGS technicians, routed the electrical cables around the interior of the shed and made the connection to the K2 data acquisition unit. The K2 contains power supply systems for the FBA's as well as the data acquisition system. In the photograph in Figure 4.5, Dr. T. Leslie Youd is resting his right hand on the K2 unit that serves the FBA's in the downhole array. This photograph was taken on April 18, 2003, the date the installation was completed. The system has been operational and recording data since that date.

Figure 4.2. PVC pipe electrical conduit extending from the top of the 25-ft (7.6-m) casing and to the trench leading to the instrument shed; note that a steel fence post has been driven near the conduit to mark the approximate location of the wellhead

Maintenance and Operation of I15DA

Operation and maintenance of the I15DA has been turned over to the University of Utah Seismograph Stations (UUSS) and the US Geological Survey (USGS). Important seismic records generated by the array will be made publicly available by

Figure 4.3. Partially installed conduit with three electrical cables threaded through pipes; note fence posts driven to mark wellhead locations

UUSS through their distribution system and links to USGS and Advanced National Network of Seismograph Stations (ANSS).

Section 5

Summary

During this project, a downhole accelerometer array (I15DA) was constructed near the intersection of I-15, I-80 and SR-201 in Salt Lake City, Utah. The street location of the array is near 2250 South and 600 West. The array consists of four downhole force

Figure 4.4. White electrical conduit, being covered, placed extended to the instrument shed foundation; a gray, external-grade electrical conduit riser is leaning against the shed; the electrical cables lying on ground surface have yet be pulled through the gray conduit

balance accelerometers (FBA's) installed at depths of 25 ft, 60 ft, 160 ft, and 390 ft (7.6 m, 18.3 m, 48.8 m, and 119 m). A surface FBA is also located at the site in the nearby instrument shed. The FBA's are locked into the bottoms of 4-in PVC casings via packs of aquarium gravel. Prior to locking the FBA's into position, they were oriented with North arrows stamped on the instrument canisters pointing northward. Electrical cables from the FBA's rise vertically through 4-in PVC casings and then horizontally through PVC conduit to the instrument shed. In the instrument shed, the cables connect to a Kinemetrics K2 data acquisition and power supply system. This system has been in operation since April 18, 2003.

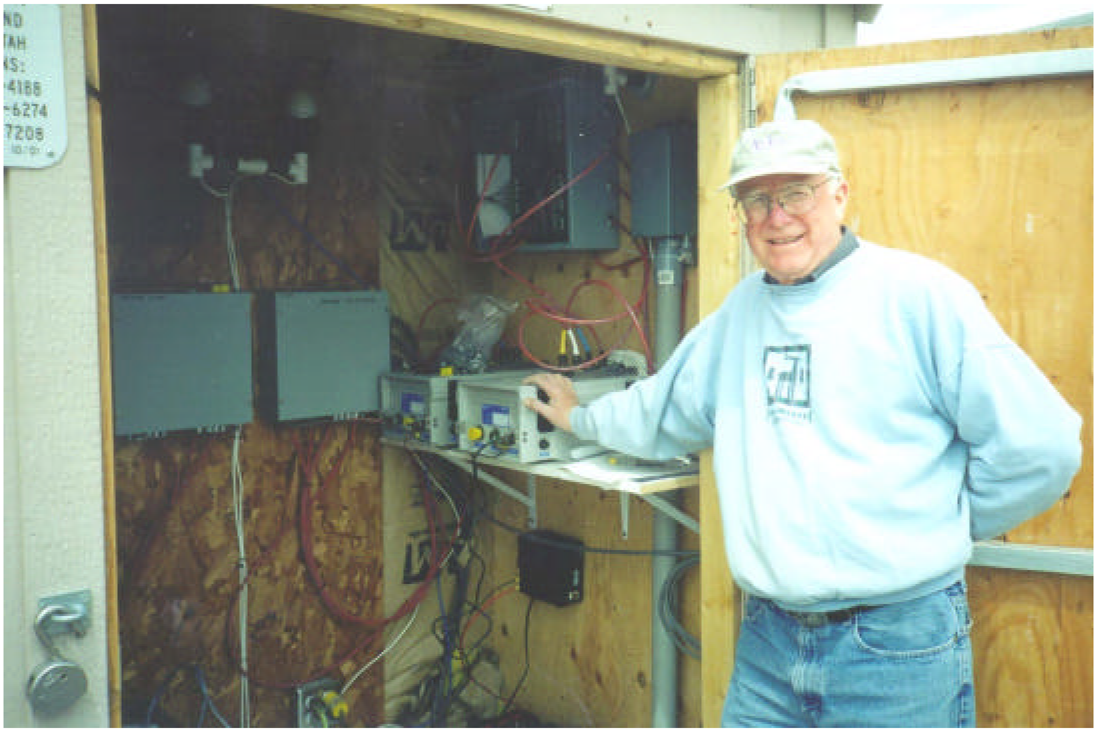


Figure 4.5. Interior of instrument shed showing the Kinematrics K2 data acquisition system installed during this project under the right hand of Dr. T. Leslie Youd

The completed system is maintained through an interagency agreement between UDOT and USGS, with USGS technicians providing periodic maintenance checks and service on the system. This interagency agreement was developed by adding a no-cost addition to a previous agreement developed for the array of FBA's attached to bridge C-846 in the nearby interchange between SR-201 and I-15. Records from the array are collected, processed and distributed by the University of Utah Seismograph Stations (UUSS), the US Geological Survey (USGS) and the Advanced National Network of Seismograph Stations (ANSS).

Section 6

Citations

Bartlett, S.F., and Farnsworth, C.B, 2002, Performance of lime cement stabilized soils for the I-15 reconstruction project, Salt Lake City Utah: TRB ID Number: 01-3314, 14p.

Case, W.F., 1985, Significant drill holes of the Wasatch Front Valleys, including Cache Valley and Tooele Valley: Utah Geological and Mineral Survey. No. 82, Salt Lake City.

GeoVision Geophysical Services, Inc., 2003, Salt Lake City UDOT 400 ft (122 m) boring at I-15 and 2200 South borehole geophysics: unpublished Project Report 2488-02, GeoVision Geophysical Services, Inc., 1151 Pomona Road, Unit P, Corona, CA 92882, 42 p.

Halling, M.W., and Petty, T., 2001, Strong motion instrumentation of I-15 bridge C-846: Utah Department of Transportation, Report No. UT -01.12.

Robertson, P.K., and Wride, C.E., 1998, Evaluating cyclic liquefaction potential using the cone penetration test: Canadian Geotechnical Journal v. 35, no. 3, p. 442-459.

Appendix 1

GEOVision
geophysical services
a division of Blackhawk Geometrics

SALT LAKE CITY

UDOT 400 FT BORING AT

I15 AND 2200 SOUTH

BOREHOLE GEOPHYSICS

May 30, 2003

SALT LAKE CITY
UDOT 400 FT BORING AT
I15 AND 2200 SOUTH
BOREHOLE GEOPHYSICS

Prepared for

Brigham Young University
368 Clyde Building
Provo, Utah 84602-4081
(801) 378-6327

Prepared by

GEOVision Geophysical Services
1151 Pomona Road, Unit P
Corona, California 92882
(909) 549-1234
Project 2488

May 30, 2003
Report 2488-02

TABLE OF CONTENTS

FIGURES

TABLES

APPENDICES

APPENDIX A FIGURES

APPENDIX A TABLES

INTRODUCTION

OYO P-S Suspension logging and electric logging were performed in one 400 ft deep land boring at the Intersection of I15 and 2200 South, in Salt Lake City. Data acquisition was performed on August 10, 2002, and April 15, 2003 by Rob Steller of GEOVision. The work was performed under subcontract with Brigham Young University (BYU), with Prof. T. Les Youd as the field liaison for BYU.

This report describes the field measurements, data analysis, and results of this work.

SCOPE OF WORK

This report presents the results of suspension velocity measurements and electric logs collected on August 9 and 10, 2002, in the uncased boring designated as the UDOT 400' boring, and April 15, 2003, in the 4 inch PVC cased boring, as detailed below. The purpose of these studies was to supplement stratigraphic information obtained during BYU's soil sampling program and to acquire shear wave velocities and compressional wave velocities as a function of depth, which, in turn, can be used to characterize ground response to earthquake motion.

BORING DESIGNATION	DATE LOGGED	GENERAL LOCATION	COORDINATES	
UDOT 400' UNCASED BORING	8/9/02, 8/10/02	SW CORNER OF INTERSECTION, ADJACENT TO CANAL	NA	NA
UDOT 400' 4" PVC CASED BORING	4/15/03	SW CORNER OF INTERSECTION, ADJACENT TO CANAL	NA	NA

Table 1. Boring location and logging dates

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. The acquired data was analyzed and a profile of velocity versus depth was produced for both compressional and horizontally polarized shear waves.

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.

A Mount Sopris Instruments MGX Digital Logger with a PolyElectric Probe containing Natural Gamma (GAMMA), Single Point Resistance (R), and 16/32/64" Normal Resistivity (R16, R32, R64) sensors was used to obtain the required electric logs.

INSTRUMENTATION

OYO PS Suspension Probe

Suspension soil velocity measurements were performed using the Model 170 Suspension Logging system, manufactured by OYO Corporation. This system directly determines the average velocity of a 3.28 ft high segment of the soil column surrounding the boring 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 boring 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 3.28 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 22 ft, with the center point of the receiver pair 15.4 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 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 boring by nylon "whiskers", therefore, source motion is not coupled directly to the boring walls; rather, the source motion creates a horizontally propagating impulsive pressure wave in the fluid filling the boring 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 boring wall. These waves propagate through the soil and rock surrounding the boring, 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 10.3 ft separation of source and receiver 1 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, as outlined in Appendix B.

Mount Sopris PolyElectric Probe

A Mount Sopris Instruments MGX Digital Logger with a PolyElectric Probe was used to obtain the required electric logs. This system consisted of a control unit and a probe designed to geophysically log the boring using two separate methods:

1. Natural Gamma to record the natural radioactivity of the soil
2. Resistivity in four separate source and receiver separations to measure the resistivity at different resolutions.

- ❖ Single Point resistance (R)
- ❖ 16 in separation normal (R16)
- ❖ 32 in separation normal (R32)
- ❖ 64 in separation normal (R64).

Following is a brief description of each method.

Gamma-Ray Logging

Gamma rays are high-energy electromagnetic waves. Nearly all gamma rays in the earth are emitted by radioactive K40, U238, and Th232. A gamma ray (GR) log indicates the amount of natural radioactivity present in a formation versus depth. In sediments, it also reflects the clay/shale content of the formation, because radioactive elements are in greater concentrations in clays/shales than in sands/sandstone. Certain volcanic rocks, such as tuffaceous ash may give rise to high natural gamma readings. Gamma-ray logs are most useful for geologic correlation, but are also used to give a quantitative indication of the bed content.

Single Point Resistance Logging

Single Point Resistance measures soil resistivity by inducing a current at the surface of the borehole and measuring the changes in resistivity as the measuring electrode is lowered down the hole. The tool is use to measure variations in formation resistivity, water salinity and variations in mud cake thickness.

Resistivity 64" long normal (R 64), 32" Medium normal (R 32) and 16" Short normal (R 16) Logging

Resistivity logging methods are designed to measure the resistivity through the mud cake into the near-surface formation. A constant current flows between two electrodes separated by a known distance. The resultant potential difference is measured between two additional electrodes and recorded on the log. For the resistivity logs used in for the survey, the electrodes have 0.4 m (16 in) separation for the short normal "R16", 0.8 m (32 in) separation for the medium normal "R32", and 1.63 m (64 in) for the long normal. The difference in electrode separation allows for variable penetration into the formation and resolution of the formation. Resistivity logs measure formation porosity, chemistry, composition of the soil/rock matrix and water salinity.

FIELD MEASUREMENT PROCEDURES

OYO PS Suspension Probe

Data collected in August 2002 was obtained in an uncased boring filled with bentonite based drilling fluid. Data collected in April 2003 was obtained in a nominal 4 in PVC cased boring filled with fresh water. In each instance, the probe was positioned with the mid-point of the receiver spacing at grade, and the mechanical and electronic depth counters were set to zero. The probe was lowered to the bottom of the boring, 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 boring.

BORING NUMBER	RUN NUMBER	DEPTH RANGE (FEET)	DEPTH AS DRILLED (FEET)	LOST TO SLOUGH/COLLAPSE (FEET)	SAMPLE INTERVAL (FEET)	DATE LOGGED
UDOT 400' BORING	1	PROBE FAILURE	400	NA	NA	8/9/02
UDOT 400' BORING	2	9.8 – 121.4	400	263.2	1.64	8/10/02
UDOT 400' BORING	3	9.8 – 236.2	400	148.4	1.64	8/10/02
UDOT 400' BORING	4	221.5 – 383.2	400 (CASED)	1.4	1.64	4/15/03

Table 2. Logging dates and depth ranges

Mount Sopris PolyElectric Probe

The boring was logged as an uncased borehole filled with bentonite based drilling fluid. Electric logging took place before the P-S Suspension logging. In accordance with the manufacturer's recommended procedures, the probe was inspected and tested prior to entering the boring. The borehole probe was then positioned as recommended by the manufacturer with the collar of the probe positioned at grade, and the electronic depth counters were set to zero. Acquisition was started on the laptop computer and the probe was lowered at a rate of 15 feet per minute to the bottom of the borehole. The approximate acquisition interval was 0.1ft. This file was then closed and a new file opened, and a new log was acquired while returning the probe to the surface. This provided both a down log file and an up log file for each borehole.

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

The up and down data files for each individual run were compared for accuracy and consistency, but the data acquired during the up run was used for analysis, due better control of the depth information, as the probe could not be momentarily "hung up" during the up run.

DATA ANALYSIS

OYO PS Suspension Probe

The recorded digital records were analyzed to locate the first minima 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 3.28 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.

The P-wave velocity calculated from the travel time over the 10.30 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 6.79 ft to correspond to the mid-point of the 10.30 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 3.9 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.

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 lowpass 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, ranging from 400 Hz in the slowest zones to 1400 Hz in the regions of highest velocity. At each depth, the filter frequency was selected to be at least twice the fundamental frequency of the S_H-wave signal being filtered.

Generally, the first maxima was picked for the 'normal' signals and the first minima 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 boring 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.

As with the P-wave data, S_H-wave velocity calculated from the travel time over the 10.30 ft interval from source to receiver 1 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 6.79 ft to correspond to the mid-point of the 10.30 ft S-R1 interval. Travel times were obtained by picking the first break of the S_H-wave signal at the near receiver and subtracting 3.9 milliseconds, the calculated and experimentally verified delay from the beginning of the record at the source trigger pulse to source impact.

Figure 2 shows an example of R1 - R2 measurements on a filtered record from a depth of 111.5 ft. In Figure 2, the time difference over the 3.28 ft interval of 4. 60 milliseconds for the horizontal signals is equivalent to an S_H-wave velocity of 713 ft/sec. Whenever possible, time differences were determined from several phase points on the S_H-waveform records to verify the data obtained from the first arrival of the S_H-wave pulse. Figure 3 displays the same record before filtering of the S_H-waveform record with an 1000 Hz FFT - IFFT digital lowpass filter, illustrating the presence of higher frequency P-wave energy at the beginning of the record, and distortion of the lower frequency S_H-wave by residual P-wave signal.

Mount Sopris PolyElectric Probe

Electric log data is provided from the Mount Sopris software as a space delimited data file, which can be imported into a spreadsheet, or other software. For this project, the data was imported to Excel for visual inspection of the data and comparison to the velocity data.

RESULTS

OYO PS Suspension Probe

Suspension R1-R2 P- and S_H-wave velocities are plotted in Figure 4. The suspension velocity data presented in this figure are presented in Tables 3 and 4. P- and S_H-wave velocity data from R1-R2 analysis and quality assurance analysis of S-R1 data are plotted together in Figure A1 to aid in visual comparison. It must be noted that R1-R2 data is an average velocity over a 3.28 ft segment of the soil column; S-R1 data is an average over 10.30 ft, creating a significant smoothing relative to the R1-R2 plots. S-R1 data are presented in tabular format in Tables A1 and A2. 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.

Calibration procedures and records for the suspension measurement system are presented in Appendix B.

Mount Sopris PolyElectric Probe

Electric logging results are presented in Figure 5. Gamma values are presented with point resistance and velocity data in Figure 6. Logging events were collected going down the boring as well as coming up the boring for QA/QC purposes and compared for consistency of signal strength and depth of transition.

In all cases the down runs and up runs were in agreement allowing the up run to be used for both of these figures.

SUMMARY

Discussion of OYO PS Suspension Results

Both P- and S_H-wave velocities were measured using the Suspension Method in one uncased land boring at depths up to 383.2 ft below grade at the Intersection of I15 and 2200 South, in Salt Lake City. The boring was located in an urban area with moderate traffic on the adjacent freeway and surface streets, however, no significant signal contamination from vehicular induced vibration was observed. A railroad yard was adjacent to the site, and data collection was stopped during periods of activity on the adjacent tracks.

The boring showed P-wave velocities less than water velocity (approximately 5000 ft/sec) above a depth of 65 ft, indicating the possibility of gas bubbles in the soil, perhaps due to organic decomposition. A substantial increase in shear wave velocity is observed at 95 ft, indicating a probable change in formation. At 165 ft, the shear wave velocity becomes quite variable, indicating interbedded sands or silts, and gravels.

The overlap of data collected on 8/10/02 and 4/15/03 does not show precise agreement between the two data sets, particularly in the shear wave velocity profiles. This region of the borehole may have been badly eroded during construction, causing different measured velocities due to the different behavior of bentonite based drilling fluid versus grout in the eroded space.

Discussion of Mount Sopris PolyElectric Probe Results

The resistivity and gamma data both show greater variation with depth than does the velocity data. Both electric log data sets indicate closely interbedded stratigraphy, probably representing successive deposits of sands, silts and gravels. The differing flat-line values of the different resistivity plots indicates a difference in salinity of the borehole fluid from that in formation.

Quality Assurance

These velocity measurements were performed using industry-standard or better methods for both measurements and analyses. All work was performed under GEOVision 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.

Data Reliability

P- and S_H-wave velocity measurement using the Suspension Method gives average velocities over a 3.28 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 and quality assurance checks add to the reliability of these data.

