APPENDIX B

SECTION B.4

GEOPHYSICAL SURVEYS PERFORMED AT PARDEE DAM, CALIFORNIA

January 1991

Prepared For:

Geo/Resource Consultants
San Francisco, CA

Dames & Moore
Oakland, CA

Prepared By:

BCA Geophysics, Inc.
3095 Kerner Boulevard
San Rafael, CA 94901
(415) 454-8565

GEOPHYSICAL SURVEYS PERFORMED AT PARDEE DAM, CALIFORNIA

3 January 1991

This report summarizes the data and results from refraction and downhole surveys performed at Pardee Dam during November, 1990. . These surveys were performed by BCA Geophysics, Inc. for Geo/Resource Consultants San Francisco, California and Dames & Moore, of Oakland, California. The principal objective of these surveys was to obtain in-situ estimates of compressional and shear wave velocities for use in evaluating the seismic response of Pardee Dam. Boreholes C-1 and C-7 in the central gallery of the dam were used for downhole measurements of compressional and shear velocities. Refraction surveys were performed on the abutments of the dam. The following is a summary of the field procedure, data analysis, and results of these surveys.

FIELD PROCEDURES

Downhole Surveys: Downhole compressional and shear velocities were estimated in pre-existing boreholes, which had been drilled for a 1967 investigation, in the upstream side of the central gallery inside the dam. Of the 9 boreholes that were found in the central gallery, only two were found to be usable for downhole surveys. C-1 was open to a depth of 34 feet, or approximately to the bottom of the concrete of the dam, and borehole C-7 was found to be open to a depth of 114 ft., 8 feet short of the bottom of the hole.

The field procedure followed for obtaining the velocity of compressional and shear waves in the concrete of the dam and the bedrock under the dam utilized a mechanical shear source at the surface with a triaxial geophone lowered down the borehole. Shearing energy was generated by using sledge hammer impacts on the opposite sides of a metal guardrail located near the borehole. Blows were made on each side of the base of this guardrail in order to induce horizontally polarized shear waves with reversible first motions. A sidewall clamping triaxial seismometer array was lowered into the borehole to receive wave arrivals at each measurement level. Measurements wer made at the bottom of the hole and at even five foot intervals. The shearing energy that travelled down through the concrete and rock column was detected by the triaxial geophone array located in the borehole. At each measurement elevation, reversed horizontal blows were made in order to generate shear waves with opposite first motions. Vertical blows were made on the surface of the walkway in the gallery near the borehole in order to generate compressional waves. A 12-channel signal enhancement seismograph (Geometrics Model ES 1210F) recorded the signals on an oscilloscope screen and on a hard-copy paper read-out. The seismograph also allowed the summing of several blows in one direction when necessary to increase the signal-to-noise ratio. Two records were made at several elevations in order to insure repeatability of signal arrivals. Shear waves were identified in the field by observing wave arrivals with opposite first motions on adjacent channels of the seismograph.

Refraction surveys: Four refraction lines were performed for this study, two lines on each of the abutments of the dam. The refraction lines are labelled SL-1 through SL-4 and their locations are shown in Figure 1. Refraction lines SL-1 and SL-4 incorporated both compressional wave and shear wave velocities. Refraction Lines SL-2 and SL-3 utilized compressional waves only, and were comprised of four spreads of approximately 100 feet per spread. A total of approximately 1000 linear feet of refraction lines were performed for this study. As shown in Figure 1, the refraction lines extend along the upper 400 feet of the abutments, parallel to the face of the dam. The risk of loosening rocks that could fall and damage property or injure the personnel around the power house at the base of the dam precluded investigating the lower lower portions of the abutments. Efforts to extend the depths of penetration of the shear wave lines showed that there was no significant shear wave contrast to depths of approximately 50 feet at the locations of lines SL-1 and SL-4.

Compressional energy for the refraction surveys was introduced into the ground by vertically striking a metal plate, located on the ground, with a sledge hammer.

Shearing energy was induced into the ground by horizontally striking either a metal stake driven into the ground, or local rock outcrops where convenient. The refraction arrivals were recorded on a Geometrics Model ES-1210F Seismograph.

DATA ANALYSIS

Downhole Survey: A representative record from the downhole survey is reproduced in Figure 2. Figure 2 was taken at a depth of 100 feet in borehole C-7 (DH-2) and shows the compressional and shear wave arrivals that were were used to determine the interval velocities. The horizontal lines in this record show, from top to bottom, six seismic signal traces and a timing line. The top pair of signal traces are nearly identical and reproduce the ground motion as recorded in the borehole by the vertical geophone from two different vertical blows at the surface. Due to background noise in the environment, the compressional wave arrival is not evident on the vertical records in Figure 2, however, this is arrival is apparent on the horizontal traces. The middle pair of signal traces are from the H1 horizontal geophone and reproduce the ground motion as observed in the borehole by a horizontal geophone. The upper of these two traces is for a horizontal blow in the southerly direction and the lower trace is for a blow in the northerly direction. The bottom pair of signal traces are for the H2 horizontal geophone and are similar to the H1 signals except that H2 is perpendicular to H1 in the horizontal plane. The upper and lower traces of the H1 and H2 pairs were recorded separately. The time scale is shown at the bottom of the figure. The vertical lines are at 2.5 millisecond intervals. The time of the first arrivals of compressional and shear energy are indicated by T_p and T_S, respectively, and T_0 indicates the start time. (For a more complete discussion of the downhole technique, see Auld,1977, or Statton et al., 1978.)

The travel-times from the surface to each measurement depth are shown in Figures 3 and 5 for the surveys in C-1 (DH-1) and C-7 (DH-2) respectively. The compressional waves, as identified on the records as the first breaks, are shown as circles on Figures 2 and 5. The shear wave arrivals, which are identifiable because of their reversals, are shown as squares in Figures 3 and 5. The horizontal offset of the travel times at the surface in Figures 3 and 5, (0 ft depth), is because the signal sources were located from 2 to 5 ft horizontally away from the borehole.

Refraction Survey:

The data from the refraction surveys was analyzed using the Generalized Reciprocal Method, (see, e.g., Palmer, 1980). The results of the analysis are shown in the cross-sections in Figures 7 through 10. On many of the spreads shown in Figure 8, there are two sets of reversed arrival times. The second pair of arrival times in each direction is for either normalized set-back shots or second arrivals. The set-backs/second arrivals enabled analysis of an horizon at a depth of approximately 40 feet on the South Abutment. A comparable horizon was not observed on the North Abutment.

Discussion of Results

Downhole Survey: The results of the downhole survey are summarized in Table 1 along with estimates for Young's modulus, (E), shear modulus, (G), and Poisson's ration, (PR). The velocity estimates for the downhole survey are based on least squares fits to linear portions of the downhole travel time curves shown in Figures 3 and 5. The slopes of these linear portions yield the average compressional and shear velocities for the appropriate depth interval. Plots of the velocity distribution with depth are shown in Figures 4 and 6. Although it is possible to calculate the velocity for each five foot interval, this procedure would result in an assumed accuracy for velocity estimates that is unwarranted by the limitations of the survey techniques. More meaningful velocity estimates are made by averaging a series of arrivals that appear to be associated with materials of similar physical properties.