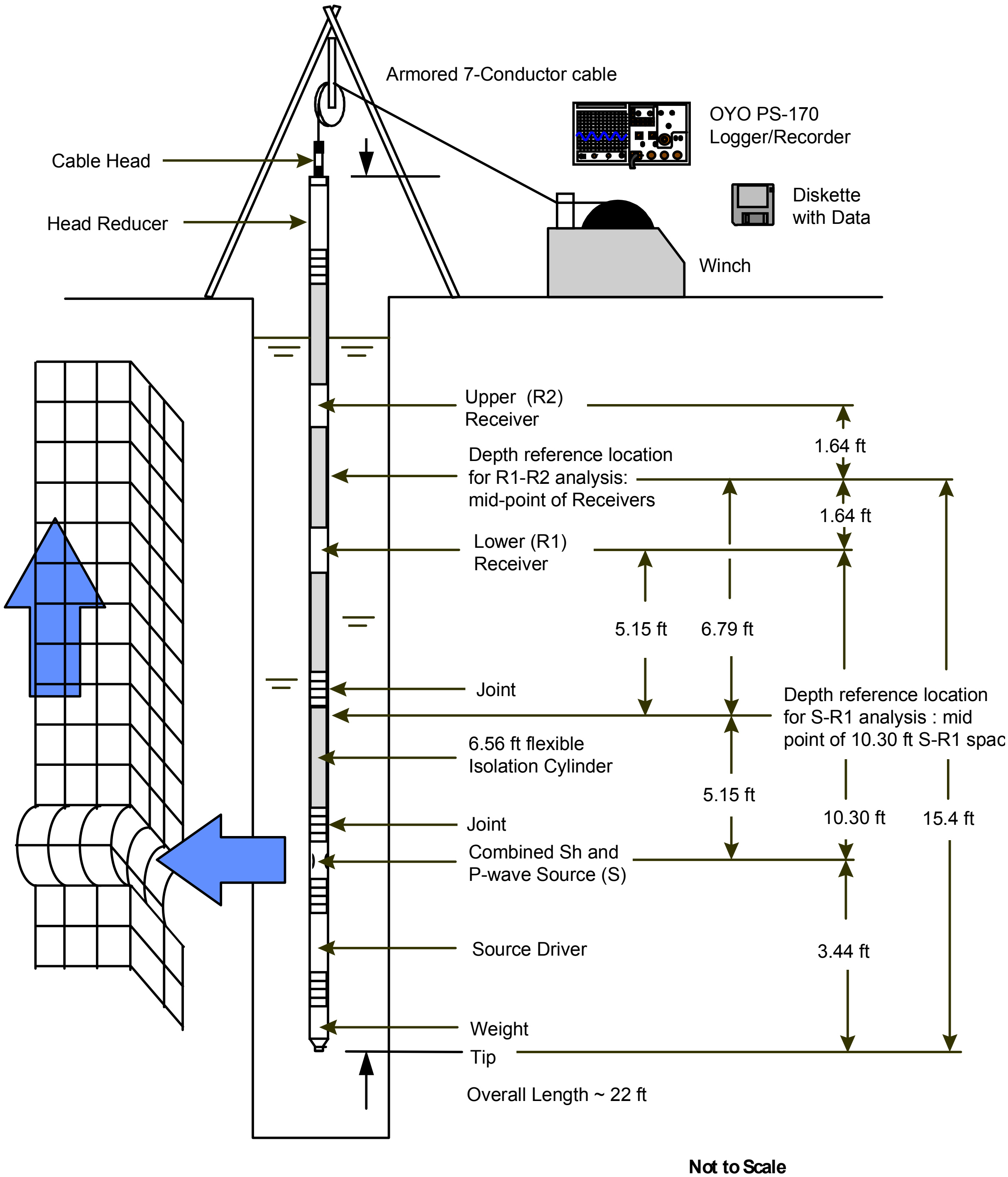


Figure 1. Concept illustration of P-S logging system

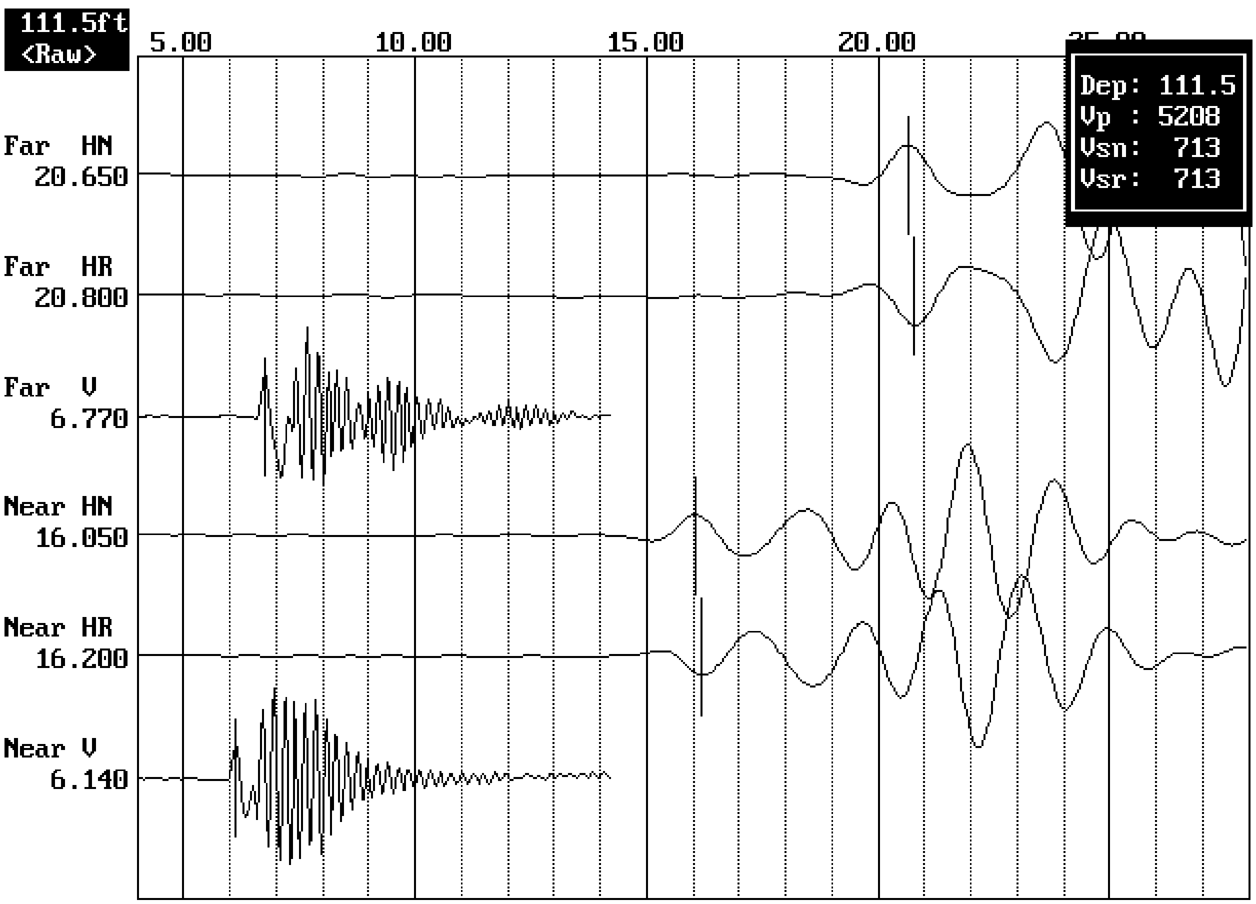


Figure 2. Example of filtered (1000 Hz lowpass) record from 111.5 ft in UDOT 400' Boring

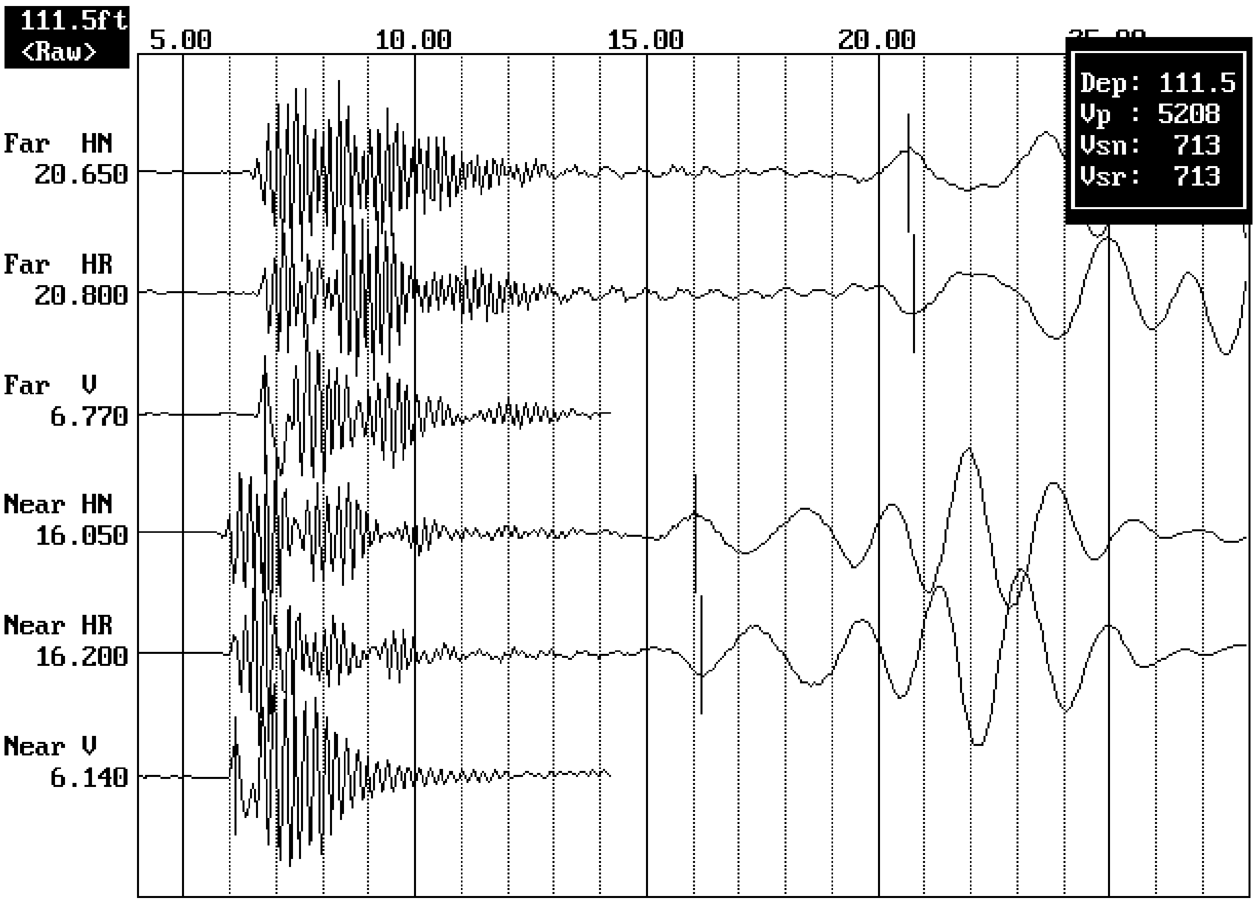


Figure 3. Example of unfiltered record from 111.5 ft in UDOT 400' Boring

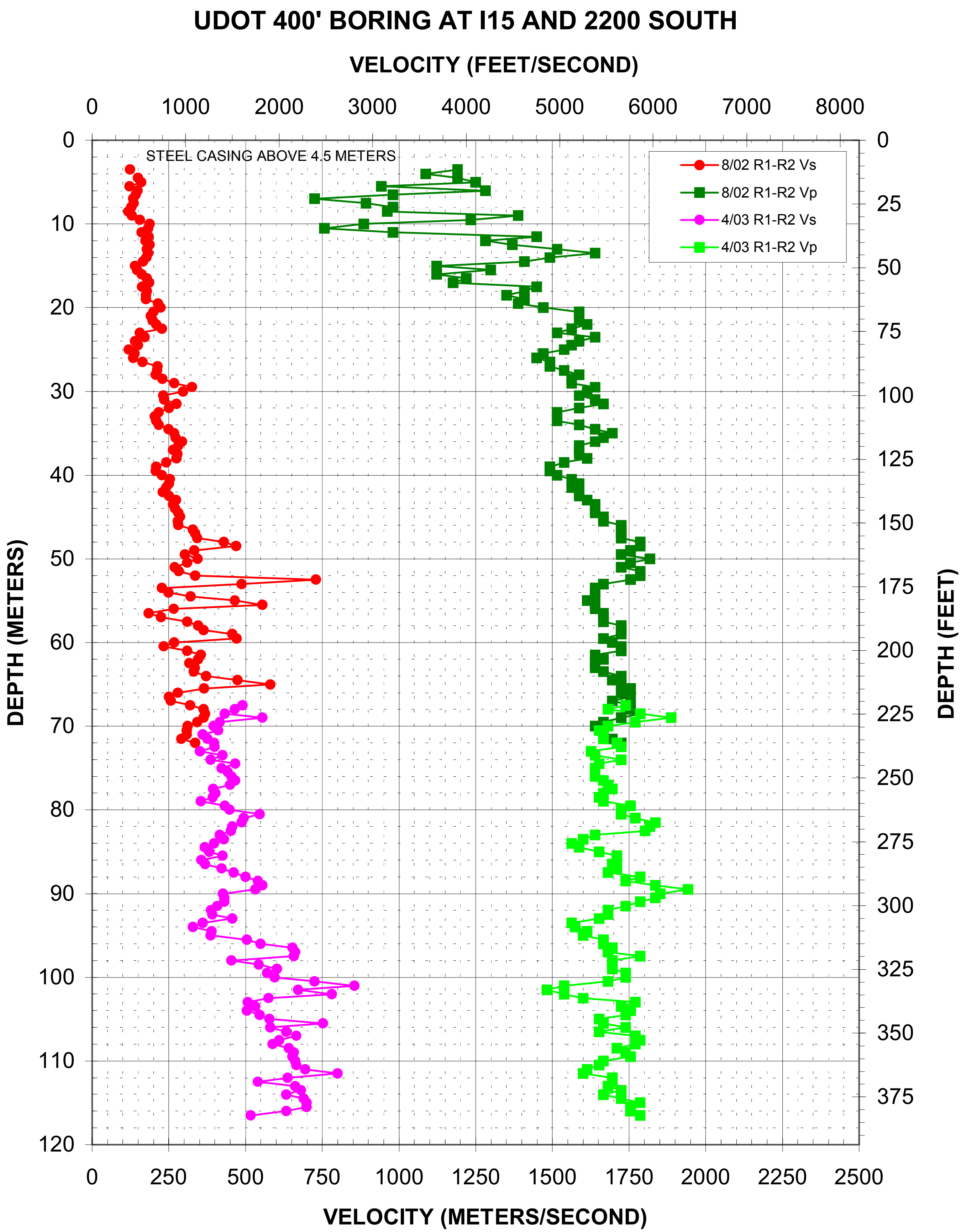


Figure 4. UDOT 400' Boring, Suspension P- and S_H-wave velocities

Depth		Pick Times						Velocity			
		Far-Hn	Far-Hr	Far-V	Near-Hn	Near-Hr	Near-V	V-S_H	V-P	V-S_H	V-P
(m)	(feet)	(millisec)	(millisec)	(millisec)	(millisec)	(millisec)	(millisec)	(m/sec)	(m/sec)	(ft/sec)	(ft/sec)
3.0	9.8				25.30		7.56			0	0
3.5	11.5	36.80		8.40	28.70		7.56	123	1190	405	3906
4.0	13.1			8.42	30.80		7.50		1087	0	3566
4.5	14.8	39.20	39.90	8.36	32.50	33.30	7.52	150	1190	493	3906
5.0	16.4	40.00	39.60	8.26	33.40	33.70	7.46	160	1250	525	4101
5.5	18.0	35.80	36.10	8.36	27.00	28.60	7.30	123	943	403	3095
6.0	19.7	34.50	35.20	8.42	27.80	28.40	7.64	148	1282	486	4206
6.5	21.3	34.60	34.60	8.98	27.30	27.90	7.96	143	980	469	3217
7.0	23.0	34.80	34.30	9.48	26.90	27.30	8.10	134	725	440	2377
7.5	24.6	34.15	33.90	9.48	26.40	26.95	8.36	136	893	446	2929
8.0	26.2	33.45	32.70	9.48	25.05	25.55	8.46	129	980	422	3217
8.5	27.9	31.85	32.55	9.18	24.10	23.40	8.14	118	962	388	3155
9.0	29.5	30.75	30.15	8.68	23.20	22.35	7.96	130	1389	427	4557
9.5	31.2	29.10	28.45	8.20	22.70	22.05	7.39	156	1235	513	4050
10.0	32.8	28.05	27.00	8.76	22.70	21.65	7.63	187	885	613	2903
10.5	34.4	27.30	26.60	8.53	21.90	21.10	7.21	183	758	602	2485
11.0	36.1	28.10	27.00	8.38	21.90	20.85	7.36	162	980	531	3217
11.5	37.7	28.05	27.00	7.26	22.90	21.30	6.57	184	1449	605	4755
12.0	39.4	28.05	27.50	7.26	22.00	22.05	6.48	174	1282	571	4206
12.5	41.0	27.75	29.05	7.26	22.55	23.60	6.53	188	1370	616	4494
13.0	42.7	30.55	29.40	7.21	24.95	23.85	6.55	179	1515	588	4971
13.5	44.3	30.65	29.40	7.13	25.30	23.85	6.52	183	1639	602	5378
14.0	45.9	30.80	30.05	7.66	25.50	24.05	6.99	177	1493	581	4897
14.5	47.6	31.20	30.20	7.64	25.15	24.15	6.93	165	1408	542	4621
15.0	49.2	31.70	30.60	7.69	24.45	23.50	6.80	139	1124	457	3686
15.5	50.9	30.10	30.30	7.82	23.75	23.00	7.05	147	1299	481	4261
16.0	52.5	29.75	28.60	7.43	23.15	22.85	6.54	162	1124	531	3686
16.5	54.1	29.10	27.75	7.28	23.00	22.70	6.46	179	1220	588	4001
17.0	55.8	26.15	27.45	7.24	20.50	22.35	6.39	186	1176	610	3860
17.5	57.4	27.40	27.85	7.40	21.05	21.95	6.71	163	1449	536	4755
18.0	59.1	26.00	27.40	7.32	20.60	21.65	6.61	179	1408	588	4621
18.5	60.7	25.80	27.15	7.31	20.10	21.45	6.57	175	1351	576	4434
19.0	62.3	25.80	26.55	7.25	20.00	21.00	6.54	176	1408	578	4621
19.5	64.0	25.00	25.20	7.18	20.20	20.70	6.46	215	1389	706	4557
20.0	65.6	25.80	26.40	7.18	21.45	21.80	6.50	223	1471	733	4825
20.5	67.3	26.40	26.40	7.15	21.40	21.45	6.52	201	1587	659	5208
21.0	68.9	26.45	26.70	6.97	21.30	21.40	6.34	191	1587	628	5208
21.5	70.5	25.70	26.40	6.95	20.70	21.30	6.32	198	1587	650	5208
22.0	72.2	27.30	26.70	6.89	22.15	22.30	6.27	209	1613	687	5292
22.5	73.8		29.45	7.02	22.40	25.05	6.38	227	1563	746	5126
23.0	75.5		28.55	7.08	22.85	22.10	6.42	155	1515	509	4971
23.5	77.1	28.20	27.70	6.86	22.10	22.10	6.25	171	1639	561	5378
24.0	78.7	29.60	29.70	7.04	22.80	22.25	6.41	140	1587	460	5208
24.5	80.4	30.00	30.20	7.05	23.40	23.45	6.41	150	1562	492	5126
25.0	82.0	30.45	30.75	7.05	22.30	22.20	6.40	120	1538	393	5047
25.5	83.7	27.85	28.10	7.06	20.80	20.75	6.38	139	1471	456	4825
26.0	85.3	26.80	26.45	7.09	19.15	19.20	6.40	134	1449	440	4755
26.5	86.9	25.15	24.95	7.06	19.00	18.95	6.39	165	1493	540	4897
27.0	88.6	23.70	24.55	7.05	19.00	19.85	6.38	213	1493	698	4897
27.5	90.2	22.50	22.55	6.97	17.65	17.95	6.32	212	1538	694	5047

Table 3. UDOT 400’ Boring, Suspension R1-R2 depth, pick times, and velocities collected 8/10/02

Depth		Pick Times						Velocity			
(m)	(feet)	Far-Hn (millisec)	Far-Hr (millisec)	Far-V (millisec)	Near-Hn (millisec)	Near-Hr (millisec)	Near-V (millisec)	V-S_H (m/sec)	V-P (m/sec)	V-S_H (ft/sec)	V-P (ft/sec)
28.0	91.9	22.10	22.20	6.93	17.30	17.35	6.30	207	1587	680	5208
28.5	93.5	21.60	21.70	6.89	17.20	17.35	6.25	229	1563	750	5126
29.0	95.1	21.20	21.15	6.85	17.35	17.55	6.21	268	1563	881	5126
29.5	96.8	21.15	21.30	6.87	18.05	18.25	6.26	325	1639	1067	5378
30.0	98.4	21.60	21.80	6.86	18.25	18.40	6.24	296	1613	972	5292
30.5	100.1	22.45	22.70	6.86	18.20	18.35	6.23	233	1587	763	5208
31.0	101.7	23.05	23.00	6.89	18.75	18.80	6.28	235	1639	772	5378
31.5	103.3	22.25	22.45	6.88	18.70	18.75	6.28	276	1667	905	5468
32.0	105.0	22.40	22.55	6.90	18.50	18.50	6.27	252	1587	825	5208
32.5	106.6	22.35	22.45	6.88	17.70	17.90	6.22	217	1515	713	4971
33.0	108.3	21.80	22.00	6.83	16.95	17.10	6.17	205	1515	673	4971
33.5	109.9	21.20	21.35	6.80	16.45	16.55	6.14	209	1515	687	4971
34.0	111.5	20.65	20.80	6.77	16.05	16.20	6.14	217	1587	713	5208
34.5	113.2	20.00	20.15	6.74	16.00	16.15	6.13	250	1639	820	5378
35.0	114.8	19.85	20.05	6.74	16.10	16.35	6.15	268	1695	881	5561
35.5	116.5	20.20	20.45	6.76	16.55	16.75	6.16	272	1667	893	5468
36.0	118.1	20.65	20.90	6.78	17.25	17.50	6.17	294	1639	965	5378
36.5	119.8	21.30	21.55	6.82	17.75	18.00	6.19	282	1587	924	5208
37.0	121.4	21.90	22.10	6.83	18.10	18.30	6.20	263	1587	863	5208
37.5	123.0	21.95	22.20	6.70	18.35	18.60	6.07	278	1587	911	5208
38.0	124.7	22.20	22.45	6.69	18.60	18.80	6.07	276	1613	905	5292
38.5	126.3	22.58	22.78	6.65	18.44	18.64	6.00	242	1538	792	5047
39.0	128.0	22.72	22.94	6.66	17.96	18.16	5.99	210	1493	688	4897
39.5	129.6	22.14	22.36	6.64	17.34	17.56	5.97	208	1493	684	4897
40.0	131.2	21.56	21.80	6.61	17.18	17.42	5.95	228	1515	749	4971
40.5	132.9	21.14	21.32	6.59	17.20	17.40	5.95	254	1562	835	5126
41.0	134.5	20.84	21.04	6.57	16.84	17.06	5.94	251	1587	822	5208
41.5	136.2	20.64	20.84	6.55	16.52	16.72	5.91	243	1563	796	5126
42.0	137.8	20.56	20.72	6.54	16.20	16.42	5.91	231	1587	758	5208
42.5	139.4	20.34	20.52	6.53	16.34	16.54	5.90	251	1587	822	5208
43.0	141.1	19.70	19.92	6.51	16.02	16.28	5.89	273	1613	896	5292
43.5	142.7	19.56	19.78	6.49	15.78	16.00	5.88	265	1639	868	5378
44.0	144.4	19.14	19.34	6.49	15.46	15.66	5.88	272	1639	892	5378
44.5	146.0	18.84	19.08	6.45	15.28	15.52	5.84	281	1639	922	5378
45.0	147.6	19.10	19.34	6.45	15.60	15.86	5.85	287	1667	940	5468
45.5	149.3	19.48	19.72	6.45	15.90	16.14	5.85	279	1667	916	5468
46.0	150.9	19.54	19.74	6.43	15.96	16.20	5.85	281	1724	922	5657
46.5	152.6	18.72	18.90	6.41	15.68	15.86	5.83	329	1724	1079	5657
47.0	154.2	18.66	18.96	6.41	15.68	15.98	5.83	336	1724	1101	5657
47.5	155.8	18.88	19.04	6.39	15.96	16.14	5.81	344	1724	1127	5657
48.0	157.5	18.04	18.24	6.37	15.70	15.92	5.81	429	1786	1408	5859
48.5	159.1	17.76	17.88	6.38	15.60	15.78	5.82	469	1786	1540	5859
49.0	160.8	18.42	18.68	6.36	15.42	15.68	5.79	333	1754	1094	5756
49.5	162.4	19.70	19.92	6.38	16.40	16.62	5.80	303	1724	994	5657
50.0	164.0	20.12	20.32	6.49	17.20	17.44	5.94	345	1818	1131	5965
50.5	165.7	19.86	20.00	6.51	16.72	16.70	5.94	311	1754	1019	5756
51.0	167.3	18.96	19.16	6.53	15.24	15.46	5.95	270	1724	884	5657
51.5	169.0	18.66	18.86	6.52	15.14	15.32	5.96	283	1786	929	5859
52.0	170.6	18.56	18.76	6.57	15.58	15.78	6.01	336	1786	1101	5859
52.5	172.2	19.70	19.94	6.53	18.34	18.56	5.96	730	1754	2395	5756

Table 3, continued. UDOT 400’ Boring, Suspension R1-R2 depth, pick times, and velocities collected 8/10/02

Depth		Pick Times						Velocity			
(m)	(feet)	Far-Hn (millisec)	Far-Hr (millisec)	Far-V (millisec)	Near-Hn (millisec)	Near-Hr (millisec)	Near-V (millisec)	V-S_H (m/sec)	V-P (m/sec)	V-S_H (ft/sec)	V-P (ft/sec)
53.0	173.9	20.58	20.54	6.63	18.42	18.60	6.03	488	1667	1600	5468
53.5	175.5	20.60	20.76	6.61	16.22	16.38	6.00	228	1639	749	5378
54.0	177.2	19.56	19.76	6.64	15.56	15.74	6.03	249	1639	818	5378
54.5	178.8	18.74	18.92	6.49	15.64	15.80	5.88	322	1639	1055	5378
55.0	180.4	18.48	18.68	6.49	16.30	16.56	5.87	465	1613	1526	5292
55.5	182.1	18.56	18.72	6.49	16.72	16.96	5.88	556	1639	1823	5378
56.0	183.7	19.54	19.78	6.46	15.80	16.04	5.85	267	1639	877	5378
56.5	185.4	21.22	21.36	6.44	15.74	16.00	5.84	185	1667	605	5468
57.0	187.0	19.52	19.74	6.47	15.10	15.26	5.87	225	1667	737	5468
57.5	188.6	17.70	17.88	6.47	14.46	14.66	5.87	310	1667	1016	5468
58.0	190.3	17.10	17.30	6.44	14.22	14.40	5.86	346	1724	1135	5657
58.5	191.9	17.06	17.28	6.43	14.32	14.52	5.85	364	1724	1193	5657
59.0	193.6	16.92	17.16	6.43	14.74	14.96	5.85	457	1724	1498	5657
59.5	195.2	17.16	17.40	6.53	15.04	15.28	5.93	472	1667	1548	5468
60.0	196.9	17.96	18.20	6.55	14.26	14.44	5.96	268	1695	880	5561
60.5	198.5	18.34	18.54	6.55	14.06	14.28	5.97	234	1724	768	5657
61.0	200.1	17.40	17.58	6.56	14.16	14.38	5.98	311	1724	1019	5657
61.5	201.8	17.32	17.58	6.57	14.54	14.72	5.96	355	1639	1163	5378
62.0	203.4	17.94	18.14	6.44	15.08	15.22	5.84	346	1667	1135	5468
62.5	205.1	19.38	19.58	6.57	16.24	16.42	5.96	317	1639	1042	5378
63.0	206.7	19.74	19.94	6.52	16.76	16.94	5.91	334	1639	1097	5378
63.5	208.3	18.68	18.94	6.52	15.66	15.94	5.92	332	1667	1090	5468
64.0	210.0	17.92	18.16	6.48	15.26	15.44	5.90	372	1724	1220	5657
64.5	211.6	17.60	17.80	6.45	15.50	15.68	5.86	474	1695	1555	5561
65.0	213.3	17.40	17.68	6.42	15.74	15.90	5.84	581	1724	1907	5657
65.5	214.9	17.80	17.98	6.43	15.08	15.22	5.86	365	1754	1197	5756
66.0	216.5	18.26	18.48	6.45	14.70	14.90	5.87	280	1724	919	5657
66.5	218.2	18.24	18.40	6.45	14.20	14.46	5.88	251	1754	822	5756
67.0	219.8	17.96	18.18	6.46	14.06	14.28	5.87	256	1695	841	5561
67.5	221.5	17.44	17.62	6.45	14.30	14.50	5.88	319	1754	1048	5756
68.0	223.1	17.16	17.36	6.46	14.42	14.60	5.89	364	1754	1193	5756
68.5	224.7	17.18	17.34	6.44	14.48	14.62	5.88	369	1786	1211	5859
69.0	226.4	17.16	17.22	6.50	14.38	14.50	5.92	364	1724	1193	5657
69.5	228.0	17.26	17.46	6.45	14.34	14.56	5.85	344	1667	1127	5468
70.0	229.7	17.36	17.56	6.51	14.14	14.36	5.90	312	1639	1022	5378
70.5	231.3	17.20	17.38	6.51	13.94	14.16	5.91	309	1667	1013	5468
71.0	232.9	16.76	16.98	6.51	13.52	13.74	5.91	309	1667	1013	5468
71.5	234.6	16.60	16.82	6.51	13.18	13.38	5.92	292	1695	957	5561
72.0	236.2	16.30	16.50	6.50	13.35	13.50	5.92	336	1724	1103	5657

Table 3, continued. UDOT 400' Boring, Suspension R1-R2 depth, pick times, and velocities collected 8/10/02

Depth		Pick Times						Velocity			
(m)	(feet)	Far-Hn (millisec)	Far-Hr (millisec)	Far-V (millisec)	Near-Hn (millisec)	Near-Hr (millisec)	Near-V (millisec)	V-S_H (m/sec)	V-P (m/sec)	V-S_H (ft/sec)	V-P (ft/sec)
67.5	221.5	10.54	10.52	6.53	8.48	8.50	5.96	490	1739	1608	5706
68.0	223.1	10.34	10.54	6.53	8.28	8.30	5.93	465	1681	1526	5514
68.5	224.7	10.90	10.98	6.53	8.60	8.66	5.97	433	1786	1420	5859
69.0	226.4	10.52	10.58	6.55	8.78	8.72	6.02	556	1887	1823	6190
69.5	228.0	12.78	12.68	6.58	10.28	10.38	6.02	417	1770	1367	5807
70.0	229.7	13.30	13.20	6.58	10.68	10.78	5.99	397	1681	1302	5514
70.5	231.3	13.82	13.76	6.61	11.36	11.36	6.00	412	1653	1350	5423
71.0	232.9	13.96	13.86	6.58	11.18	11.10	5.98	361	1667	1184	5468
71.5	234.6	14.36	14.36	6.52	11.68	11.72	5.92	376	1667	1233	5468
72.0	236.2	14.48	14.40	6.58	11.96	11.90	6.00	398	1709	1307	5608
72.5	237.9	13.98	14.00	6.58	11.44	11.54	6.00	400	1724	1312	5657
73.0	239.5	14.26	14.16	6.55	11.34	11.40	5.93	352	1626	1155	5335
73.5	241.1	11.68	11.86	6.48	9.38	9.46	5.87	426	1639	1396	5378
74.0	242.8	13.60	13.70	6.63	11.08	11.04	6.05	386	1724	1267	5657
74.5	244.4	14.66	14.60	6.60	12.50	12.48	5.99	467	1653	1533	5423
75.0	246.1	14.70	14.66	6.61	12.30	12.32	6.00	422	1639	1384	5378
75.5	247.7	12.76	12.84	6.63	10.50	10.58	6.02	442	1639	1452	5378
76.0	249.3	12.74	12.66	6.62	10.48	10.52	6.01	455	1639	1491	5378
76.5	251.0	12.76	12.78	6.58	10.58	10.68	5.98	467	1667	1533	5468
77.0	252.6	12.88	12.84	6.55	10.68	10.60	5.96	450	1681	1478	5514
77.5	254.3	12.78	12.72	6.50	10.20	10.24	5.91	395	1695	1297	5561
78.0	255.9	12.84	12.94	6.47	10.38	10.42	5.87	402	1667	1318	5468
78.5	257.5	12.68	12.72	6.60	10.10	10.22	5.99	394	1653	1292	5423
79.0	259.2	12.58	12.52	6.59	9.72	9.74	5.99	355	1667	1163	5468
79.5	260.8	14.60	14.68	6.55	12.28	12.38	5.98	433	1754	1420	5756
80.0	262.5	14.66	14.70	6.57	12.40	12.50	5.99	448	1724	1471	5657
80.5	264.1	14.60	14.60	6.57	12.72	12.82	5.99	546	1724	1793	5657
81.0	265.7	15.66	15.86	6.60	13.62	13.86	6.04	495	1770	1624	5807
81.5	267.4	12.34	12.18	6.62	10.30	10.12	6.08	488	1835	1600	6020
82.0	269.0	14.38	14.44	6.65	12.16	12.28	6.10	457	1818	1498	5965
82.5	270.7	12.44	13.52	6.53	10.22	11.32	5.97	452	1802	1485	5911
83.0	272.3	14.42	14.50	6.68	12.02	12.10	6.07	417	1639	1367	5378
83.5	274.0	12.42	13.60	6.70	10.10	11.26	6.08	429	1600	1408	5249
84.0	275.6	12.64	12.74	6.56	10.14	10.22	5.92	398	1563	1307	5126
84.5	277.2	12.64	14.54	6.66	10.06	11.68	6.03	368	1587	1206	5208
85.0	278.9	13.06	14.00	6.62	10.52	11.30	6.02	382	1653	1252	5423
85.5	280.5	12.52	12.62	6.60	10.20	10.24	6.01	426	1709	1396	5608
86.0	282.2	14.14	14.20	6.58	11.30	11.42	6.00	356	1709	1168	5608
86.5	283.8	13.68	13.80	6.56	10.96	11.10	5.97	369	1695	1211	5561
87.0	285.4	11.90	12.02	6.54	9.54	9.64	5.96	422	1709	1384	5608
87.5	287.1	11.68	11.86	6.54	9.56	9.64	5.94	461	1681	1512	5514
88.0	288.7	11.66	13.44	6.49	9.92	11.18	5.93	500	1786	1640	5859
88.5	290.4	11.74	12.76	6.52	10.06	10.74	5.94	541	1739	1773	5706
89.0	292.0	12.08	12.40	6.52	10.36	10.52	5.98	556	1835	1823	6020
89.5	293.6	12.38	12.62	6.51	10.58	10.66	6.00	532	1942	1745	6371
90.0	295.3	12.82	12.92	6.54	10.52	10.54	6.00	427	1852	1402	6076
90.5	296.9	12.94	12.86	6.61	10.58	10.58	6.06	431	1835	1414	6020
91.0	298.6	12.74	12.74	6.64	10.38	10.46	6.08	431	1786	1414	5859
91.5	300.2	16.32	16.36	6.66	13.86	13.92	6.09	408	1739	1339	5706
92.0	301.8	16.28	16.36	6.67	13.68	13.80	6.07	388	1681	1272	5514

Table 4. UDOT 400' Boring, Suspension R1-R2 depth, pick times, and velocities collected 4/15/03

Depth		Pick Times						Velocity			
(m)	(feet)	Far-Hn (millisec)	Far-Hr (millisec)	Far-V (millisec)	Near-Hn (millisec)	Near-Hr (millisec)	Near-V (millisec)	V-S_H (m/sec)	V-P (m/sec)	V-S_H (ft/sec)	V-P (ft/sec)
92.5	303.5	13.12	16.64	6.63	10.80	13.86	6.04	392	1681	1287	5514
93.0	305.1	12.92	13.00	6.64	10.78	10.76	6.03	457	1653	1498	5423
93.5	306.8	12.82	16.94	6.65	9.90	14.32	6.01	361	1562	1184	5126
94.0	308.4	14.62	14.62	6.65	11.56	11.60	6.01	329	1575	1079	5167
94.5	310.0	14.26	14.16	6.61	11.66	11.62	5.99	389	1613	1277	5292
95.0	311.7	14.26	14.28	6.55	11.66	11.70	5.93	386	1600	1267	5249
95.5	313.3	11.44	11.66	6.52	9.70	9.44	5.92	505	1667	1657	5468
96.0	315.0	11.52	11.58	6.50	9.68	9.78	5.90	549	1667	1803	5468
96.5	316.6	11.36	11.48	6.48	9.84	9.94	5.89	654	1695	2144	5561
97.0	318.2	11.24	11.36	6.43	9.76	9.82	5.84	662	1681	2173	5514
97.5	319.9	11.18	11.16	6.53	9.64	9.66	5.97	658	1786	2158	5859
98.0	321.5	10.92	10.88	6.58	8.76	8.64	5.99	455	1695	1491	5561
98.5	323.2	10.18	10.20	6.56	8.40	8.30	5.97	543	1695	1783	5561
99.0	324.8	9.72	9.62	6.61	8.04	7.98	6.02	602	1695	1976	5561
99.5	326.4	9.96	9.94	6.62	8.24	8.16	6.04	571	1739	1875	5706
100.0	328.1	9.78	9.74	6.62	8.10	8.06	6.04	595	1739	1953	5706
100.5	329.7	9.90	9.90	6.62	8.52	8.52	6.02	725	1681	2377	5514
101.0	331.4	10.08	10.06	6.73	8.92	8.88	6.08	855	1538	2804	5047
101.5	333.0	12.60	12.66	6.58	11.10	11.18	5.90	671	1481	2202	4861
102.0	334.6	12.28	12.24	6.52	10.96	11.00	5.87	781	1538	2563	5047
102.5	336.3	10.62	12.58	6.52	8.96	10.76	5.89	575	1600	1886	5249
103.0	337.9	10.78	12.60	6.45	8.92	10.52	5.88	508	1770	1665	5807
103.5	339.6	10.50	12.42	6.57	8.68	10.48	5.99	532	1724	1745	5657
104.0	341.2	10.36	10.44	6.57	8.40	8.44	6.00	505	1754	1657	5756
104.5	342.8	10.40	10.34	6.57	8.56	8.52	6.00	546	1739	1793	5706
105.0	344.5	10.22	10.16	6.59	8.50	8.42	5.98	578	1653	1896	5423
105.5	346.1	10.04	10.08	6.45	8.72	8.74	5.85	752	1667	2467	5468
106.0	347.8	10.14	10.08	6.48	8.44	8.34	5.90	581	1739	1907	5706
106.5	349.4	10.20	10.20	6.63	8.60	8.64	6.02	633	1653	2076	5423
107.0	351.0	10.04	10.00	6.47	8.52	8.52	5.90	667	1770	2187	5807
107.5	352.7	10.00	9.94	6.48	8.30	8.36	5.92	610	1786	2001	5859
108.0	354.3	9.84	9.76	6.50	8.10	8.10	5.93	588	1770	1930	5807
108.5	356.0	9.78	10.14	6.53	8.22	8.58	5.95	641	1709	2103	5608
109.0	357.6	9.52	9.54	6.52	7.98	8.04	5.95	658	1739	2158	5706
109.5	359.3	9.46	9.50	6.59	7.92	7.98	6.02	654	1754	2144	5756
110.0	360.9	9.38	9.40	6.60	7.86	7.90	6.00	662	1667	2173	5468
110.5	362.5	9.34	9.36	6.61	7.82	7.88	6.00	667	1653	2187	5423
111.0	364.2	9.36	9.34	6.62	7.90	7.92	6.00	694	1613	2278	5292
111.5	365.8	9.32	9.26	6.61	8.06	8.02	5.98	800	1600	2625	5249
112.0	367.5	9.36	9.34	6.56	7.82	7.74	5.97	637	1695	2090	5561
112.5	369.1	9.54	9.56	6.54	7.68	7.72	5.95	541	1695	1773	5561
113.0	370.7	9.34	9.34	6.54	7.82	7.84	5.94	662	1681	2173	5514
113.5	372.4	9.34	9.20	6.55	7.82	7.78	5.97	680	1724	2232	5657
114.0	374.0	9.30	9.28	6.52	7.70	7.72	5.92	633	1667	2076	5468
114.5	375.7	9.28	9.26	6.48	7.80	7.84	5.90	690	1724	2263	5657
115.0	377.3	9.20	9.24	6.49	7.74	7.84	5.93	699	1786	2294	5859
115.5	378.9	9.22	9.32	6.49	7.78	7.90	5.92	699	1754	2294	5756
116.0	380.6	9.40	9.54	6.46	7.80	7.98	5.89	633	1754	2076	5756
116.5	382.2	9.46	9.58	6.34	7.52	7.66	5.78	518	1786	1700	5859

Table 4, continued. UDOT 400' Boring, Suspension R1-R2 depth, pick times, and velocities collected 4/15/03