E, G, and PR are estimated using the following relationships between wave velocities and elastic moduli:

$$PR = 0.5 * ((V_p/V_s)^2-2) / (V_p/V_s)^2-1),$$

$$G = r * (V_s)^2, \text{ and}$$

$$E = 2G * (1+PR),$$

where V_p = compressional wave velocity, V_s = shear wave velocity, and r = density.

The velocities and elastic moduli for the concrete and the bedrock in the borehole are representative of those found for medium strength concrete and comparable rocks of the Central California area, (see, e.g., Clarke, 1966, or Bollinger, 1971).

<u>Refraction Survey:</u> The results of the seismic lines along the abutments of the dam are summarized in Table 2. SL-1 shows a near surface low velocity layer with V_p = 1700 fps and V_s = 900 fps underlain with an intermediate velocity layer with V_p = 5300 fps and V_s = 3300 fps at 2 to 5 feet below ground surface. The low velocity surface layer is soil, loose rock, and highly weathered bedrock with bedrock outcrops exposed at the surface. The intermediate velocity layer is probably continuous weathered bedrock. SL-4 showed a similar velocity distribution with a highly weathered near-surface layer overlying a moderately weathered bedrock layer, with the weathered bedrock showing slightly higher velocities of V_p = 8500 fps and V_s = 5000 fps. The long refraction line on the north abutment, SL-3, shows a similar compressional wave velocity structure as the short lines and may be assumed to exhibit a similar shear velocity structure to a depth of approximately 50 feet, the maximum depth of analysis of the line. SL-2 on the south abutment shows a high compressional wave velocity horizon at approximately 30 to 40 foot depth, Vp = 14,900 fps at the center of the line. This high velocity horizon appears to correlate with the unweathered bedrock velocity observed under the dam in borehole C-7. From these refraction lines, the unweathered bedrock appears to be slightly deeper on the north abutment then on the south abutment. However, the elevation of the unweathered bedrock, as shown on SL-2, on the south abutment correlates closely with the elevation of the base of the dam, inferring that the dam is founded on unweathered bedrock.

In summary, the downhole and refraction surveys indicate that the concrete in the bottom 45 feet of Pardee dam has compressional wave velocity of approximately 15,000$\pm$1200 fps and shear wave velocity of approximately 9000$\pm$1000 fps. Under Pardee dam, the compressional velocity is 17,250$\pm$1200 fps and the shear velocity is 11,000 fps to a depth 114 feet below the central gallery. The abutments indicate slightly lower compressional velocity for the unweathered bedrock with V_p of 15,500$\pm$1200 fps.

REFERENCES

Auld, Bruce C. (1977), "Crosshole and Downhole Vs by Mechanical Impulse". Jour Geotech Eng Div, ASCE, Vol. 103, No. GT12, Dec 1977, pp. 1381-1398.

Statton, C.T., B. C. Auld, and A. Fritz, (1978), "In Situ Seismic Shear-Wave Velocity Measurements and Proposed Procedures" in Dynamic Geotechnical Testing. ASTM STP 654, pp.56-65.

Bollinger, G. A., (1971), Blast Vibration Analysis. Southern Illinois University Press, 132p.

Clark, Sydney P., (1966), editor, Handbook of Physical Constants. GSA Memoir Number 97.

Palmer, Derecke, 1980, The Generalized Reciprocal Method of Seismic Refraction Interpretation. SEG, Tulsa, OK, 104p.

TABLE 1 -- DOWNHOLE VELOCITIES AT PARDEE DAM*

Borehole	Depth (ft)	Vp (fps)	Vs (fps)	Density(pcf)	E(dyn/cm²)	G(dyn/cm²)	PR
DH-1	0-34	13,400±1200	7,700±500	150	3.31×10^{11}	1.32×10^{11}	.254
DH-2	0-45	15,250±1200	10,000±500	150	5.01×10^{11}	2.23×10^{11}	.123
	45-114	17,250±1200	11,000±500	150	6.25×10^{11}	2.70×10^{11}	.157