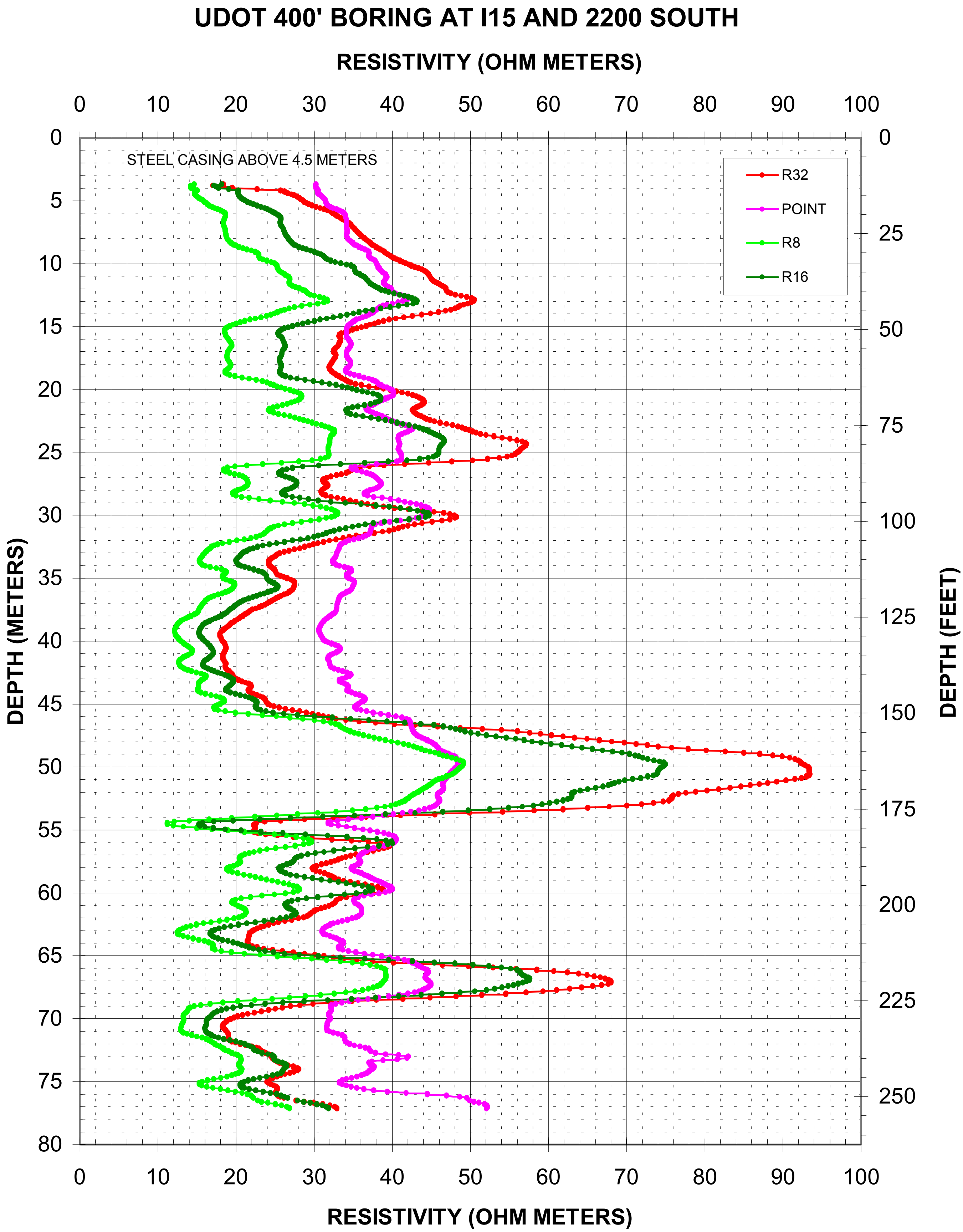


Figure 5. UDOT 400' Boring, Resistivity data

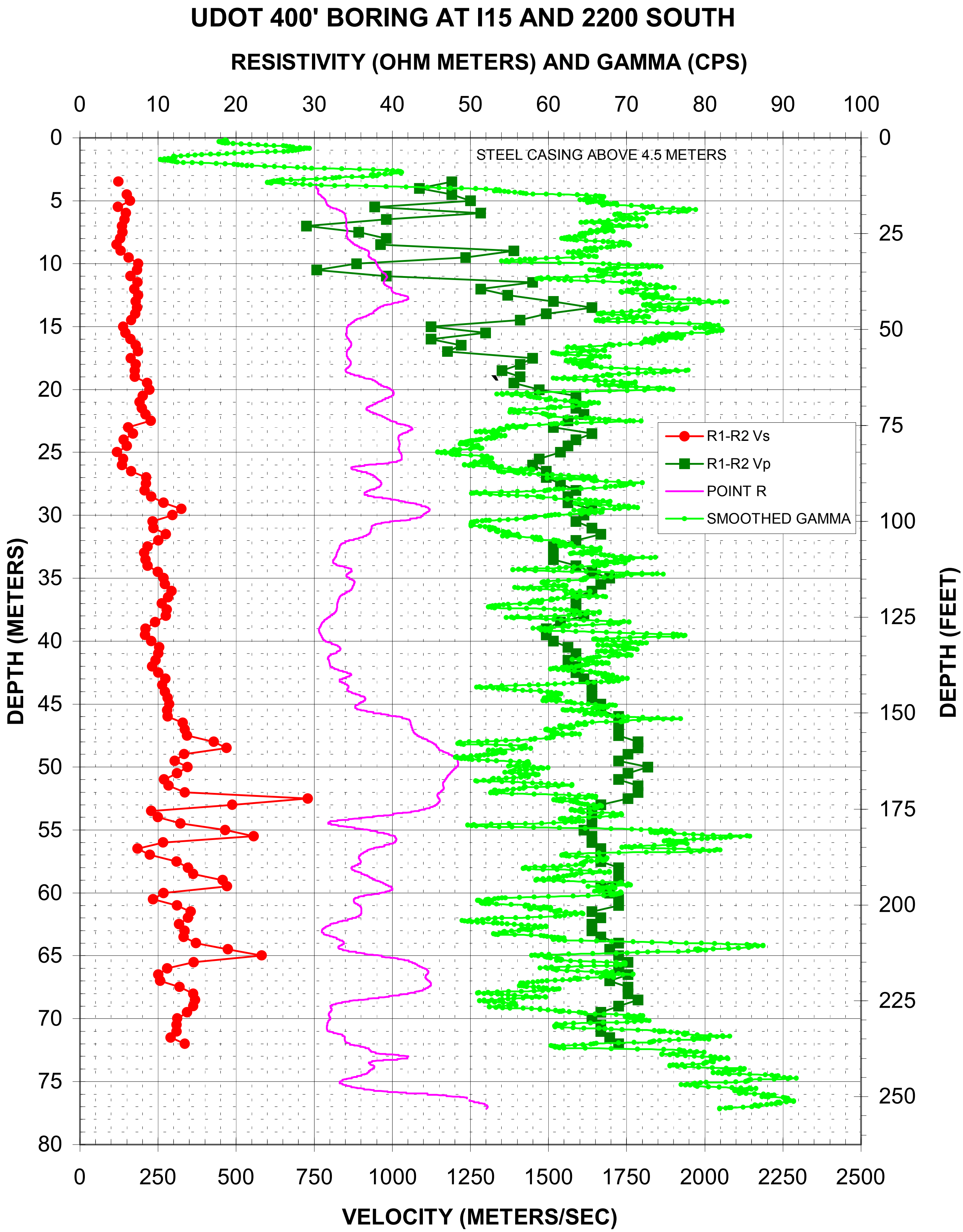


Figure 6. UDOT 400' Boring, Gamma, Point Resistivity and Suspension velocities

APPENDIX A

SUSPENSION VELOCITY MEASUREMENT
QUALITY ASSURANCE SUSPENSION SOURCE
TO RECEIVER ANALYSIS RESULTS

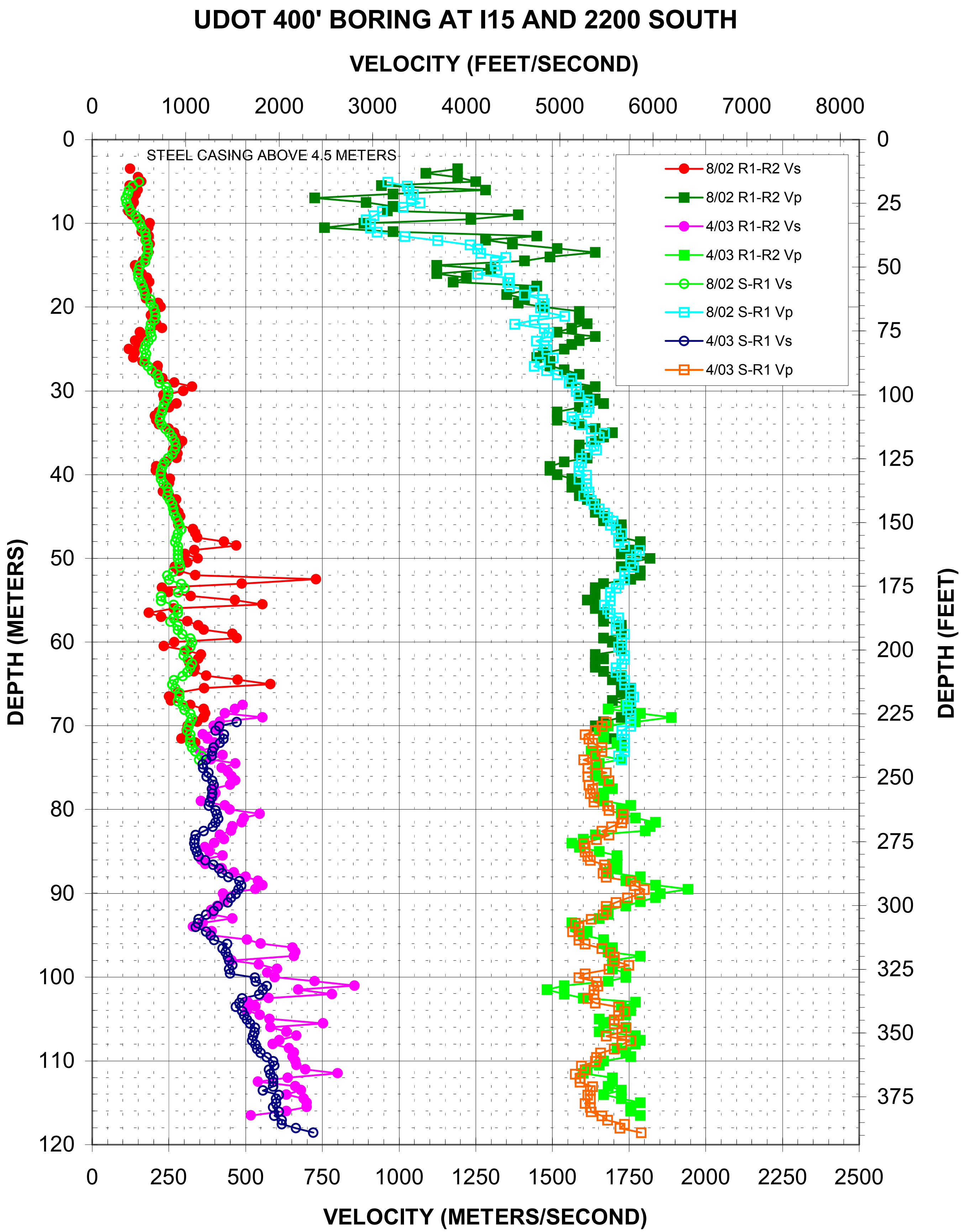


Figure A-1. UDOT 400' Boring, R1 - R2 high resolution analysis and S-R1 quality assurance analysis P- and S_H-wave data

Depth (meters)	Velocity V-S_H (m/sec)	Velocity V-p (m/sec)	Depth (feet)	Velocity V-S_H (ft/sec)	Velocity V-p (ft/sec)	Depth (meters)	Velocity V-S_H (m/sec)	Velocity V-p (m/sec)	Depth (feet)	Velocity V-S_H (ft/sec)	Velocity V-p (ft/sec)
5.1	153	963	16.6	503	3160	25.1	170	1481	82.3	557	4859
5.6	132	1026	18.3	435	3367	25.6	175	1454	83.9	576	4769
6.1	120	1033	19.9	394	3389	26.1	173	1502	85.5	568	4929
6.6	116	1047	21.6	380	3434	26.6	172	1460	87.2	564	4792
7.1	110	1040	23.2	360	3411	27.1	181	1440	88.8	594	4726
7.6	113	1068	24.8	371	3504	27.6	195	1481	90.5	640	4859
8.1	119	1013	26.5	392	3323	28.1	211	1517	92.1	694	4977
8.6	126	946	28.1	414	3103	28.6	218	1562	93.7	715	5125
9.1	141	918	29.8	464	3012	29.1	219	1554	95.4	719	5100
9.6	146	892	31.4	480	2927	29.6	242	1578	97.0	792	5177
10.1	156	908	33.0	513	2977	30.1	248	1578	98.7	814	5177
10.6	162	908	34.7	531	2977	30.6	248	1586	100.3	814	5203
11.1	173	929	36.3	568	3048	31.1	243	1619	101.9	799	5310
11.6	176	1019	38.0	579	3345	31.6	235	1619	103.6	772	5310
12.1	176	1125	39.6	579	3692	32.1	231	1619	105.2	757	5310
12.6	182	1231	41.2	597	4040	32.6	228	1610	106.9	747	5283
13.1	181	1256	42.9	594	4121	33.1	222	1562	108.5	728	5125
13.6	181	1266	44.5	594	4154	33.6	220	1570	110.1	723	5151
14.1	176	1348	46.2	579	4421	34.1	226	1594	111.8	741	5229
14.6	173	1314	47.8	568	4310	34.6	239	1627	113.4	783	5338
15.1	156	1314	49.4	513	4310	35.1	252	1670	115.1	827	5480
15.6	152	1319	51.1	499	4329	35.6	262	1653	116.7	858	5422
16.1	150	1256	52.7	491	4121	36.1	270	1627	118.3	884	5338
16.6	151	1359	54.4	495	4460	36.6	273	1635	120.0	896	5366
17.1	159	1353	56.0	522	4440	37.1	270	1644	121.6	884	5394
17.6	165	1359	57.6	541	4460	37.6	262	1610	123.3	858	5283
18.1	170	1440	59.3	557	4726	38.1	248	1594	124.9	814	5229
18.6	173	1408	60.9	568	4620	38.6	235	1594	126.5	772	5229
19.1	189	1467	62.6	621	4814	39.1	229	1586	128.2	752	5203
19.6	191	1474	64.2	626	4837	39.6	225	1586	129.8	738	5203
20.1	201	1460	65.8	658	4792	40.1	223	1610	131.5	733	5283
20.6	205	1474	67.5	673	4837	40.6	225	1586	133.1	737	5203
21.1	207	1539	69.1	678	5050	41.1	232	1610	134.7	762	5283
21.6	204	1440	70.8	669	4726	41.6	245	1610	136.4	804	5283
22.1	192	1377	72.4	630	4518	42.1	248	1619	138.0	815	5310
22.6	189	1474	74.0	619	4837	42.6	245	1602	139.7	804	5256
23.1	190	1488	75.7	622	4882	43.1	254	1627	141.3	832	5338
23.6	195	1481	77.3	640	4859	43.6	261	1635	142.9	857	5366
24.1	183	1447	79.0	599	4747	44.1	263	1653	144.6	864	5422
24.6	174	1474	80.6	572	4837	44.6	267	1670	146.2	876	5480

Table A-1. UDOT 400' Boring, S - R1 quality assurance analysis P- and S_H -wave data collected 8/10/02

Depth (meters)	Velocity V-S_H (m/sec)	Velocity V-p (m/sec)	Depth (feet)	Velocity V- S_H (ft/sec)	Velocity V-p (ft/sec)
45.1	274	1679	147.9	897	5509
45.6	280	1697	149.5	918	5569
46.1	284	1688	151.1	933	5539
46.6	291	1707	152.8	956	5599
47.1	280	1725	154.4	918	5660
47.6	275	1716	156.1	904	5629
48.1	271	1716	157.7	890	5629
48.6	280	1735	159.4	918	5692
49.1	280	1784	161.0	918	5853
49.6	280	1774	162.6	918	5820
50.1	280	1754	164.3	918	5755
50.6	284	1754	165.9	933	5755
51.1	287	1764	167.6	942	5788
51.6	263	1735	169.2	864	5692
52.1	245	1735	170.8	804	5692
52.6	250	1735	172.5	821	5692
53.1	289	1716	174.1	949	5629
53.6	301	1707	175.8	989	5599
54.1	280	1688	177.4	918	5539
54.6	225	1688	179.0	737	5539
55.1	225	1688	180.7	737	5539
55.6	265	1670	182.3	870	5480
56.1	280	1679	184.0	918	5509
56.6	280	1688	185.6	918	5539
57.1	267	1716	187.2	876	5629
57.6	256	1707	188.9	839	5599
58.1	278	1716	190.5	912	5629
58.6	280	1707	192.2	918	5599
59.1	294	1735	193.8	965	5692
59.6	320	1725	195.4	1051	5660
60.1	326	1725	197.1	1071	5660
60.6	320	1716	198.7	1051	5629
61.1	301	1725	200.4	989	5660
61.6	299	1735	202.0	981	5692
62.1	312	1735	203.6	1024	5692
62.6	326	1725	205.3	1071	5660
63.1	320	1707	206.9	1051	5599
63.6	309	1707	208.6	1015	5599
64.1	296	1725	210.2	972	5660
64.6	267	1735	211.8	876	5692

Depth (meters)	Velocity V-S_H (m/sec)	Velocity V-p (m/sec)	Depth (feet)	Velocity V- S_H (ft/sec)	Velocity V-p (ft/sec)
65.1	261	1735	213.5	857	5692
65.6	271	1754	215.1	890	5755
66.1	284	1754	216.8	933	5755
66.6	284	1764	218.4	933	5788
67.1	280	1754	220.0	918	5755
67.6	296	1744	221.7	972	5723
68.1	301	1744	223.3	989	5723
68.6	320	1754	225.0	1051	5755
69.1	326	1754	226.6	1071	5755
69.6	320	1754	228.2	1051	5755
70.1	315	1754	229.9	1032	5755
70.6	310	1725	231.5	1016	5660
71.1	320	1725	233.2	1051	5660
71.6	320	1735	234.8	1051	5692
72.1	320	1735	236.5	1051	5692
72.6	326	1735	238.1	1071	5692
73.1	336	1735	239.7	1103	5692
73.6	356	1716	241.4	1168	5629
74.1	349	1725	243.0	1145	5660

Table A-1, continued. UDOT 400' Boring, S - R1 quality assurance analysis P- and S_H -wave data collected 8/10/02

Depth (meters)	Velocity V-S_H (m/sec)	Velocity V-p (m/sec)	Depth (feet)	Velocity V- S_H (ft/sec)	Velocity V-p (ft/sec)
69.6	471	1675	228.2	1547	5494
70.1	414	1661	229.9	1359	5451
70.6	402	1640	231.5	1319	5380
71.1	430	1606	233.2	1411	5269
71.6	428	1619	234.8	1404	5310
72.1	417	1631	236.5	1368	5352
72.6	396	1661	238.1	1301	5451
73.1	393	1661	239.7	1288	5451
73.6	389	1640	241.4	1275	5380
74.1	372	1602	243.0	1221	5256
74.6	360	1644	244.7	1181	5394
75.1	362	1614	246.3	1187	5297
75.6	379	1675	247.9	1244	5494
76.1	374	1614	249.6	1226	5297
76.6	393	1684	251.2	1288	5524
77.1	396	1619	252.9	1301	5310
77.6	391	1631	254.5	1281	5352
78.1	393	1623	256.1	1288	5324
78.6	389	1635	257.8	1275	5366
79.1	383	1635	259.4	1256	5366
79.6	381	1679	261.1	1250	5509
80.1	403	1684	262.7	1321	5524
80.6	407	1730	264.3	1334	5676
81.1	411	1730	266.0	1348	5676
81.6	403	1725	267.6	1321	5660
82.1	394	1693	269.3	1293	5554
82.6	363	1661	270.9	1192	5451
83.1	338	1684	272.5	1108	5524
83.6	334	1644	274.2	1097	5394
84.1	333	1602	275.8	1094	5256
84.6	336	1606	277.5	1103	5269
85.1	341	1606	279.1	1120	5269
85.6	347	1614	280.7	1140	5297
86.1	369	1623	282.4	1209	5324
86.6	394	1670	284.0	1294	5480
87.1	414	1675	285.7	1359	5494
87.6	423	1666	287.3	1388	5465
88.1	445	1675	288.9	1459	5494
88.6	480	1754	290.6	1575	5755
89.1	486	1769	292.2	1595	5804

Depth (meters)	Velocity V-S_H (m/sec)	Velocity V-p (m/sec)	Depth (feet)	Velocity V- S_H (ft/sec)	Velocity V-p (ft/sec)
89.6	477	1799	293.9	1566	5904
90.1	469	1784	295.5	1538	5853
90.6	452	1744	297.1	1484	5723
91.1	442	1707	298.8	1451	5599
91.6	409	1675	300.4	1341	5494
92.1	396	1675	302.1	1301	5494
92.6	372	1666	303.7	1221	5465
93.1	347	1627	305.3	1140	5338
93.6	344	1574	307.0	1130	5164
94.1	338	1586	308.6	1108	5203
94.6	372	1566	310.3	1221	5138
95.1	387	1586	311.9	1269	5203
95.6	398	1586	313.5	1307	5203
96.1	440	1606	315.2	1443	5269
96.6	426	1661	316.8	1397	5451
97.1	435	1688	318.5	1427	5539
97.6	442	1702	320.1	1451	5584
98.1	448	1702	321.8	1469	5584
98.6	458	1749	323.4	1502	5739
99.1	447	1684	325.0	1467	5524
99.6	450	1606	326.7	1476	5269
100.1	530	1586	328.3	1740	5203
100.6	534	1644	330.0	1752	5394
101.1	569	1648	331.6	1866	5408
101.6	557	1635	333.2	1827	5366
102.1	545	1635	334.9	1789	5366
102.6	489	1614	336.5	1605	5297
103.1	480	1640	338.2	1575	5380
103.6	469	1716	339.8	1538	5629
104.1	489	1735	341.4	1605	5692
104.6	495	1716	343.1	1625	5629
105.1	505	1702	344.7	1656	5584
105.6	515	1702	346.4	1689	5584
106.1	530	1740	348.0	1740	5707
106.6	529	1725	349.6	1734	5660
107.1	525	1675	351.3	1723	5494
107.6	522	1754	352.9	1711	5755
108.1	531	1725	354.6	1743	5660
108.6	538	1702	356.2	1764	5584
109.1	549	1657	357.8	1801	5436

Table A-2. UDOT 400' Boring, S - R1 quality assurance analysis P- and S_H -wave data collected 4/15/03

Depth (meters)	Velocity V-S_H (m/sec)	Velocity V-p (m/sec)	Depth (feet)	Velocity V- S_H (ft/sec)	Velocity V-p (ft/sec)
109.6	569	1644	359.5	1868	5394
110.1	590	1640	361.1	1936	5380
110.6	595	1594	362.8	1951	5229
111.1	577	1606	364.4	1894	5269
111.6	581	1574	366.0	1908	5164
112.1	590	1590	367.7	1936	5216
112.6	590	1590	369.3	1936	5216
113.1	590	1631	371.0	1936	5352
113.6	557	1623	372.6	1827	5324
114.1	609	1614	374.2	1996	5297
114.6	599	1623	375.9	1966	5324
115.1	599	1606	377.5	1966	5269
115.6	590	1623	379.2	1936	5324
116.1	609	1627	380.8	1996	5338
116.6	595	1661	382.4	1951	5451
117.1	618	1679	384.1	2028	5509
117.6	618	1735	385.7	2028	5692
118.1	665	1721	387.4	2183	5645
118.6	720	1789	389.0	2363	5870

Table A-2, continued. UDOT 400' Boring, S - R1 quality assurance analysis P- and S_H -wave data collected 4/15/03

APPENDIX B

OYO 170 VELOCITY LOGGING SYSTEM

NIST TRACEABLE

CALIBRATION PROCEDURE

TABLE B1

GEOVISION VELOCITY LOGGING EQUIPMENT DESCRIPTION AND CALIBRATION PROCEDURES

EQUIPMENT	FUNCTION	CALIBRATION REQUIREMENTS	MAINTENANCE REQUIREMENTS
OYO Model 170 Suspension Logging Data Logger	Records data from probe and sends control signals to probe	Every twelve months, calibrate sample clock using an NTIS-traceable external signal counter and signal generator per attached procedure. (see Attachment B2)	Diagnose and repair by manufacturer's authorized representative if sample clock is out of specification or instrument fails.
OYO Model 170 Suspension Logging Probe	Suspended in borehole to provide both seismic source and sense wave arrivals at two locations 1 meter apart	No sensor calibration is necessary, as amplitude is not important to the velocity measurement.	Repair as needed by manufacturer-trained personnel.
Winch System (several interchangeable models available)	The winch and cable suspend the probe in the borehole and connect it to the data logger	No calibration required	Repair as needed. Lubricate moving parts frequently, and keep cable clean.

ATTACHMENT B2

CALIBRATION PROCEDURE FOR GEOVISION'S VELOCITY LOGGING SYSTEM

1.0 OYO Model 170 Data Logger Unit

1.1 Purpose

The purpose of this calibration procedure is to verify that the sample clock of the OYO Model 170 is accurate to within 1%.

1.2 Calibration Frequency

The calibration described in this procedure shall be performed every twelve months minimum.

1.3 Test Equipment

- Function Generator, Krohn Hite 5400B or equivalent
- Frequency Counter, HP 5315A or equivalent, current NIST traceable calibration
- Test cable, function generator to OYO 170 Data Logger input channels

1.4 Procedure

- Connect function generator to OYO Model 170 data logger using test cable
- Set up function generator to produce a 100.0 Hz, 0.250 volt peak square wave
- Record a data record with 100 microsecond sample period
- Measure the square wave frequency in the digital data using the data logger's screen display or utility software

1.5 Calibration Criteria

The measured square wave frequency in the digital data must fall between 99.0 and 101.0 Hz to be deemed acceptable. If outside this range, the data logger must be repaired and retested.

Calibration Report

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

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.

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
K4350	K4350 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

All standards used are either traceable to the National Institute of Standards or have intrinsic accuracy. All services performed have used proper manufacturer and industrial service techniques and are warranted for no less than (30) days. This report may not be reproduced in part without written permission of Micro Precision's Quality Assurance Manager.

GEOVision
geophysical services
a division of Blackhawk Geometrics

SEISMOGRAPH CALIBRATION DATA SHEET REV 2/16/99

INSTRUMENT DATA

SYSTEM MFR: OYO — MODEL NO.: 3331 A
SERIAL NO.: 19029 — CALIBRATION DATE: 2/26/02
BY: R. STELLER — DUE DATE: 2/26/03

COUNTER MFR: TENMA — MODEL NO.: 72-5085
SERIAL NO.: MB00006378 — CALIBRATION DATE: 2/25/02
BY: MICROPRECISION CAL — DUE DATE: 2/25/03

FCTN GEN MFR: TENMA — MODEL NO.: 72-5085
SERIAL NO.: MB00006378 — CALIBRATION DATE: 2/25/02
BY: MICRO PRECISION 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 2/26/02 2:26 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	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	90.1	90.1	90.1	99.9

CALIBRATED BY: ROBERT STELLER 2/26/02 [signature]
NAME DATE SIGNATURE

GEOVision
geophysical services
a division of Blackhawk Geometrics

SEISMOGRAPH CALIBRATION DATA SHEET REV 2/16/99

INSTRUMENT DATA

SYSTEM MFR:	OYO	MODEL NO.:	3331
SERIAL NO.:	12004	CALIBRATION DATE:	2/26/02
BY:	R. STELLER	DUE DATE:	2/26/03
COUNTER MFR:	TENMA	MODEL NO.:	72-5085
SERIAL NO.:	MB00006378	CALIBRATION DATE:	2/25/02
BY:	MICRO PRECISION CAL	DUE DATE:	2/25/03
FCTN GEN MFR:	TENMA	MODEL NO.:	72-5085
SERIAL NO.:	MB00006378	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	2/26/02 1:54 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	101	100.0	90.0	90.0	90.0	100.0
SQUARE	102	100.0	90.0	90.0	90.0	100.0
SINE	103	100.0	90.0	89.9	90.0	100.1
SINE	104	100.0	89.9	90.0	90.1	100.0

CALIBRATED BY: ROBERT STELLER 2/26/02 [signature]
NAME DATE SIGNATURE

GEOVision
geophysical services
a division of Blackhawk Geometrics

SEISMOGRAPH CALIBRATION DATA SHEET REV 2/16/99

INSTRUMENT DATA

SYSTEM MFR: OYO MODEL NO.: 3331
SERIAL NO.: 15014 CALIBRATION DATE: 2/26/02
BY: R. STELLER DUE DATE: 2/26/03

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

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

SYSTEM SETTINGS:

GAIN: 10
FILTER: 20kHZ
RANGE: 100 mSEC
DELAY: 0
STACK: 1 (STD) 1
PULSE: 1.6 mSEC
DISPLAY: VARIABLE
SYSTEM: DATE = CORRECT DATE & TIME 2/26/02 1:30 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	89.9	89.9	100.1
SQUARE	002	100.0	90.0	90.0	90.0	100.0
SINE	003	100.0	90.0	90.1	90.1	99.9
SINE	004	100.0	89.9	90.0	90.0	100.1

CALIBRATED BY: ROBERT STELLER 2/26/02 [signature]
NAME DATE SIGNATURE

Appendix 2

Kinematrics Information Sheets:

A. **K2 Digital Recorder**
B. **Shallow Borehole EpiSensor (SBEPI) Force Balance Accelerometer**
C. **HypoSensor Force Balance Accelerometer**

K2
Digital Recorder

The K2 is a full-featured Digital Recorder designed with the end user in mind. Technical advances and innovative engineering have increased performance and flexibility of this recorder to offer a dynamic range ~114 dB. The high dynamic range and superior resolution offer significant advantages for applications where signal fidelity and data integrity are vital.

In order to provide the greatest flexibility in data storage, retrieval and communications, Kinemetrics has included two fully compliant PCMCIA card slots that support a wide variety of nonproprietary memory cards, hard disks and modems. This allows users to easily configure the K2 for their specific applications.

Developed for Microsoft Windows™, our QuickTalk® and QuickLook® software provide a user-friendly environment, making system setup, communications and rapid data analysis quick and easy.

K2 Data Sheet--PDF format

Key Features	
	Dynamic range ~114 dB (200 sps ,0-50 Hz BW RMS noise/RMS clip)
	Multi-tasking operating system that allows simultaneous data acquisition and interrogation
	Timing accuracy to ± 0.5 milliseconds due to synchronized sampling with optional GPS timing system
	Zero Channel Skew through the utilization of an individual A/D Converter and Digital Signal Processing for each channel
	Remote alerting capability for system event or auto- diagnostic failure
	Remote data acquisition with real time digital data stream output

Application	
	Structural monitoring arrays
	Dense arrays: 2 and 3 dimensional
	Aftershock study arrays
	Local, regional and national seismic networks and arrays
Data Acquisition	
Type:	Over sampled delta sigma system with 24-bit DSP
Anti-alias filter:	Brickwall FIR filter. Cut-off at 80% of output Nyquist; 120 dB down at output Nyquist
Dynamic range:	>114 dB Typical DC to 50 Hz
Frequency response:	DC to 80 Hz @ 200 sps
Sampling rates:	20, 40, 50, 100, 200, 250 sps
Chan./chan. skew:	None -- simultaneous sampling of all channels
Acquisition modes:	Continuous, trigger
Output data format:	24-bit signed (3 bytes)
Parameter calculations:	Calculations of key parameters in real-time
Real time digital output:	RS-232 output of digital stream (contact Kinemetrics for available formats)
Trigger	
Type:	IIR bandpass filter (three types available)
Trigger selection:	Independently selected for each channel
Threshold trigger:	Internal, external and network trigger votes with arithmetic combination
Trigger voting:	Internal, external trigger votes with arithmetic combination
Additional trigger:	STA/LTA
Storage	

Type:	Two fully compliant PCMCIA storage system (two slots)
Compatibility:	PCMCIA standard 2.1. Sockets accept Type I, II, III card formats. Type I or II modem
Primary storage slot:	16 MB Memory Card (minimum). Optional larger cards available.
2nd storage slot:	Same as primary slot
2nd parallel slot:	Accepts Type I or II modem with connectors
Recording capacity:	Approximately 22 minutes per channel per MB on Memory Card, 24-bit data @ 200 sps.
Recording format:	Data is stored in DOS file system that allows cards to be read directly by PC.
Firmware	
Type:	Multi-tasking operating system supports simultaneous acquisition and interrogation. Boot loader allows remote firmware upgrades.
System control:	Configure sample rate, filter type, trigger type and voting; maintains communications and event storage.
User interface:	Packetized protocol and simple terminal loop control and data retrieval, via RS-232 interface.
Intelligent alerting:	System can be configured to initiate communications when an event is detected or if an auto-diagnostic failure occurs
Auto-diagnostics:	System can be configured to continuously check system voltages, temperature, RAM, code integrity and timing system integrity.
Rapid setup:	Unit can be configured from parameter file stored in PCMCIA memory card
Timing	
Type:	Free-running disciplined oscillator (standard); GPS (optional)
GPS option:	Integrates completely with system, providing timing, internal oscillator correction and position information.
Timing	5 microseconds of UTC with GPS

accuracy (GPS):	
Power (GPS):	Power cycling is software controlled. 110mA at 12V (active)
I/O and Display	
Display:	Matrix of 8 LEDs. Display indicates acquisition mode, event, recording, battery voltage, memory capacity used
Power input:	Mil-style connector for 24 Vdc charge input, external battery, standby power
RS-232 interface:	Full RS-232C interface with modem control
Auxiliary input:	Military-style connector for 4th channel input, IRIG out, IRIG in, clock sync., 1 pps out, trigger in, trigger out, alarm out, real time digital output (Tx and Rx), external 12V out. Interface for interconnection of multiple units.
EMI/RMI protection:	All I/O lines are protected from both EMI/RFI emission and susceptibility problems by ferrite filters and transient suppressors.
Power Supply	
Type:	High efficiency switched power supply and charger system
Input:	Nominal 24 Vdc from charger
Operating range:	10.5V to 15V
Ext. charger voltage:	100-250 Vac 50/60 Hz
Charging voltages:	Charging circuit is temperature-compensated for capability with gelled, sealed, lead-acid batteries, 2 outputs with separate protection circuitry allows unit to recharge flat battery and work with reversed or damaged battery in multi-battery system
Fuses:	Four 2-amp fuses for charger and batteries
Batteries:	Internal battery 12V 12 Ah (standard); external battery optional
Current drain:	390mA @ 12V (standard configuration)
Power	> 36 hours with internal battery

autonomy:	
Housing	
Type:	Lexan structural foam housing internally coated with EMI/RFI shielding material, 5/16" aluminum base support for mounting
Mounting:	Single hole for 1/4" stud
Size:	10.1" (256mm) W x 15" (381mm) L x 7" (178mm) H
Weight:	24 pounds (10.9 kg) including battery
Support Software	
***QuickTalk*®*:**	Windows-based control and data retrieval program for easy setup and data retrieval by direct connection or modem.
***QuickLook*®*:**	Windows-based data retrieval program for rapid review of waveforms and event information. Also operates with DOS communication software
***Antelope*:**	Comprehensive commercial network operational and management system for medium and large networks
***Earthworm*:**	Comprehensive public domain network operational and management system for medium and large networks
***NMS*:**	Commercial PC-based network management system for small to medium sized networks via modem or real-time data
***SMARTS*:**	Commercial open architecture user-extensible real-time data collection and processing software that runs on a variety of computers
***PSD*:**	Commercial Power Spectral Density software for earthquake data analysis
***SMA*:**	Commercial Strong Motion Analyst software for earthquake data analysis and processing
***K2COSMOS**:**	Conversion software from Altus EVT file format to COSMOS v1.20 format
*No charge	
Format converters:	Provides option to convert data to ASCII and other formats. Consult Kinemetrics for other options.

Environment	
Operating temp:	-20°C to 70°C
Humidity:	0-100% RH

Home
About KMI
Job Opportunities
Contact Us
What's New
Products
Solutions
Projects
Foreign Rep
Downloads
Y2K
References/FAQ
Links
Comments
USGS

SBEPI (Shallow Borehole EpiSensor)
Force Balance Accelerometer

Model SBEPI is a *cost effective* triaxial downhole package useful for relatively shallow borehole installations. The unit consists of three EpiSensor force balance accelerometer modules mounted orthogonally in one small convenient package. The diameter of the SBEPI is only 2.625″, making it suitable for installation in a 3″ diameter hole.

With full-scale recording ranges of ± 0.25 to ± 4g, the SBEPI provides on-scale recording of earthquake motions even at near-fault locations.

The significant bandwidth of DC to 200 Hz allows engineers and scientists to study motions at higher frequencies while maintaining the very important DC response that allows simple field calibration and reduces post-processing confusion.

Output circuitry is also significantly en-hanced. Four types of outputs can be selected by the user: ± 2.5V single-ended, ± 10V single-ended, ± 5V differential or ± 20V differential. The ± 2.5V single-ended output is appro-priate for use with traditional Kinematrics earthquake recording instruments. The ± 10V single-ended output and ± 20V differential output are well suited for use with a wide range of digital recorders currently on the market.

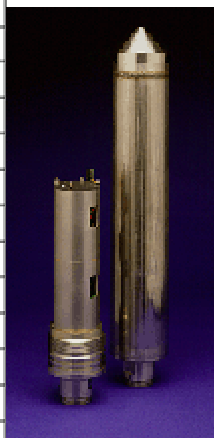
EpiSensor force balance accelerometers are also available in the HypoSensor deep borehole package, Model FBA ES-DH.

Key Features	
	Low noise
	Fits in 3" diameter hole
	Extended bandwidth – DC to 200 Hz
	Factory-selectable full-scale range
	Calibration coil (standard)
	Single-end or differential output (user selectable)

	Double-stage transient protection
Options	
	Single 12Vdc supply
Cable:	110-meter cable (in place of the 40 m cable)
Wellhead junction box:	P/N 108390-04-PL
Specifications	
Dynamic range:	155 dB+
Bandwidth:	DC to 200 Hz
Calibration coil:	Standard
Full-scale range:	Factory-selectable at ± 0.25g, ± 0.5g, ± 1g, ± 2g or ± 4g
Outputs (user selectable at):	± 2.5V single-ended
	± 10V single-ended
	± 5V differential
	± 20V differential
Linearity:	< 1000 µ g/g^2
Hysteresis:	< 0.1% of full scale
Cross-axis sensitivity:	< 1% (including misalignment)
Zero point thermal drift:	< 500 µ g/°C (1g sensor)
Power consumption:	12mA from +/- 12V (Standard Amp)
	35mA from +/- 12V(Low Noise Amp)
	Single supply option available
Operating Temperature:	-20° to 70°C (0° to 160°F)
Housing:	Watertight to 140 psi, 67 mm diameter x 250 mm (2.625" x 10" stainless steel) Provided with attached 40 m cable
Weight:	2.3 kg (5 lbs)(85 lbs. with 40 m cable in shipping

	container)
Ordering Information:	Specify: Full-scale range, outputs, noise (standard or low) and options, if any

KINEMETRICS INC.



HypoSensor
Force Balance Accelerometer

Model FBA ES-DH is a triaxial downhole package useful for deep borehole installations. The unit consists of three EpiSensor force balance accelerometer modules mounted orthogonally in one small convenient package.

With full-scale recording ranges of ± 0.25 to ± 4g, the HypoSensor provides on-scale recording of earthquake motions even at near-fault locations.

The significant bandwidth of DC to 200 Hz allows engineers and scientists to study motions at higher frequencies while maintaining the very important DC response that allows simple field calibration and reduces post-processing confusion.

Output circuitry is also significantly enhanced. Four types of outputs can be selected by the user: ± 2.5V single-ended, ± 10V single-ended, ± 5V differential or ± 20V differential. The ± 2.5V single-ended output is appropriate for use with traditional Kinemetrics earthquake recording instruments. The ± 10V single-ended output and ± 20V differential output are well suited for use with a wide range of digital recorders currently on the market. HypoSensor force balance accelerometers are also available in the Model SBEPI shallow borehole package.