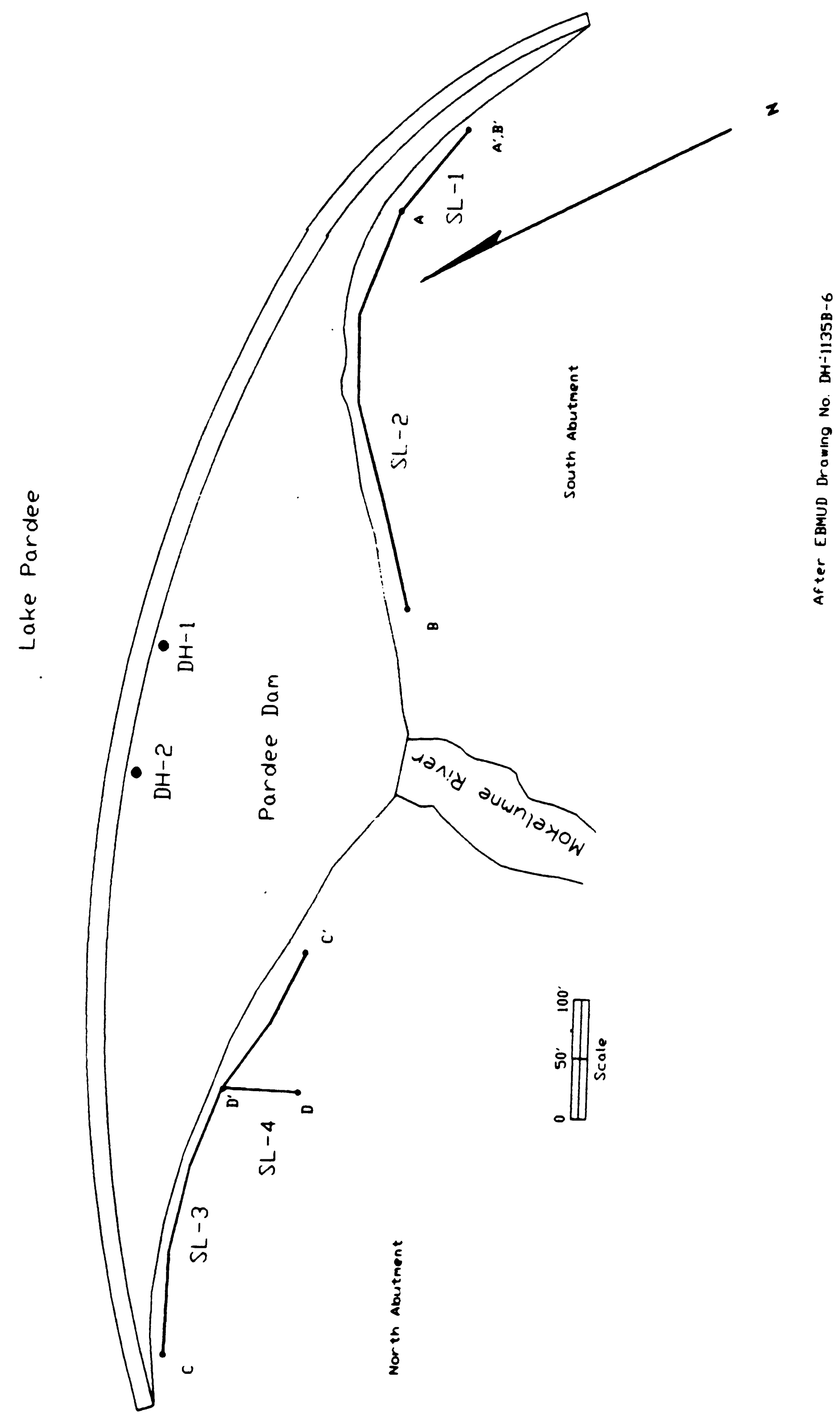
TABLE 2 -- REFRACTION VELOCITIES AT PARDEE DAM*

Borehole	Depth (ft)	Vp (fps)	Vs (fps)	Density(pcf)	E(dyn/cm²)	G(dyn/cm²)	PR
SL-1	1-5	1700±200	900±100	110	0.035×10^{11}	0.013×10^{11}	.305
	below 5**	5300±500	3300±300	110	0.422×10^{11}	0.178×10^{11}	.183
SL-4	1-5	2000±200	1100±100	125	0.058×10^{11}	0.023×10^{11}	.283
	below 5**	8500±800	5000±400	150	1.38×10^{11}	0.56×10^{11}	.235

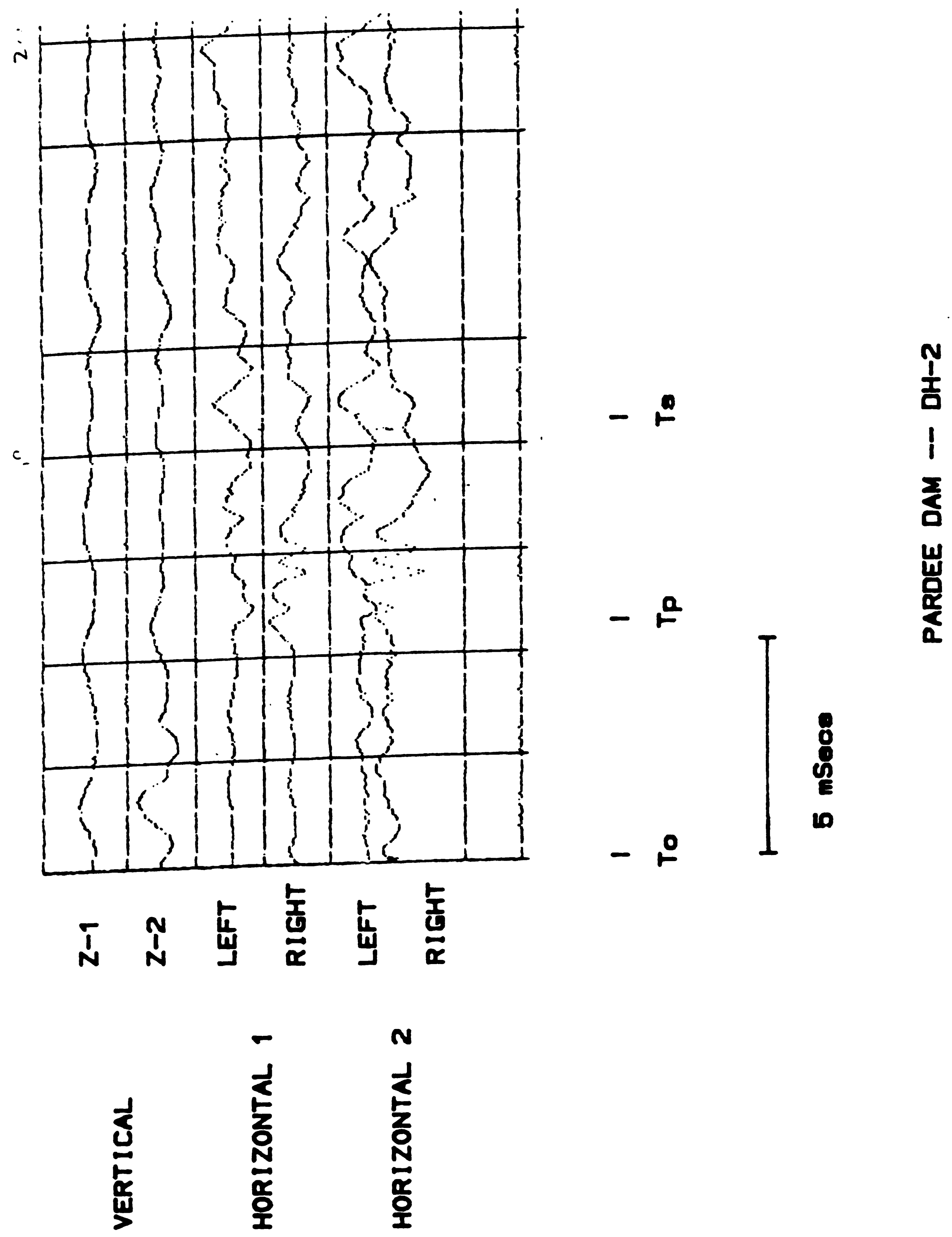
* $G = r \times Vs^2$ [Shear Modulus]
$PR = ((Vp/Vs)^2 - 2)/((Vp/Vs)^2 - 1) / 2$ [Poisson's Ratio]
$E = 2 \times G (1 + PR)$ [Young's Modulus]
r = Density

To convert from dynes/cm² to psi multiply E & G values in table by (14.5×10^{-6} psi/dynes/cm²)
e.g. 3.31×10^{11} dynes/cm² = $3.31 \times 10^{11} \times 14.5 \times 10^{-6} = 4.80 \times 10^{6}$ psi