Key Features	
	Low noise
	Extended bandwidth – DC to 200 Hz
	Factory-selectable full-scale range
	Calibration coil (standard)
	Single-end or differential output (user selectable)
	Double-stage transient protection
Options	
	Single 12Vdc supply

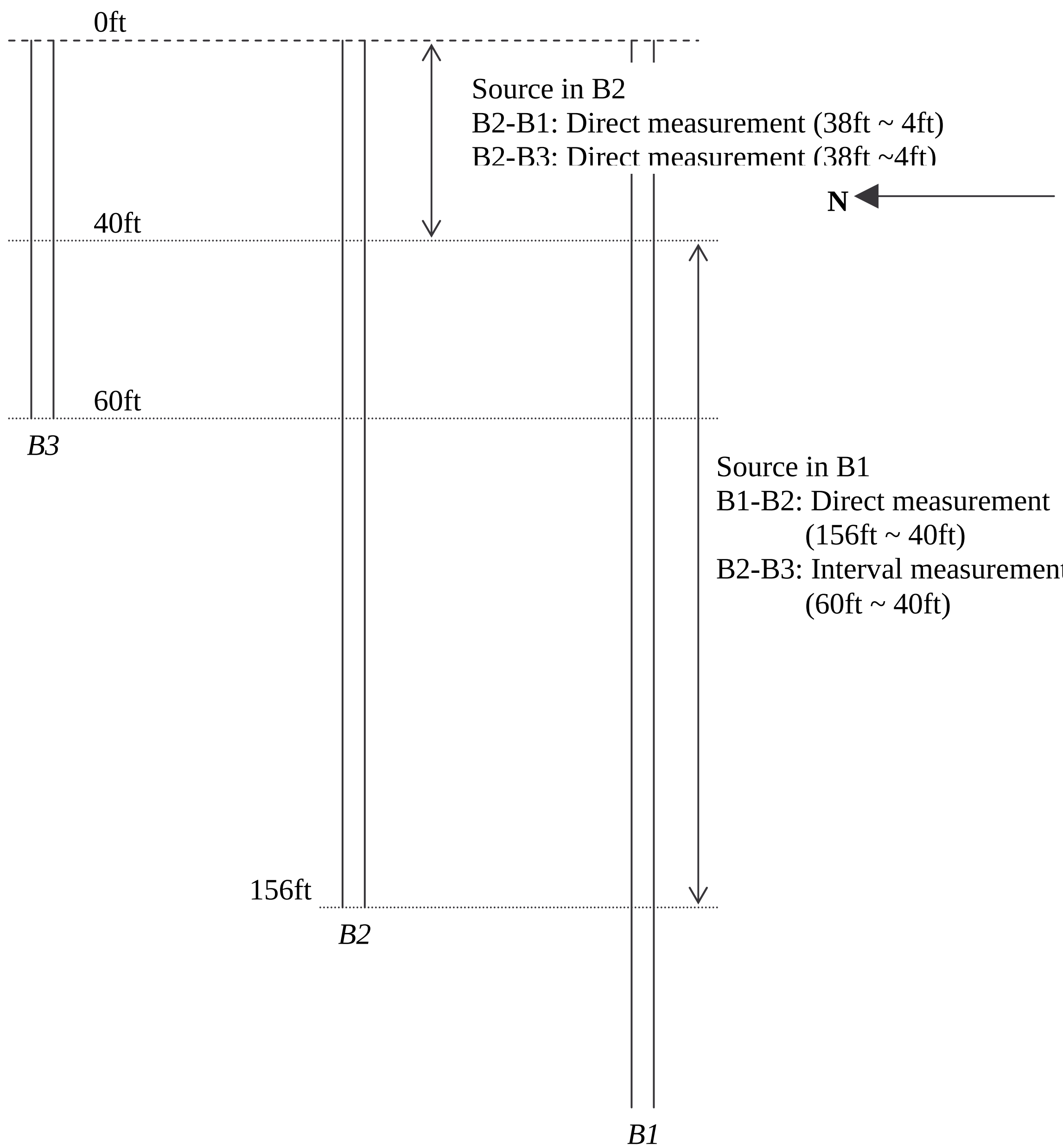
Internal compass:	P/N 110501-PL
Wellhead junction box:	P/N 108390-04-PL
EPRI-Youd Wedging System:	PN 108365-PL
Yoke adapter for loading poles:	PN 105080-PL
Master orientation pole:	P/N 105060-PL
Loading pole (10 ft extens. pole):	P/N 105071-PL
Loading pole clamp:	P/N 105075-PL
Centering spiders:	P/N 108369-PL
Specifications	
Dynamic range:	155 dB+
Bandwidth:	DC to 200 Hz
Calibration coil:	Standard
Full-scale range:	Factory-selectable at ± 0.25g, ± 0.5g, ± 1g, ± 2g or ± 4g
Outputs (user selectable at):	± 2.5V single-ended
	± 10V single-ended
	± 5V differential
	± 20V differential
Linearity:	< 1000 μ g/g^2
Hysteresis:	< 0.1% of full scale
Cross-axis sensitivity:	< 1% (including misalignment)

Zero point thermal drift:	< 500 µ g/°C (1g sensor)
Power consumption:	12mA from +/- 12V (Standard Amp)
	35mA from +/- 12V(Low Noise Amp)
	Single supply option available
Operating Temperature:	-20° to 70°C (0° to 160°F)
Housing:	Watertight to 1000 psi, 75 mm diameter x 470 mm (3" x 18 ¾" stainless steel type 316)
Weight:	6 kg (13 ¼ lbs)
Ordering Information:	Mating connector and cable, P/N 700306-XXX (-XXX: Must specify desired cable length.)

Appendix 3

Cross Hole data by Dr. James Bay, Utah State University

Test Description at I-15 and 2100 South



We measured p and shear wave velocities like the description above.
Because we could not obtain clear phase due to the long spacing (B1-B3), we moved our source from B1 to B2 for 38ft-4ft measurements.

Cross hole testing at I-15 and 2100 South from Utah State University

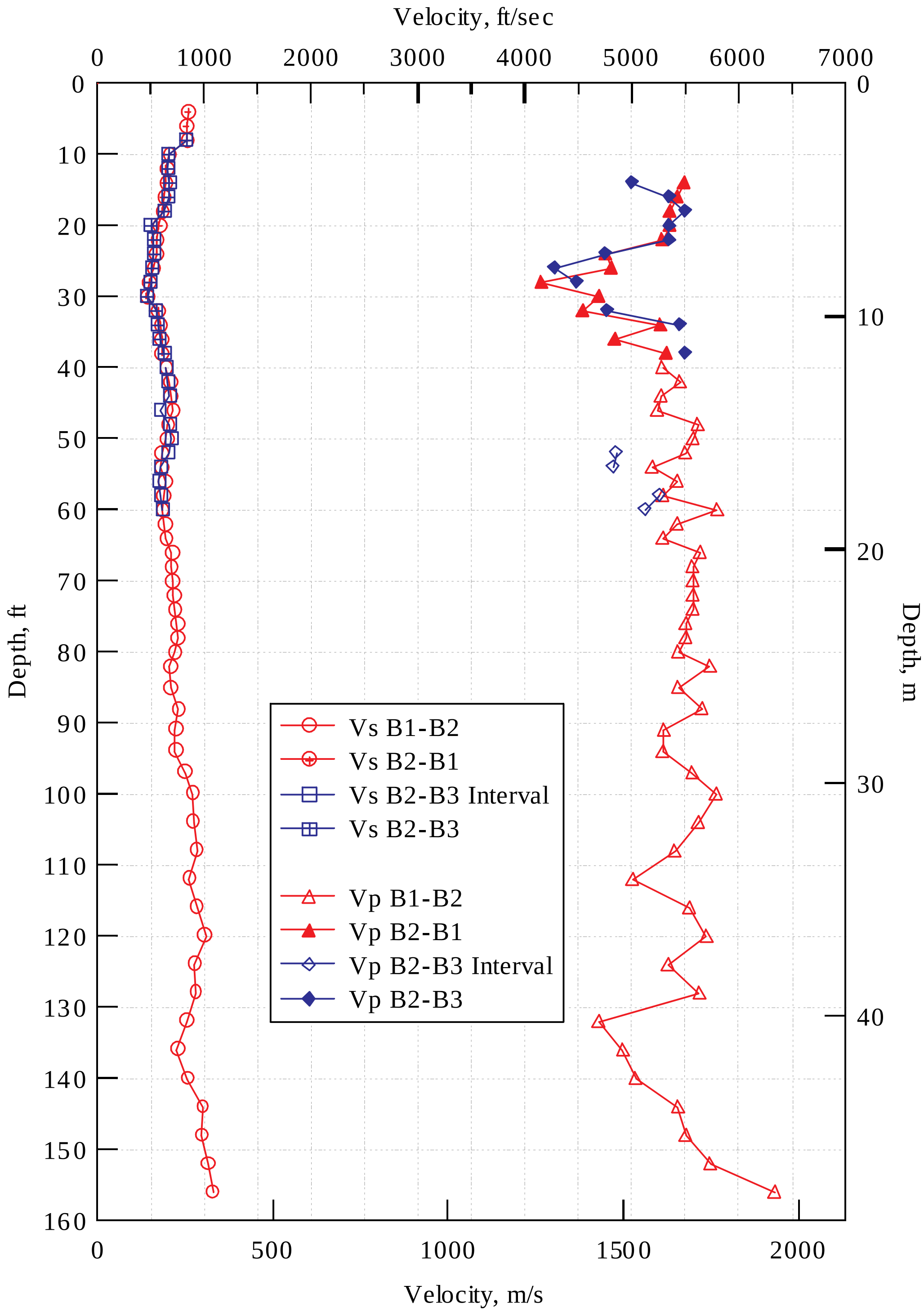


Figure 1. Velocity profile

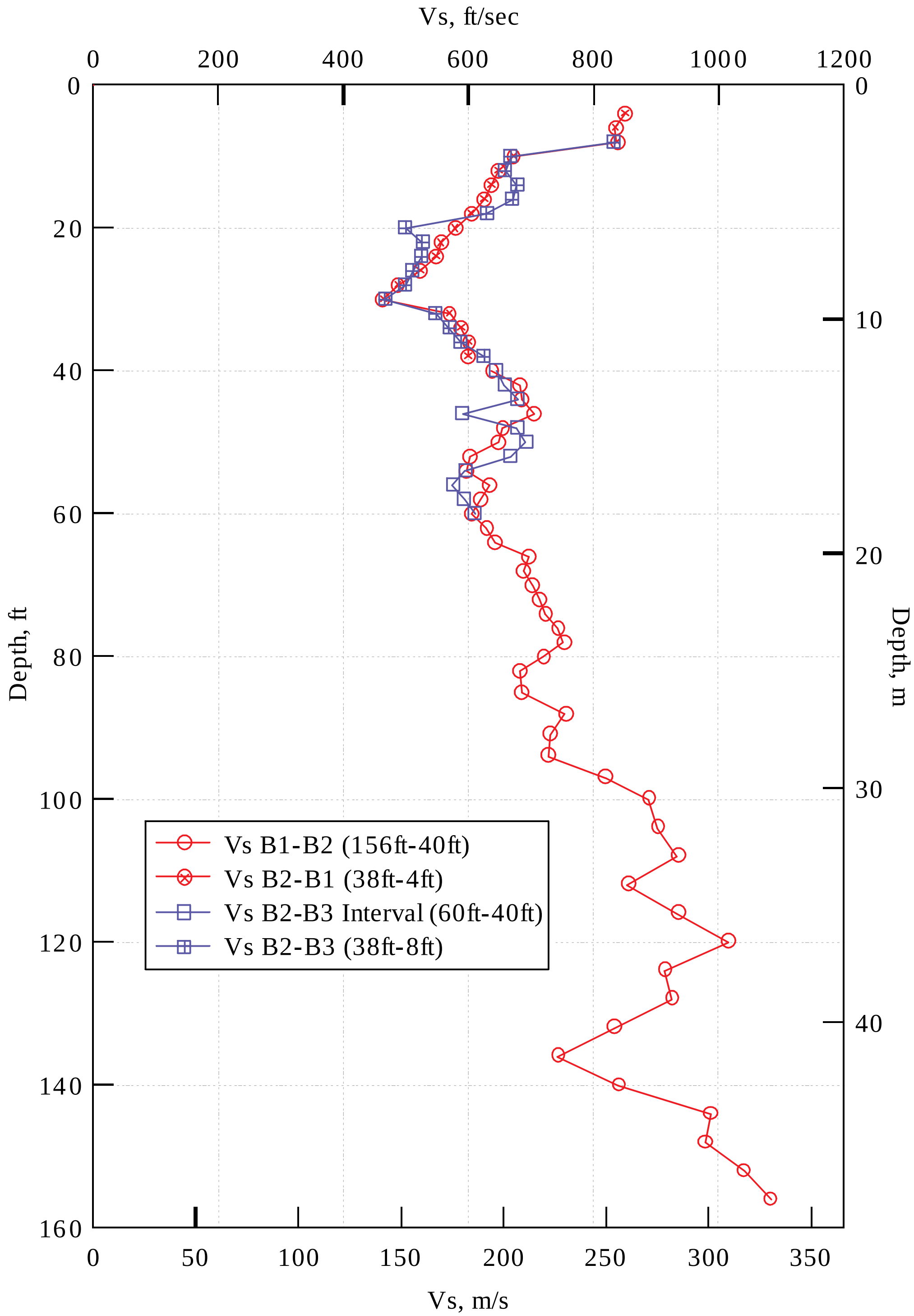


Figure 2. Shear wave velocity

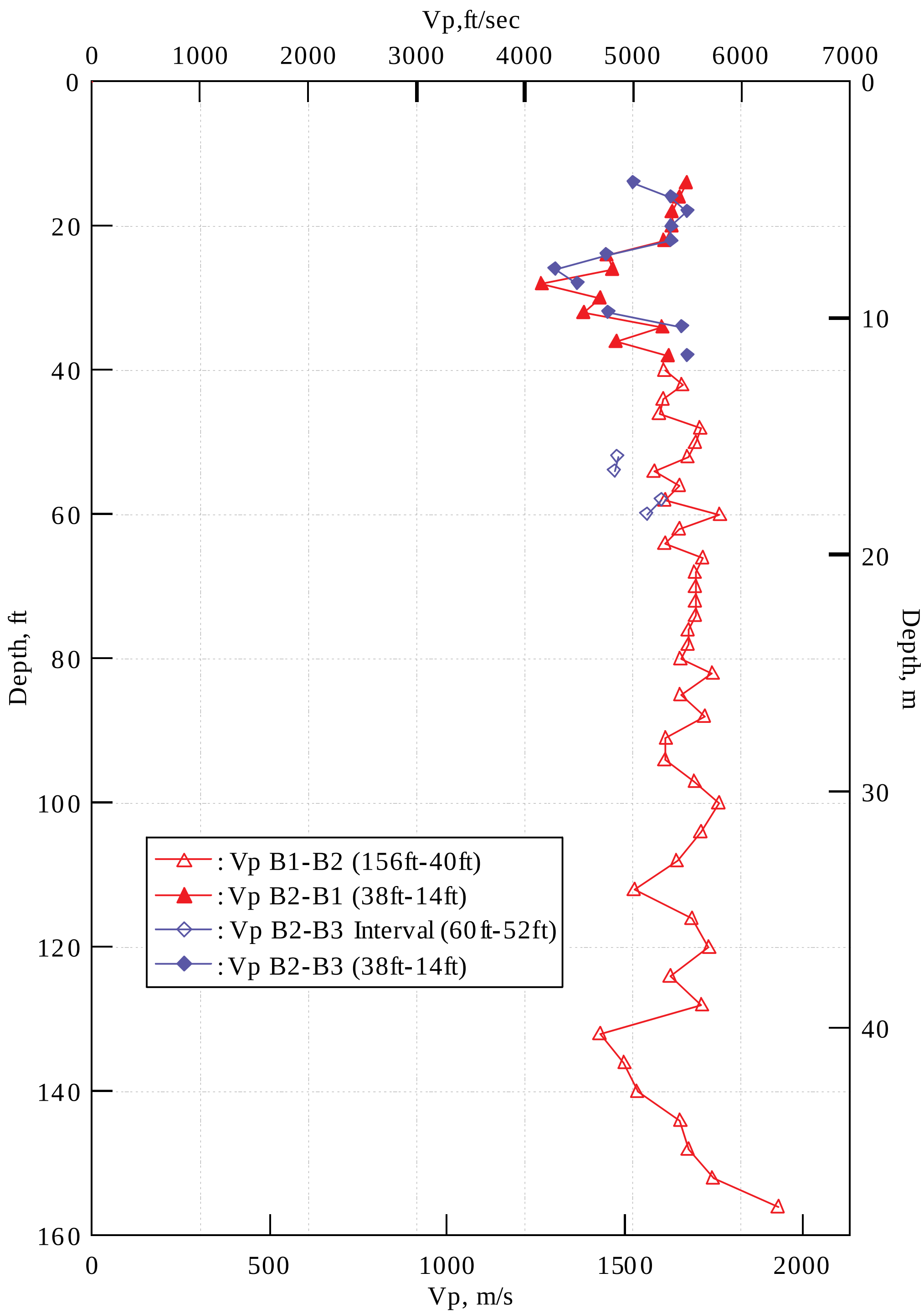


Figure 3. P-wave velocity

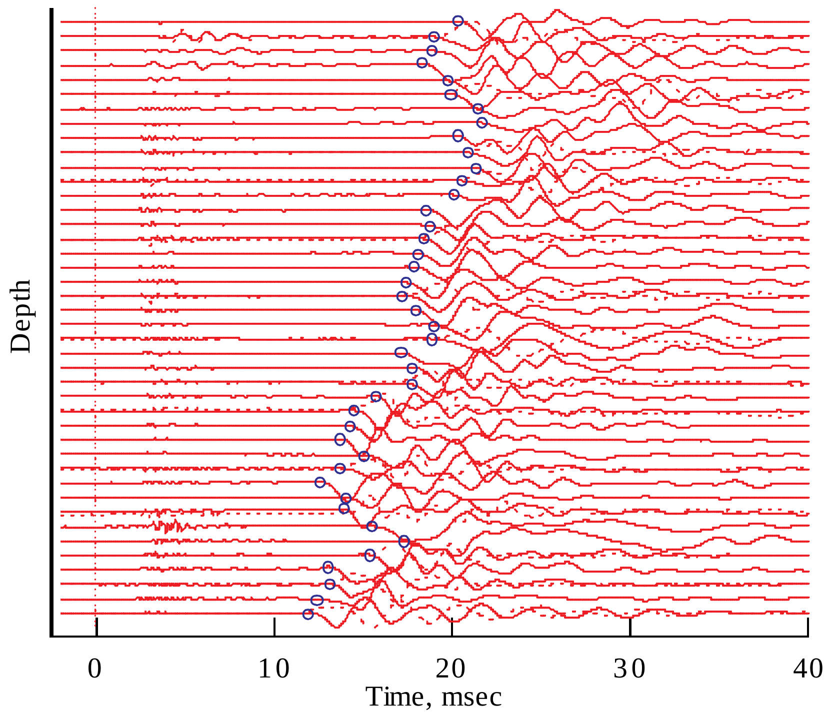


Figure 4. Picks for Vs at B1-B2 (156ft-40ft)

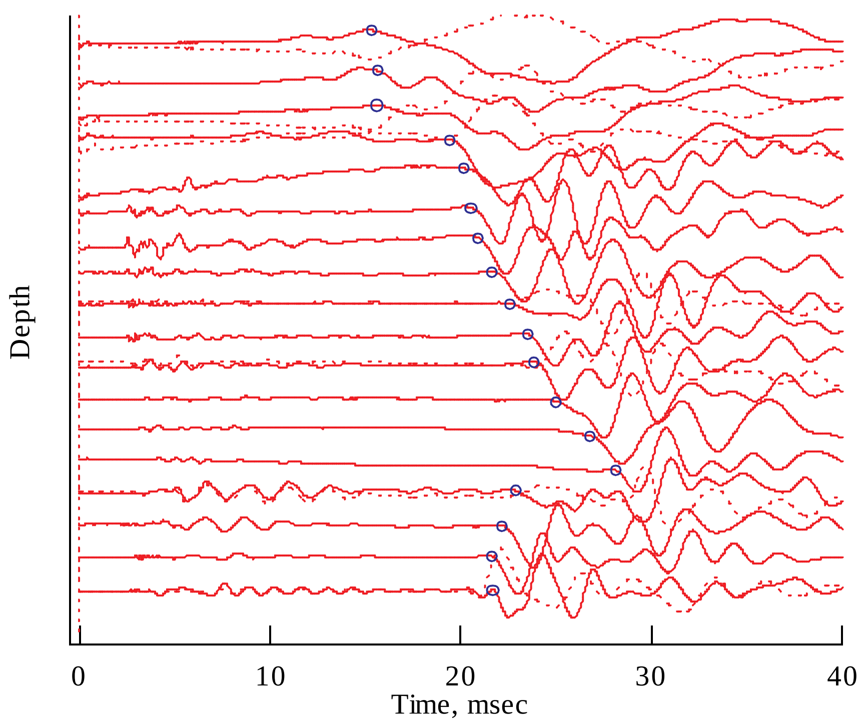


Figure 5. Picks for Vs at B2-B1 (38ft-4ft)

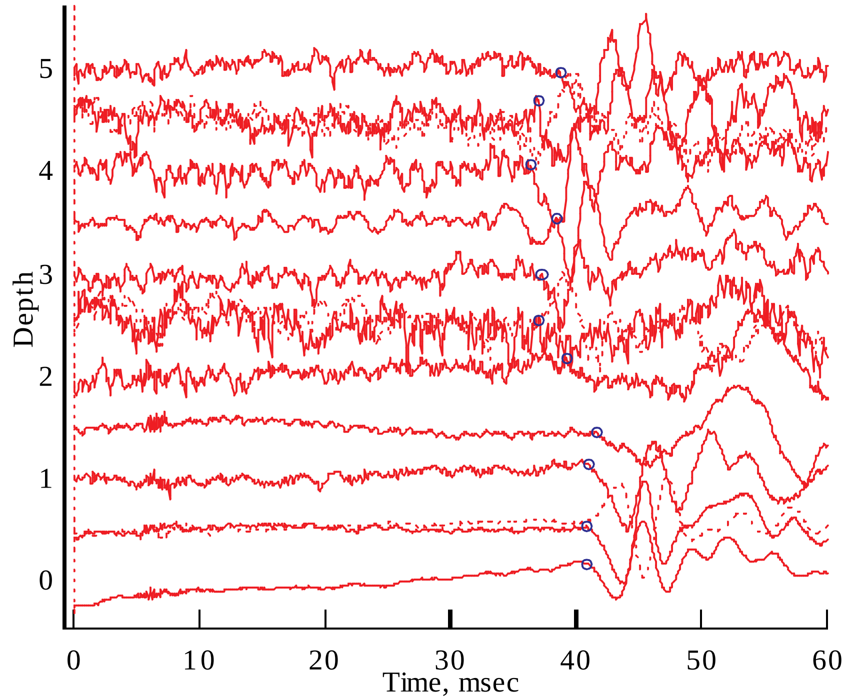


Figure 6. Picks for Vs at B2-B3 interval (60ft-40ft)

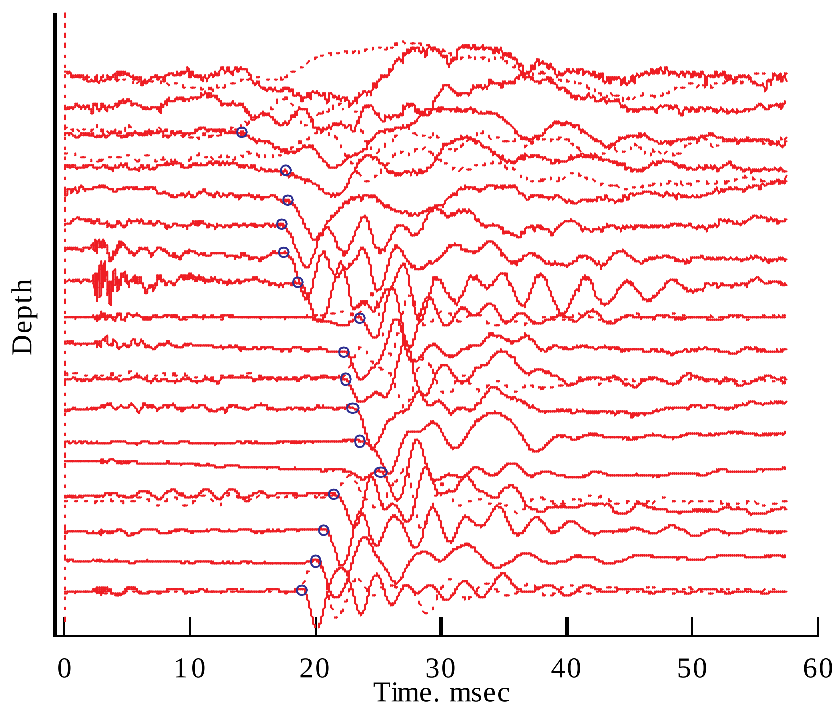


Figure 7. Picks for Vs at B2-B3 (38ft-4ft)

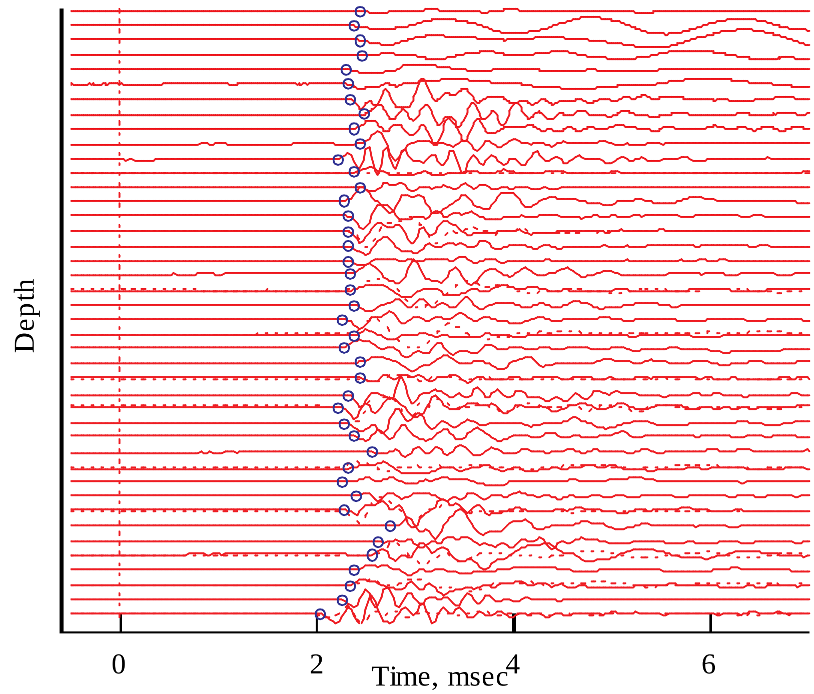


Figure 8. Picks for Vp at B1-B2 (156ft-40ft)

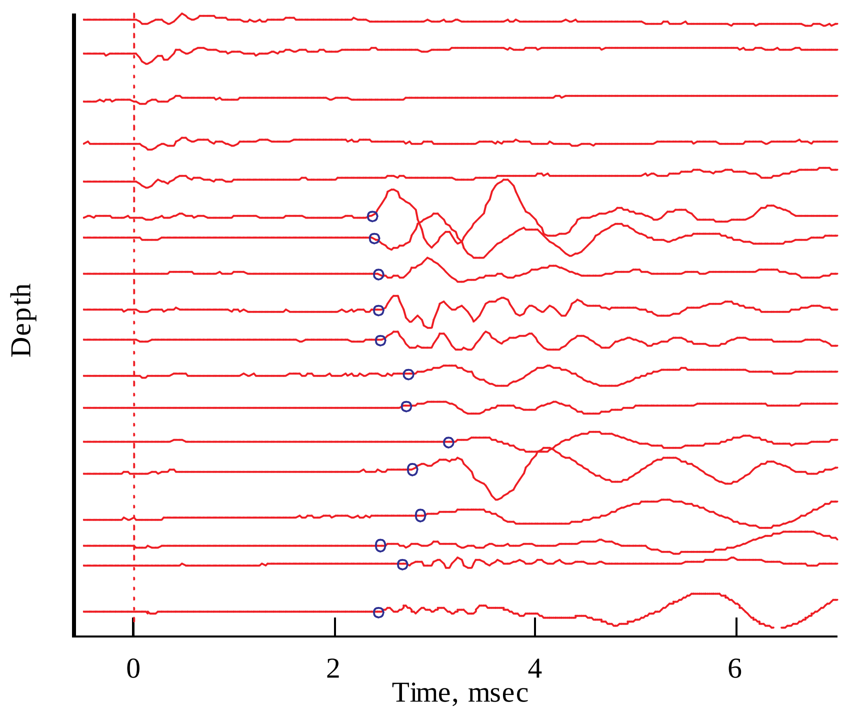


Figure 9. Picks for Vp at B2-B1 (38ft-4ft)

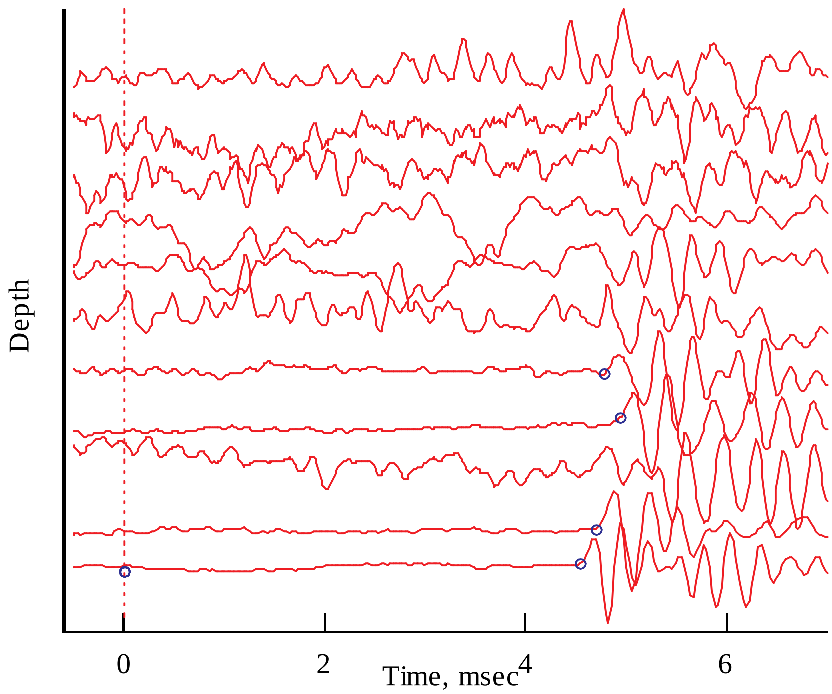


Figure 10. Picks for Vp at B2-B3 interval (60ft-40ft)

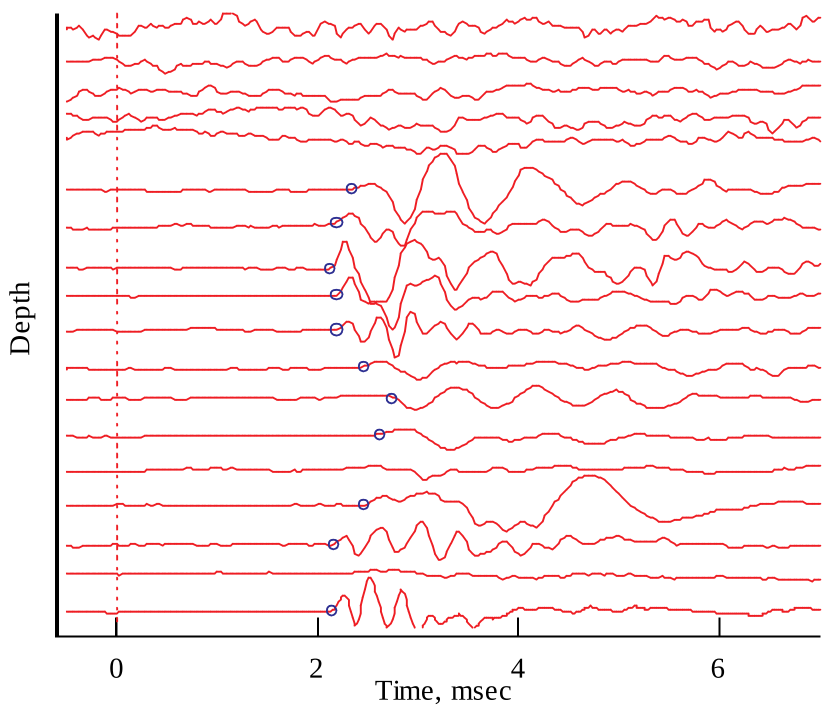


Figure 11. Picks for Vp at B2-B3 (38ft-4ft)

Direct Measurement B1-B2

Depth, ft	Spacing, ft	Shear Wave Δt, msec	Shear Wave Vs, ft/sec	P-Wave Δt, msec	P-Wave Vp, ft/sec
156	12.9721	11.963	1084.35	2.0447	6344.25
152	12.9593	12.451	1040.82	2.2583	5738.52
148	12.9465	13.214	979.757	2.3499	5509.39
144	12.9335	13.092	987.895	2.3804	5433.34
140	12.9192	15.381	839.944	2.5635	5039.67
136	12.9114	17.365	743.531	2.6245	4919.57
132	12.9042	15.503	832.369	2.7466	4698.25
128	12.8945	13.947	924.533	2.2888	5633.72
124	12.8851	14.099	913.903	2.4109	5344.52
120	12.8719	12.665	1016.33	2.2583	5699.8
116	12.8624	13.763	934.562	2.3193	5545.8
112	12.8581	15.045	854.64	2.5635	5015.82
108	12.8614	13.763	934.488	2.3804	5403.02
104	12.8776	14.282	901.664	2.2888	5626.34
100	12.9003	14.526	888.084	2.2278	5790.61
97	12.9178	15.778	818.721	2.3193	5569.69
94	12.9326	17.761	728.146	2.4414	5297.21
91	12.9429	17.731	729.961	2.4414	5301.44
88	12.9497	17.151	755.041	2.2888	5657.86
85	12.9525	18.921	684.559	2.3804	5441.33
82	12.9527	19.012	681.291	2.2583	5735.6
80	12.9512	17.975	720.51	2.3804	5440.75
78	12.9486	17.212	752.299	2.3499	5510.26
76	12.9451	17.426	742.864	2.3499	5508.8
74	12.9411	17.883	723.653	2.3193	5579.74
72	12.9367	18.127	713.67	2.3193	5577.84
70	12.9321	18.402	702.754	2.3193	5575.85
68	12.9279	18.799	687.688	2.3193	5574.03
66	12.9245	18.555	696.551	2.2888	5646.85
64	12.9218	20.142	641.533	2.4414	5292.77
62	12.92	20.538	629.077	2.3804	5427.65
60	12.9193	21.362	604.78	2.2278	5799.14
58	12.921	20.874	618.997	2.4414	5292.43
56	12.9251	20.386	634.02	2.3804	5429.82
54	12.9302	21.667	596.768	2.4872	5198.69
52	12.9359	21.484	602.116	2.3499	5504.85
50	12.9422	19.958	648.471	2.3193	5580.21
48	12.9513	19.775	654.934	2.3041	5620.98
46	12.9628	18.372	705.573	2.4719	5244.06
44	12.9743	18.921	685.707	2.4567	5281.17
42	12.9858	19.043	681.919	2.3804	5455.3
40	12.9968	20.386	637.537	2.4567	5290.36

Direct Measurement B2-B1

Depth, ft	Spacing, ft	Shear Wave Δt, msec	Shear Wave Vs, ft/sec	P-Wave Δt, msec	P-Wave Vp, ft/sec
38	13.0072	21.698	599.467	2.4414	5327.78
36	13.0166	21.667	600.756	2.6855	4846.99
34	13.0259	22.156	587.917	2.4719	5269.59
32	13.0342	22.858	570.224	2.8687	4543.58
30	13.0418	28.107	464.004	2.7771	4696.18
28	13.0505	26.764	487.613	3.1433	4151.84
26	13.0599	24.994	522.521	2.7161	4808.33
24	13.068	23.804	548.985	2.7466	4757.89
22	13.0748	23.499	556.399	2.4719	5289.38
20	13.0805	22.583	579.217	2.4414	5357.77
18	13.0828	21.637	604.648	2.4414	5358.71
16	13.0834	20.905	625.851	2.4109	5426.77
14	13.0841	20.538	637.066	2.3804	5496.58
12	13.0843	20.172	648.635		
10	13.0854	19.47	672.078		
8	13.0891	15.625	837.704		
6	13.0959	15.686	834.878		
4	13.1058	15.411	850.417		

B1: Borehole 1
B2: Borehole 2
B2: Borehole 3

Interval Measurement B2-B3

Depth, ft	Spacing, ft	Shear Wave		P-Wave	
		Δt, msec	Vs, ft/sec	Δt, msec	Vp, ft/sec
60	11.899	19.471	611.112	2.3193	5130.41
58	11.8898	20.02	593.898	2.2583	5264.95
56	11.8762	20.63	575.677		
54	11.8669	19.959	594.566	2.4566	4830.64
52	11.8631	17.762	667.894	2.4414	4859.15
50	11.8638	17.151	691.728		
48	11.8653	17.517	677.358		
46	11.861	20.08	590.685		
44	11.8541	17.456	679.085		
42	11.8486	18.005	658.072		
40	11.8436	18.371	644.692		

Direct Measurement B2-B3

Depth, ft	Spacing, ft	Shear Wave		P-Wave	
		Δt, msec	Vs, ft/sec	Δt, msec	Vp, ft/sec
38	11.8409	18.951	624.815	2.1515	5503.54
36	11.8271	20.111	588.091		
34	11.8133	20.752	569.26	2.1667	5452.2
32	11.8023	21.515	548.562	2.4719	4774.59
30	11.793	25.238	467.271		
28	11.7784	23.59	499.298	2.6245	4487.88
26	11.7638	23.01	511.247	2.7466	4283.04
24	11.7554	22.4	524.796	2.4719	4755.63
22	11.7528	22.308	526.843	2.1973	5348.75
20	11.7568	23.56	499.017	2.1973	5350.58
18	11.7557	18.677	629.42	2.1362	5503.08
16	11.7524	17.517	670.915	2.1973	5348.57
14	11.7552	17.334	678.159	2.3499	5002.43
12	11.7655	17.853	659.023		
10	11.782	17.639	667.949		
8	11.7966	14.16	833.095		

B1: Borehole 1
B2: Borehole 2
B2: Borehole 3

Time Log of Drilling Operations
(Compiled by David Briggs)

Appendix 4

Hole (1) **25 feet** **Date Started** 7/31/2002 **Date Finished** 8/2/2002 **Drillers:** Dale Gordon, Ryan Christianson, (Milo-part time)

Date	**Time**	**Notes:**
7/31/2002	2pm	Drillers arrive on site
	3pm	Prepared to drill
	3pm	Bob Bean of Publice Works stopped drilling for fear a 14" pressure sewer main exsisted below drill rig. Unable to reach anyone to give go-a-head to drill, the drillers were dismissed at 4:30pm.
8/1/2002	9am	Kyle Kingsberry, Dir. of S. Salt Lake Public Works marked sewer main and gave the go-a-head to drill.
	9am	Driller arrive on site.
	9:10am	Culvert discovered and marked to avoid
	9:30am	Drilling commenced.
		Used air for first 5' using tri-cone bit.
		Problems began with rig mounted pump mud pump.
	1:30pm	Drillers leave site to find solution to broken mud pump
	2:30pm	Drillers arrive back with trailer mounted pump.
	2:48pm	Drillers reach 25'. Polymer used to give hole definition.
	4:45pm	Drilling stopped. Water pump broken, thus preventing the grouting of the hole.
8/2/2002	7am	New pump brought in and grouting of the hole started.
	8am	Grouting complete.
	9:30am	Mud tub dumped and 60' hole started.

Hole (2) **60 feet** **Date Started** 8/2/2002 **Date Finished** 8/5/2002

		10' long steel casing inserted in hole about 8' deep. Steel casing shortly undercut and fell into hole, forcing a stop in work to weld wings to the casing.
	11:45am	Welding complete and drilling started.
	1:20pm	Hydraulic Line burst, spilling food grade oil. Currently at 17'
	3pm	Hydraulic line fixed with help of Doug, drilling supervisor.
	3:13pm	Hit 40'
	3:45pm	Hit 60'
	4:35pm	While installing PVC casing, it is discovered that hole collapesed at about 37' due to sand seem.