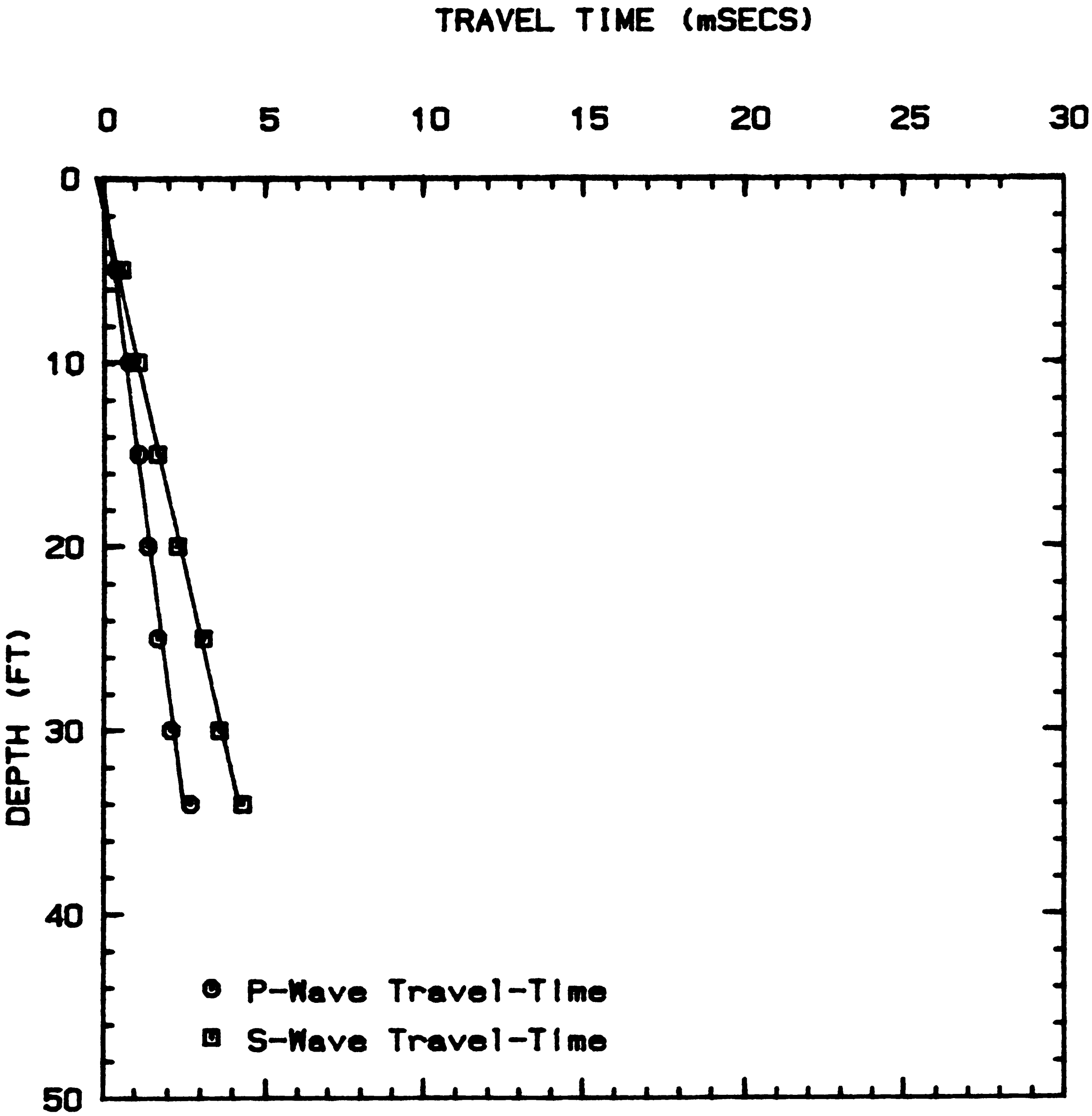
** below 5 ft to the maximum depth of penetration of approximately 50 feet.



BCA GEOPHYSICS		PARDEE DAM REFRACTION & DOWNHOLE SURVEYS	Fig 1
Job No 090-A01	01-02-1991		

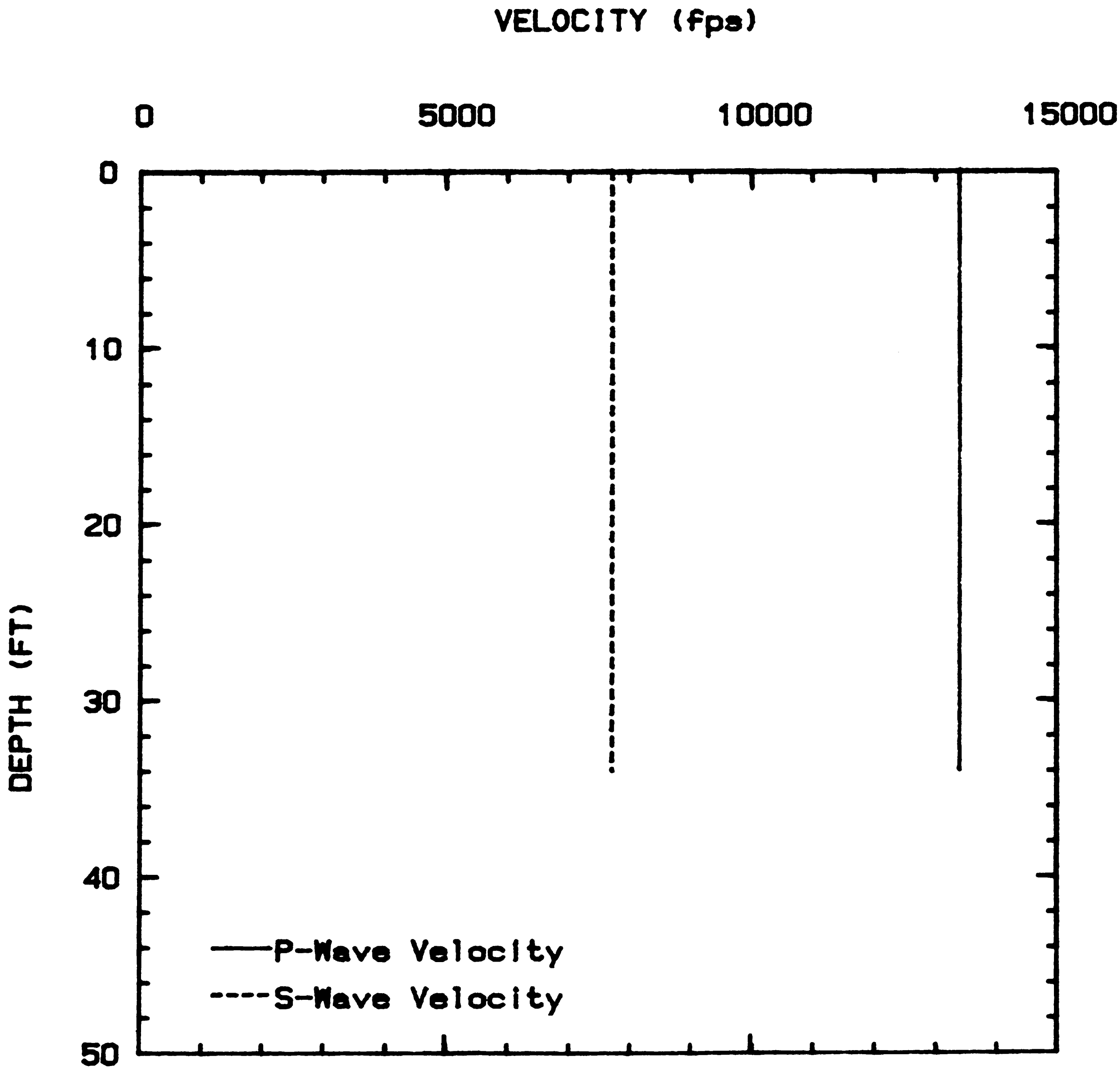


BCA GEOPHYSICS		REPRESENTATIVE RECORD -- 100FT	Fig
Job No 090-A01	01-01-1991	DOWNHOLE SURVEY	2



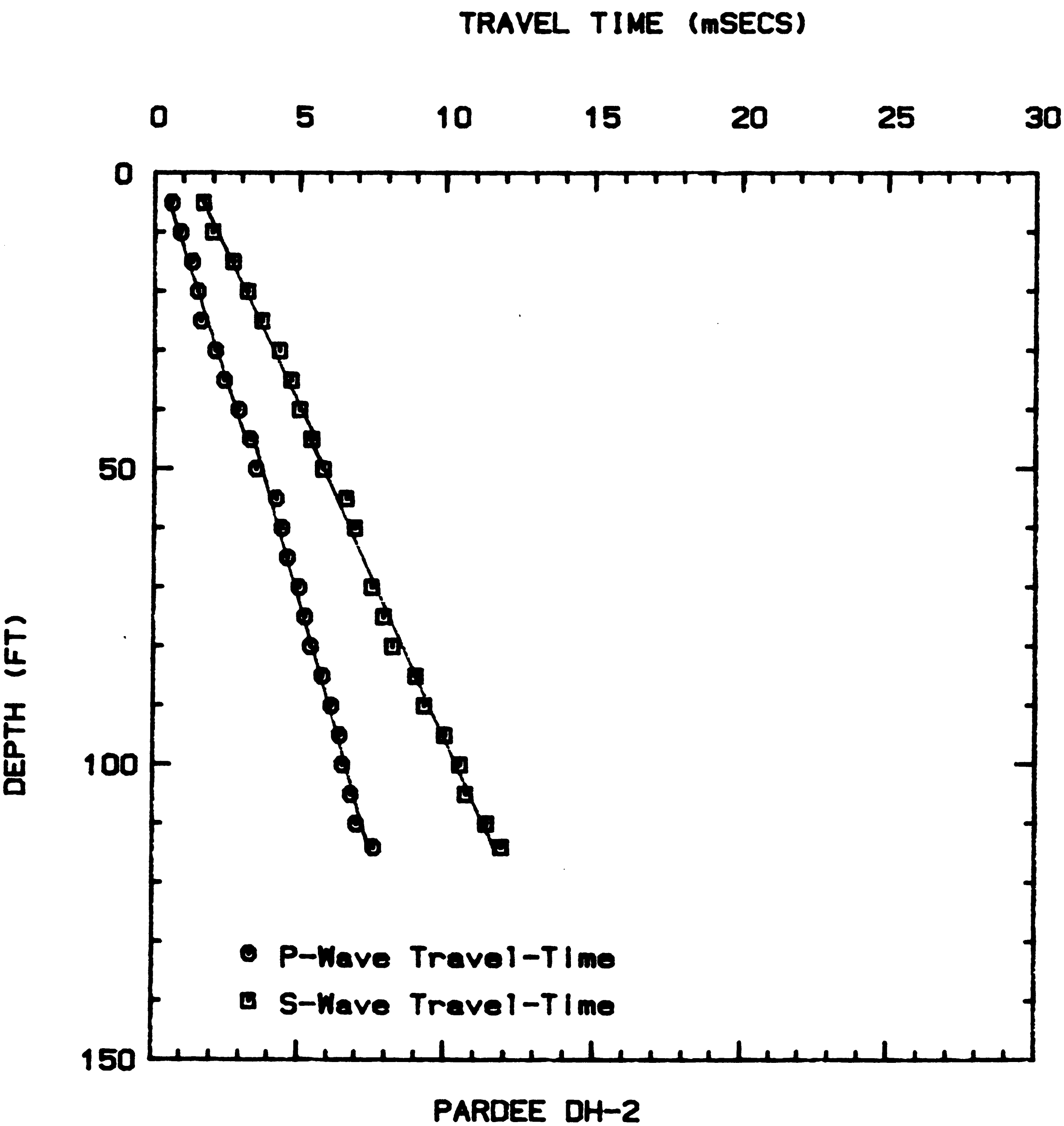
Pardee DH-1