8/5/2002	7:45am	Drillers arrive and start on hole
	1:20pm	60' hole completely grouted

Hole (3) **160 feet** **Date Started** 8/5/2002 **Date Finished** 8/7/2002

	3pm	Start hole
	5pm	Hit 60'
	5:15pm	Hit 80' Driller not sure where clays begin till 50' where clay is definiate
8/6/2002	7am	Start at 80'
	8am	Hit 90'
	8:15am	Hit 100'
	9:05am	Hit 120'
	9:40am	Hit 140' Driller commented that drilling has been uniform and consistant, no change in material
	9:52am	Hit 150'
	10am	Hit 160' Condition hole for 1.5 hours
	12 noon	Trip out and install PVC casing with centralizers at: 158', 100', 70', and 45'
	1pm	Insert casing
	2:25pm	Casing in. At 90' of grout pipe, ran into heaving sands and penetration difficult.
	3:30pm	Grout plant broke down, wait for machanic
	5pm	Grout bottom of casing
	5:30pm	Finished
8/7/2002	7am	finish grouting H-3
	8:25am	Grouting done

Hole (4) **400 feet** **Date Started** 8/7/2002 **Date Finished** 8/8/2002

	10:05am	Air drill H-4 to insert steel casing
	5:30pm	Hit 230' with out SPT sampling
8/8/2002	7am	Start at 230'
	9:30am	Hit 300'
	12 noon	Collar dropped down steel casing- 1 hour down
	1:15pm	Collar removed from hole
	3:37pm	Hit 400' and circulate
	4:30pm	All leave.
8/9/2002	7am	Start
	9am	Trip Rod
	10:40am	Set up Geovision Equipment
	11:15am	At 150', hole closed in and damaged probe. Pull probe out and clean hole
		Notes from Driller when cleaning hole: Blockages at 72', between 180'-185', and 190'-195', and 210

		Circulate hole
	4:30pm	All leave.
8/10/2002	7am	Circulate hole
	8:30am	Trip Rod
		Geovision went down to 250' due to impedance
	2:40pm	Finish putting casing in, no problem. Grout bottom 80' (about)
	3:45pm	Leave
8/12/2002	7am	Get trimmy tube down 270' and grout from there.
	11:35am	Grouting down, begin clean up. -dillers gone about one hour getting supplies from shop
8/13/2002	7am	Finish cleaning up and I installed the utility boxes.
	2:30pm	Leave

Appendix 5

Digitized data for CPT-SV-CS-11

ConeTec Inc. - CPT Interpretation
Interpretation Output - Release 1.00.06
Run No: 96-0709-1243-2138
Job No: 96-308
Client: Dames & Moore
Project: I15 2400S Project
Site: SV-CS-11
Location: 600W & Andy Ave
Cone: 20 TON A 081
CPT Date: 96/22/04
CPT Time: 08:53
CPT File: 308CS11.COR

Page: 1

Water Table (m): 3.80 (ft): 12.5
Averaging Increment (m): 0.25
Su Nkt used: 12.50
Phi Method : Robertson and Campanella, 1983
Dr Method : Jamiolkowski - All Sands
Used Unit Weights Assigned to Soil Zones

Depth (ft)	Depth (m)	AvgQt (kPa)	AvgFs (kPa)	AvgRf (%)	E.Stress (kPa)	Hyd. Pr. (kPa)	N60 (blows/ft)	(N1)60 (blows/ft)	Su (kPa)	Dr (%)	Phi (deg.)	OCR (ratio)
0.41	0.12	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	1.0
1.23	0.38	0.0	0.0	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0
2.05	0.62	0.0	0.0	0.0	12.2	0.0	0.0	0.0	0.0	0.0	0.0	1.0
2.87	0.88	0.0	0.0	0.0	17.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0
3.69	1.12	0.0	0.0	0.0	21.9	0.0	0.0	0.0	0.0	0.0	0.0	1.0
4.51	1.38	0.0	0.0	0.0	26.8	0.0	0.0	0.0	0.0	0.0	0.0	1.0
5.33	1.62	0.0	0.0	0.0	31.7	0.0	0.0	0.0	0.0	0.0	0.0	1.0
6.15	1.88	0.0	0.0	0.0	36.6	0.0	0.0	0.0	0.0	0.0	0.0	1.0
6.97	2.12	1974.3	88.3	4.5	41.2	0.0	19.7	30.1	154.7	0.0	0.0	6.0
7.79	2.38	1505.5	58.3	3.9	45.6	0.0	15.1	21.8	116.8	0.0	0.0	6.0
8.61	2.62	721.5	24.1	3.3	49.9	0.0	7.2	10.0	53.7	0.0	0.0	6.0
9.43	2.88	574.8	15.3	2.7	54.3	0.0	5.7	7.6	41.6	0.0	0.0	3.0
10.25	3.12	1007.2	38.4	3.8	58.7	0.0	10.1	12.9	75.9	0.0	0.0	6.0
11.07	3.38	997.3	43.7	4.4	63.1	0.0	10.0	12.3	74.7	0.0	0.0	6.0
11.89	3.62	1344.1	42.8	3.2	67.5	0.0	9.0	10.7	102.1	0.0	0.0	6.0
12.71	3.88	1025.0	17.6	1.7	71.3	0.7	5.1	5.9	76.2	0.0	0.0	6.0
13.53	4.12	1352.6	39.5	2.9	73.3	3.2	6.8	7.7	102.1	0.0	0.0	6.0
14.35	4.38	2480.6	28.9	1.2	75.4	5.6	9.9	11.2	192.0	31.4	36.0	6.0
15.17	4.62	5487.5	28.8	0.5	77.5	8.1	13.7	15.2	0.0	53.7	40.0	1.0
15.99	4.88	7113.6	47.7	0.7	79.8	10.5	17.8	19.5	0.0	60.7	42.0	1.0
16.81	5.12	8279.4	112.4	1.4	82.1	13.0	20.7	22.4	0.0	64.7	42.0	1.0
17.63	5.38	5207.9	149.9	2.9	84.3	15.5	20.8	22.2	408.7	51.0	40.0	10.0
18.45	5.62	5368.3	132.2	2.5	86.3	17.9	21.5	22.6	421.1	51.5	40.0	10.0
19.27	5.88	2548.9	88.5	3.5	88.4	20.4	12.7	13.3	195.2	0.0	0.0	6.0
20.09	6.12	1488.7	49.6	3.3	90.4	22.8	9.9	10.2	110.0	0.0	0.0	6.0
20.92	6.38	1677.7	47.9	2.9	92.5	25.3	8.4	8.5	124.8	0.0	0.0	6.0
21.74	6.62	1373.6	33.6	2.4	94.5	27.7	6.9	6.9	100.1	0.0	0.0	6.0
22.56	6.88	1490.7	41.5	2.8	96.6	30.2	7.5	7.4	109.1	0.0	0.0	6.0
23.38	7.12	940.1	22.2	2.4	98.6	32.6	4.7	4.6	64.7	0.0	0.0	3.0
24.20	7.38	791.3	12.7	1.6	100.7	35.1	4.0	3.9	52.4	0.0	0.0	3.0
25.02	7.62	1006.7	17.8	1.8	102.7	37.5	5.0	4.9	69.3	0.0	0.0	3.0
25.84	7.88	825.4	14.2	1.7	104.8	40.0	4.1	3.9	54.4	0.0	0.0	3.0
26.66	8.12	907.4	17.1	1.9	106.8	42.4	4.5	4.3	60.7	0.0	0.0	3.0
27.48	8.38	768.0	11.4	1.5	108.9	44.9	3.8	3.6	49.1	0.0	0.0	1.5
28.30	8.62	702.1	9.3	1.3	110.9	47.3	3.5	3.3	43.5	0.0	0.0	1.5
29.12	8.88	717.5	12.2	1.7	113.0	49.8	3.6	3.3	44.4	0.0	0.0	1.5
29.94	9.12	653.2	10.6	1.6	115.0	52.2	3.3	3.0	38.9	0.0	0.0	1.5
30.76	9.38	648.6	8.2	1.3	117.1	54.7	3.2	2.9	38.1	0.0	0.0	1.5
31.58	9.62	662.3	8.0	1.2	119.1	57.1	3.3	3.0	38.9	0.0	0.0	1.5
32.40	9.88	634.4	7.6	1.2	121.2	59.6	3.2	2.8	36.3	0.0	0.0	1.5
33.22	10.12	663.1	7.1	1.1	123.2	62.0	3.3	2.9	38.2	0.0	0.0	1.5
34.04	10.38	708.4	7.8	1.1	125.2	64.5	3.5	3.1	41.5	0.0	0.0	1.5
34.86	10.62	705.3	7.9	1.1	127.3	67.0	3.5	3.1	40.9	0.0	0.0	1.5
35.68	10.88	831.0	14.3	1.7	129.3	69.4	4.2	3.6	50.6	0.0	0.0	1.5
36.50	11.12	627.5	7.3	1.2	131.4	71.9	3.1	2.7	33.9	0.0	0.0	1.5
37.32	11.38	706.1	6.9	1.0	133.4	74.3	3.5	3.0	39.9	0.0	0.0	1.5
38.14	11.62	781.4	10.9	1.4	135.5	76.8	3.9	3.3	45.5	0.0	0.0	1.5
38.96	11.88	1410.2	23.0	1.6	137.5	79.2	5.6	4.7	95.5	30.0	30.0	3.0
39.78	12.12	815.8	9.8	1.2	139.6	81.7	4.1	3.4	47.6	0.0	0.0	1.5
40.60	12.38	1976.3	55.5	2.8	141.6	84.1	9.9	8.1	140.0	0.0	0.0	3.0
41.42	12.62	1865.0	52.8	2.8	143.7	86.6	9.3	7.6	130.8	0.0	0.0	3.0
42.24	12.88	1741.5	38.7	2.2	145.7	89.0	8.7	7.1	120.5	0.0	0.0	3.0

ConeTec Inc. - CPT Interpretation
Run No: 96-0709-1243-2138
CPT File: 308CS11.COR

Depth (ft)	Depth (m)	AvgQt (kPa)	AvgFs (kPa)	AvgRf (%)	E.Stress (kPa)	Hyd. Pr. (kPa)	N60 (blows/ft)	(N1)60 (blows/ft)	Su (kPa)	Dr (%)	Phi (deg.)	OCR (ratio)
43.06	13.12	2012.4	49.6	2.5	147.8	91.5	10.1	8.1	141.9	0.0	0.0	3.0
43.88	13.38	1179.6	26.8	2.3	149.8	93.9	5.9	4.7	74.9	0.0	0.0	1.5
44.70	13.62	1328.6	29.4	2.2	151.9	96.4	6.6	5.3	86.4	0.0	0.0	3.0
45.52	13.88	9207.7	207.3	2.3	154.0	98.8	30.7	24.2	0.0	58.7	40.0	1.0
46.34	14.12	4775.6	238.5	5.0	156.0	101.3	47.8	37.4	361.5	0.0	0.0	6.0
47.16	14.38	1303.9	54.9	4.2	157.9	103.7	13.0	10.2	83.4	0.0	0.0	3.0
47.98	14.62	12447.2	271.3	2.2	160.0	106.2	41.5	32.1	0.0	66.8	40.0	1.0
48.80	14.88	9037.4	230.9	2.6	162.2	108.6	30.1	23.2	0.0	57.4	40.0	1.0
49.62	15.12	1362.8	29.4	2.2	164.3	111.1	6.8	5.2	87.0	0.0	0.0	3.0
50.44	15.38	2615.9	45.4	1.7	166.3	113.6	10.5	7.9	186.9	30.0	32.0	6.0
51.26	15.62	1814.4	30.9	1.7	168.4	116.0	7.3	5.5	122.4	30.0	30.0	3.0
52.08	15.88	7139.7	183.6	2.6	170.4	118.5	28.6	21.4	548.1	50.0	38.0	6.0
52.90	16.12	1552.0	64.3	4.1	172.4	120.9	15.5	11.6	100.7	0.0	0.0	3.0
53.72	16.38	1354.3	32.7	2.4	174.4	123.4	6.8	5.0	84.5	0.0	0.0	1.5
54.54	16.62	996.5	14.2	1.4	176.4	125.8	5.0	3.7	55.5	0.0	0.0	1.5
55.36	16.88	993.6	15.2	1.5	178.5	128.3	5.0	3.6	54.9	0.0	0.0	1.5
56.18	17.12	1152.6	20.1	1.7	180.5	130.7	5.8	4.2	67.3	0.0	0.0	1.5
57.00	17.38	1025.3	16.7	1.6	182.6	133.2	5.1	3.7	56.8	0.0	0.0	1.5
57.82	17.62	970.2	15.4	1.6	184.6	135.6	4.9	3.5	52.0	0.0	0.0	1.5
58.64	17.88	1190.3	22.4	1.9	186.7	138.1	6.0	4.3	69.2	0.0	0.0	1.5
59.46	18.12	1552.5	39.4	2.5	188.7	140.5	7.8	5.5	97.9	0.0	0.0	3.0
60.28	18.38	1710.1	38.5	2.3	190.8	143.0	8.6	6.1	110.1	0.0	0.0	3.0
61.10	18.62	1642.0	39.3	2.4	192.8	145.4	8.2	5.8	104.3	0.0	0.0	3.0
61.93	18.88	1328.5	22.7	1.7	194.9	147.9	6.6	4.7	78.9	0.0	0.0	1.5
62.75	19.12	1419.7	29.3	2.1	196.9	150.3	7.1	5.0	85.8	0.0	0.0	1.5
63.57	19.38	1623.2	36.3	2.2	199.0	152.8	8.1	5.6	101.7	0.0	0.0	3.0
64.39	19.62	1434.5	27.6	1.9	201.0	155.2	7.2	5.0	86.3	0.0	0.0	1.5
65.21	19.88	1573.3	33.6	2.1	203.1	157.7	7.9	5.4	97.0	0.0	0.0	1.5
66.03	20.12	2212.3	55.1	2.5	205.1	160.1	11.1	7.6	147.8	0.0	0.0	3.0
66.85	20.38	1534.8	30.7	2.0	207.1	162.6	7.7	5.2	93.2	0.0	0.0	1.5
67.67	20.62	1635.2	28.9	1.8	209.2	165.1	6.5	4.4	100.9	30.0	30.0	1.5
68.49	20.88	2671.4	77.4	2.9	211.2	167.5	13.4	9.0	183.4	0.0	0.0	3.0
69.31	21.12	7023.8	178.3	2.5	213.3	170.0	28.1	18.8	531.2	46.3	36.0	6.0
70.13	21.38	3669.1	115.8	3.2	215.3	172.4	18.3	12.2	262.5	0.0	0.0	6.0
70.95	21.62	3242.6	96.6	3.0	217.4	174.9	16.2	10.8	228.0	0.0	0.0	6.0
71.77	21.88	3491.4	93.3	2.7	219.4	177.3	14.0	9.2	247.6	30.0	32.0	6.0
72.59	22.12	4821.8	145.9	3.0	221.5	179.8	19.3	12.7	353.6	35.0	34.0	6.0
73.41	22.38	3767.5	126.4	3.4	223.5	182.2	18.8	12.3	268.9	0.0	0.0	6.0
74.23	22.62	8316.9	184.6	2.2	225.6	184.7	27.7	18.1	0.0	50.3	38.0	1.0
75.05	22.88	9840.1	183.5	1.9	227.8	187.1	32.8	21.3	0.0	55.0	38.0	1.0
75.87	23.12	6276.9	134.5	2.1	230.0	189.6	20.9	13.5	0.0	42.0	34.0	1.0
76.69	23.38	2394.9	58.8	2.5	232.1	192.0	9.6	6.2	157.7	30.0	30.0	3.0
77.51	23.62	1833.2	51.3	2.8	234.1	194.5	9.2	5.9	112.4	0.0	0.0	1.5
78.33	23.88	1824.1	57.0	3.1	236.2	196.9	9.1	5.8	111.3	0.0	0.0	1.5
79.15	24.12	5859.2	216.9	3.7	238.2	199.4	29.3	18.6	433.7	0.0	0.0	6.0
79.97	24.38	20828.6	512.7	2.5	240.3	201.8	69.4	43.8	0.0	75.7	42.0	1.0
80.79	24.62	25250.9	664.5	2.6	242.5	204.3	84.2	52.9	0.0	81.1	42.0	1.0
81.61	24.88	27425.6	785.5	2.9	244.8	206.7	137.1	85.8	0.0	83.4	42.0	1.0
82.43	25.12	25880.6	680.1	2.6	247.0	209.2	86.3	53.7	0.0	81.6	42.0	1.0
83.25	25.38	31205.1	867.8	2.8	249.2	211.7	156.0	96.7	0.0	86.8	42.0	1.0
84.07	25.62	32359.0	955.6	3.0	251.5	214.1	161.8	99.8	0.0	87.7	44.0	1.0
84.89	25.88	30145.7	889.3	2.9	253.8	216.6	150.7	92.6	0.0	85.6	42.0	1.0
85.71	26.12	32366.6	718.3	2.2	256.1	219.0	80.9	49.5	0.0	87.5	44.0	1.0
86.53	26.38	28740.9	296.6	1.0	258.5	221.5	57.5	35.0	0.0	83.9	42.0	1.0
87.35	26.62	23376.1	408.6	1.7	260.8	223.9	58.4	35.4	0.0	77.9	42.0	1.0
88.17	26.88	22917.7	268.9	1.2	263.2	226.4	45.8	27.7	0.0	77.2	42.0	1.0
88.99	27.12	26159.7	328.1	1.3	265.6	228.8	52.3	31.4	0.0	80.8	42.0	1.0
89.81	27.38	28077.3	314.7	1.1	268.0	231.3	56.2	33.6	0.0	82.7	42.0	1.0
90.63	27.62	29914.5	322.9	1.1	270.5	233.7	59.8	35.6	0.0	84.4	42.0	1.0
91.45	27.88	29720.3	262.9	0.9	272.9	236.2	59.4	35.2	0.0	84.1	42.0	1.0
92.27	28.12	28461.7	241.6	0.8	275.3	238.6	57.3	33.8	0.0	82.9	42.0	1.0
93.09	28.38	11530.1	121.4	1.1	277.7	241.1	28.8	16.9	0.0	56.7	38.0	1.0
93.91	28.62	3190.0	85.3	2.7	279.8	243.5	12.8	7.5	213.3	30.0	30.0	3.0
94.73	28.88	2722.4	72.0	2.6	281.9	246.0	10.9	6.3	175.6	30.0	30.0	3.0
95.55	29.12	2052.3	54.1	2.6	283.9	248.4	10.3	6.0	121.6	0.0	0.0	1.5
96.37	29.38	1984.0	41.8	2.1	286.0	250.9	7.9	4.6	115.8	30.0	30.0	1.5
97.19	29.62	2103.6	42.6	2.0	288.0	253.3	8.4	4.9	125.0	30.0	30.0	1.5
98.01	29.88	2173.5	42.5	2.0	290.1	255.8	8.7	5.0	130.2	30.0	30.0	1.5
98.83	30.12	2842.2	81.1	2.9	292.1	258.2	14.2	8.1	183.3	0.0	0.0	3.0

ConeTec Inc. - CPT Interpretation
Run No: 96-0709-1243-2138
CPT File: 308CS11.COR

Depth (ft)	Depth (m)	AvgQt (kPa)	AvgFs (kPa)	AvgRf (%)	E.Stress (kPa)	Hyd. Pr. (kPa)	N60 (blows/ft)	(N1)60 (blows/ft)	Su (kPa)	Dr (%)	Phi (deg.)	OCR (ratio)
99.65	30.38	2501.7	56.9	2.3	294.2	260.7	10.0	5.7	155.7	30.0	30.0	3.0
100.47	30.62	5320.5	146.9	2.8	296.2	263.2	21.3	12.1	380.9	33.6	32.0	6.0
101.29	30.88	6143.6	190.1	3.1	298.3	265.6	24.6	13.9	446.4	37.6	32.0	6.0
102.11	31.12	15226.5	359.9	2.4	300.4	268.1	50.8	28.7	0.0	63.6	38.0	1.0
102.94	31.38	22889.1	528.2	2.3	302.6	270.5	76.3	42.9	0.0	75.1	40.0	1.0
103.76	31.62	22877.8	596.7	2.6	304.7	273.0	76.3	42.8	0.0	75.0	40.0	1.0
104.58	31.88	24130.9	570.9	2.4	306.9	275.4	80.4	44.9	0.0	76.5	40.0	1.0
105.40	32.12	25059.7	505.3	2.0	309.1	277.9	62.6	34.9	0.0	77.4	42.0	1.0
106.22	32.38	28412.8	361.9	1.3	311.5	280.3	56.8	31.5	0.0	80.9	42.0	1.0
107.04	32.62	30078.9	213.6	0.7	313.9	282.8	60.2	33.2	0.0	82.4	42.0	1.0
107.86	32.88	26054.0	148.6	0.6	316.3	285.2	52.1	28.7	0.0	78.2	42.0	1.0
108.68	33.12	19122.8	132.6	0.7	318.8	287.7	38.2	21.0	0.0	69.2	40.0	1.0
109.50	33.38	6704.3	118.3	1.8	321.1	290.1	22.3	12.2	0.0	39.1	34.0	1.0
110.32	33.62	2584.0	45.5	1.8	323.2	292.6	10.3	5.6	157.5	30.0	30.0	1.5
111.14	33.88	2306.5	37.8	1.6	325.2	295.0	9.2	5.0	134.9	30.0	30.0	1.5
111.96	34.12	2226.8	38.1	1.7	327.3	297.5	8.9	4.8	128.2	30.0	30.0	1.5
112.78	34.38	2097.9	31.2	1.5	329.3	299.9	8.4	4.5	117.5	30.0	30.0	1.5
113.60	34.62	2024.7	26.9	1.3	331.4	302.4	8.1	4.4	111.3	30.0	30.0	1.5
114.42	34.88	2050.9	26.1	1.3	333.4	304.8	8.2	4.4	113.0	30.0	30.0	1.5
115.24	35.12	2113.7	28.2	1.3	335.5	307.3	8.5	4.5	117.7	30.0	30.0	1.5
116.06	35.38	2118.6	26.6	1.3	337.5	309.8	8.5	4.5	117.7	30.0	30.0	1.5
116.88	35.62	2437.8	31.8	1.3	339.5	312.2	9.8	5.2	142.9	30.0	30.0	1.5
117.70	35.88	4377.8	98.1	2.2	341.6	314.7	17.5	9.3	297.7	30.0	30.0	3.0
118.52	36.12	12374.2	263.6	2.1	343.7	317.1	41.2	21.8	0.0	55.7	38.0	1.0
119.34	36.38	3715.1	116.7	3.1	345.8	319.6	18.6	9.8	244.0	0.0	0.0	3.0
120.16	36.62	3446.2	89.6	2.6	347.9	322.0	13.8	7.2	222.1	30.0	30.0	3.0
120.98	36.88	2586.1	39.5	1.5	349.9	324.5	10.3	5.4	152.9	30.0	30.0	1.5