BCA GEOPHYSICS		TRAVEL-TIME DATA	Fig
Job No 090-A01	11-03-1990	DOWN-HOLE VELOCITY SURVEY	3

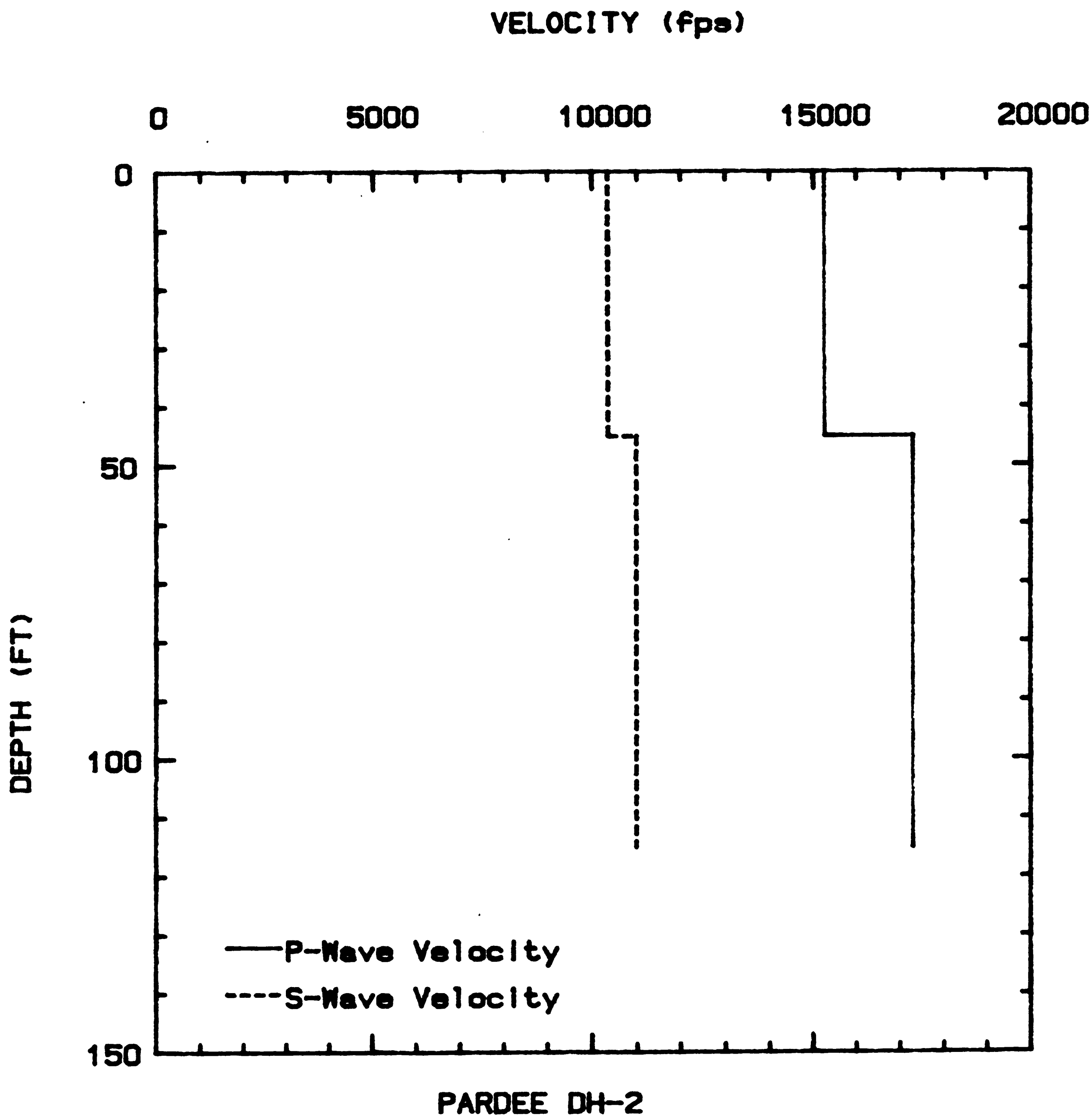


Pardee DH-1

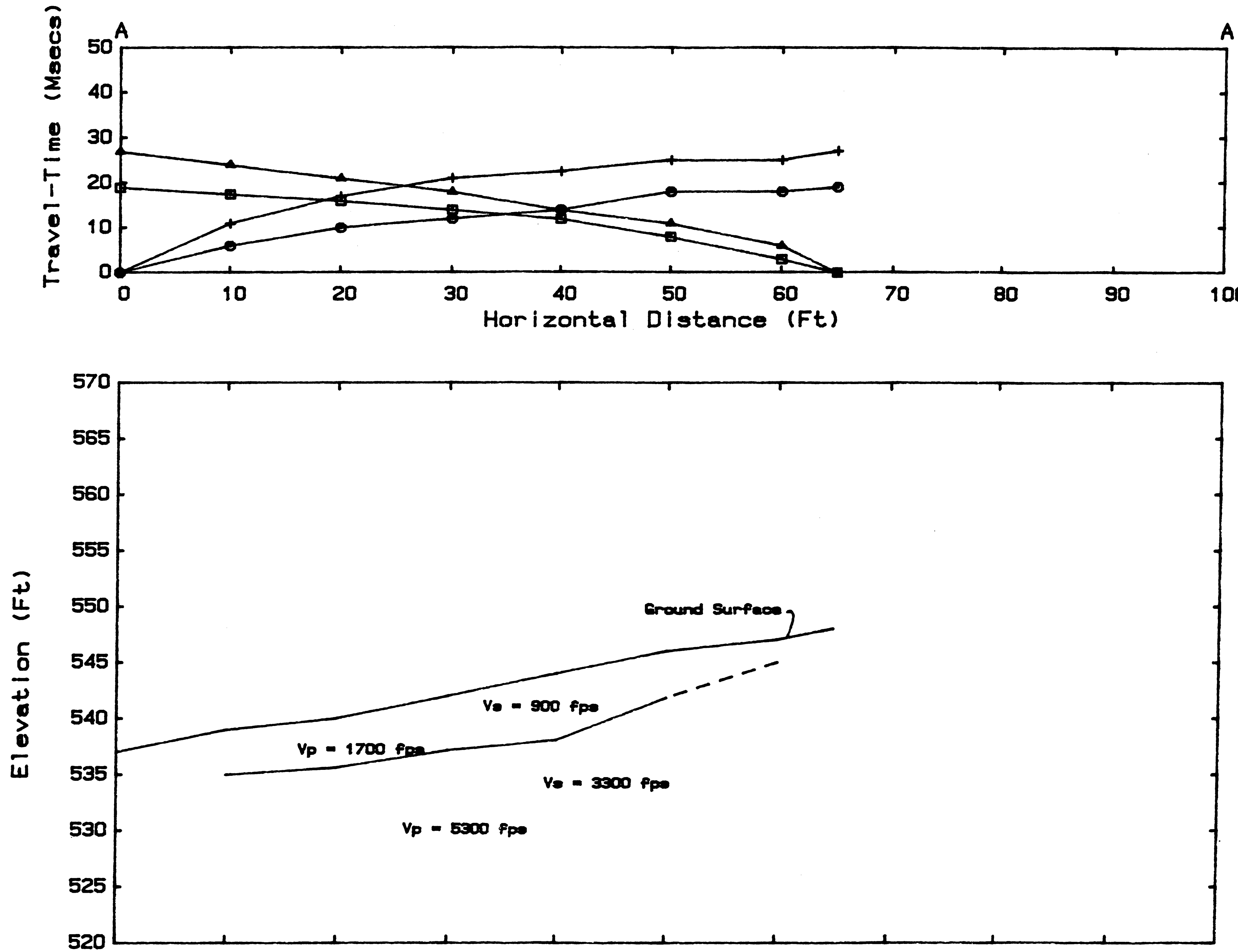
BCA GEOPHYSICS		VELOCITY-DEPTH RELATIONSHIPS	Fig
Job No 090-A01	11-03-1990	DOWN-HOLE VELOCITY SURVEY	4



BCA GEOPHYSICS		TRAVEL-TIME DATA	Fig
Job No 090-A01	12-31-1990	DOWN-HOLE VELOCITY SURVEY	5

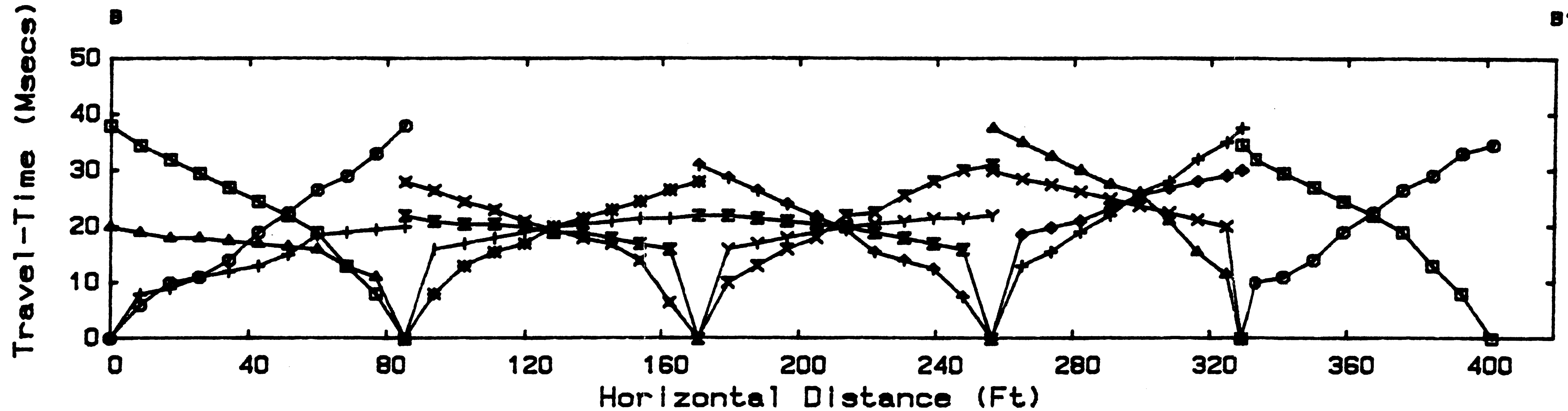


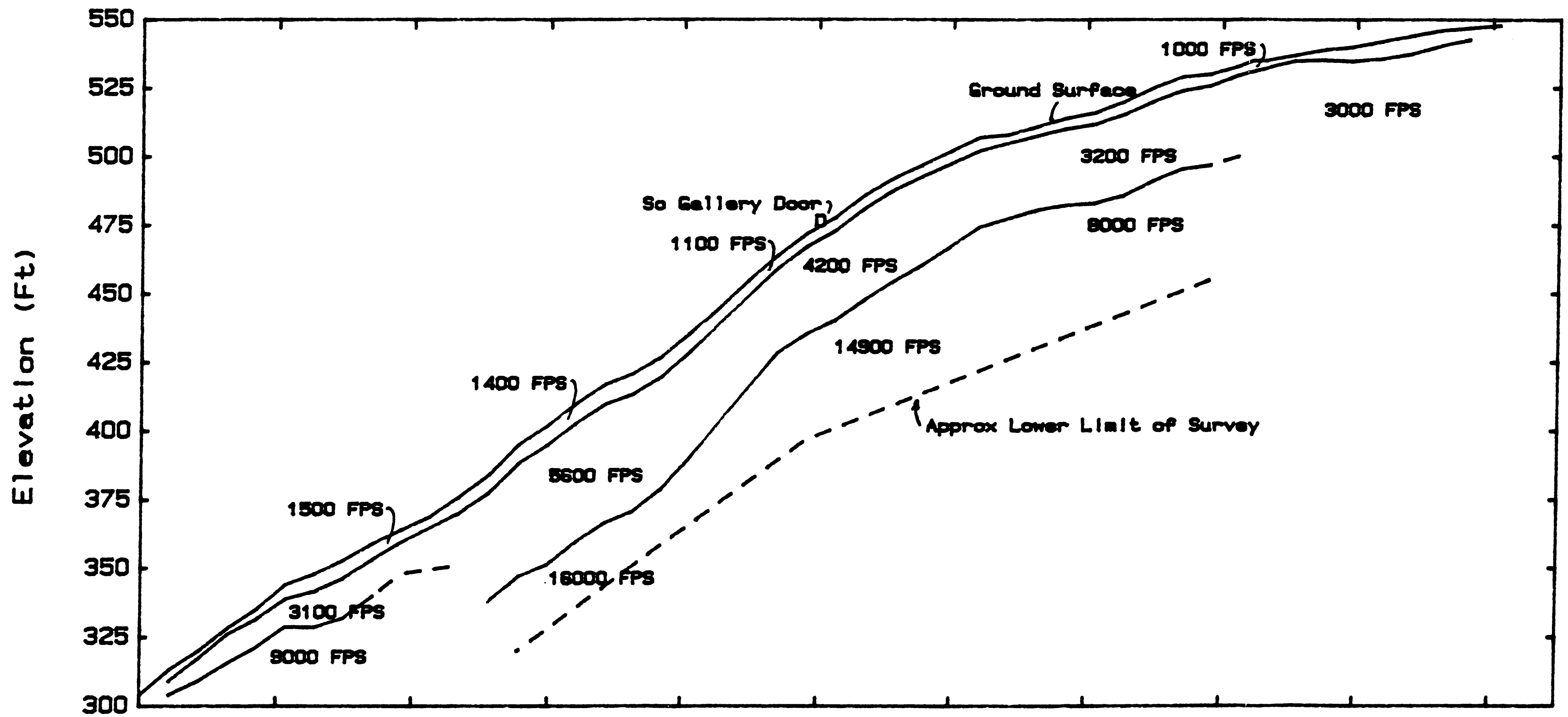
BCA GEOPHYSICS		VELOCITY-DEPTH RELATIONSHIPS	Fig
Job No 090-A01	12-31-1990	DOWN-HOLE VELOCITY SURVEY	6



PARDEE SL-1 (Vp & Vs - So. Abutment)

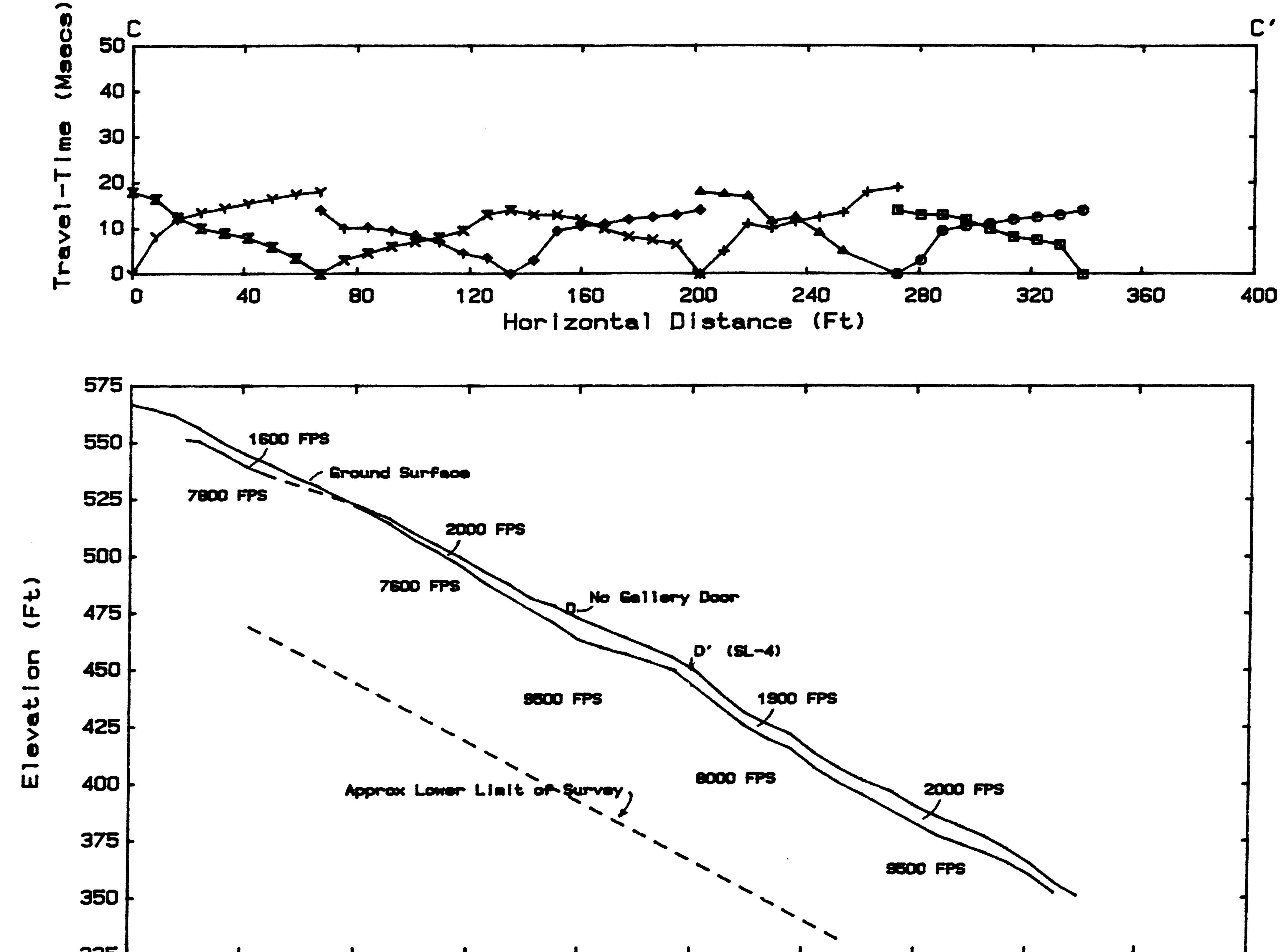
BCA GEOPHYSICS		PARDEE DAM SURVEYS	Fig
Job No 090-A01	01-03-1991	REFRACTION LINE SL-1	7





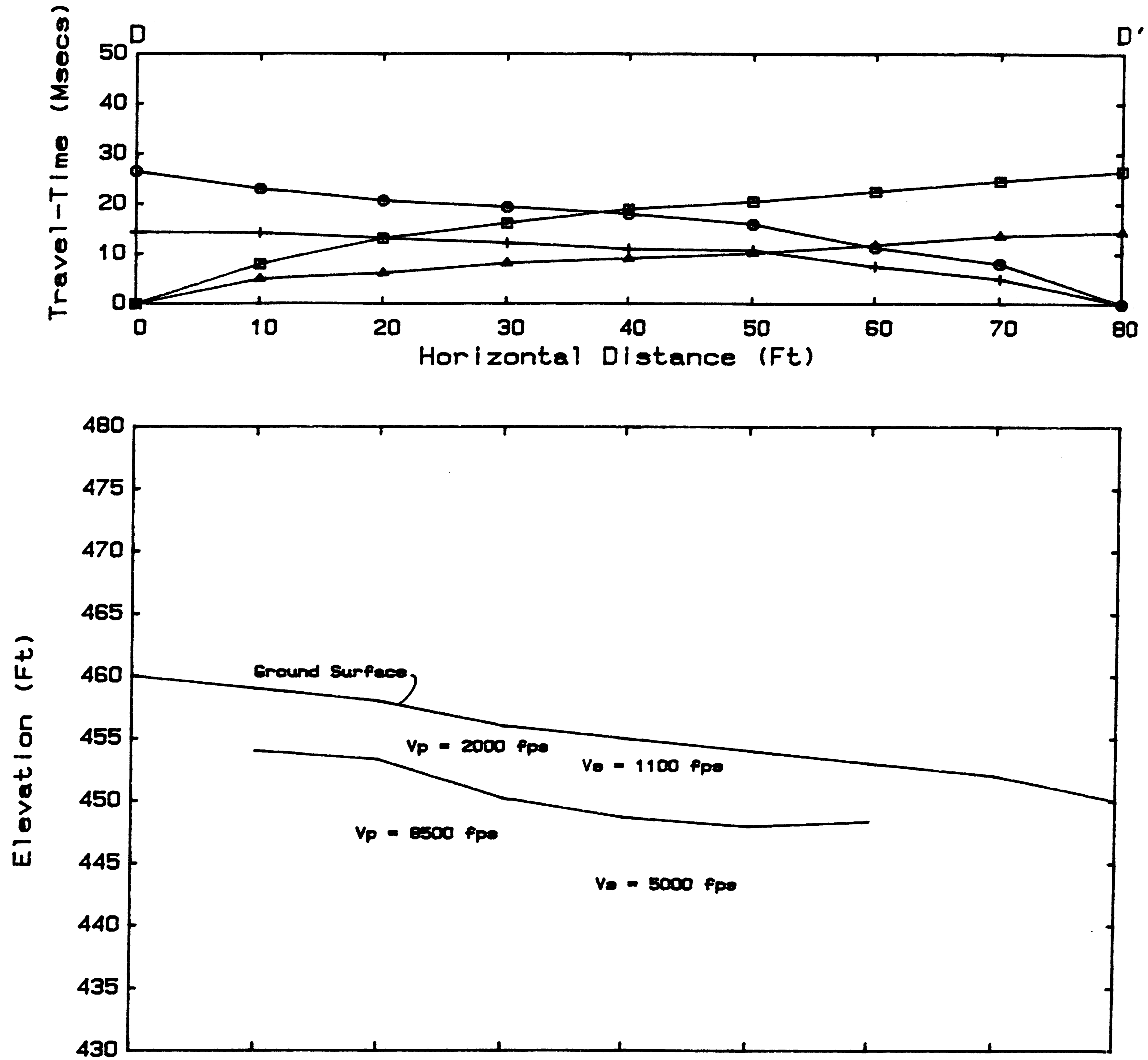
PARDEE SL-2 (South Abutment)

BCA GEOPHYSICS		PARDEE DAM SURVEYS	Fig
Job No 090-A01	01-03-1991	REFRACTION LINE SL-2	8



PARDEE SL-3 (North Abutment)

BCA GEOPHYSICS		PARDEE DAM SURVEYS	Fig
Job No 090-A01	01-03-1991	REFRACTION LINE SL-3	9



PARDEE SL-4 (Vp & Vs - No. Abutment)

BCA GEOPHYSICS		PARDEE DAM SURVEYS	Fig
Job No 090-A01	01-03-1991	REFRACTION LINE SL-4	10