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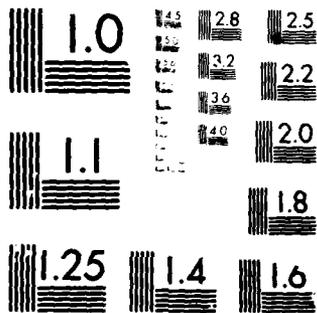
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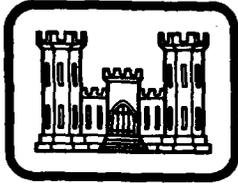
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RAYLEIGH-WAVE VELOCITY DETERMINATIONS FOR COTTONWOOD CREEK PROJECT CALIFORNIA

by

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U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

January 1980

Final Report

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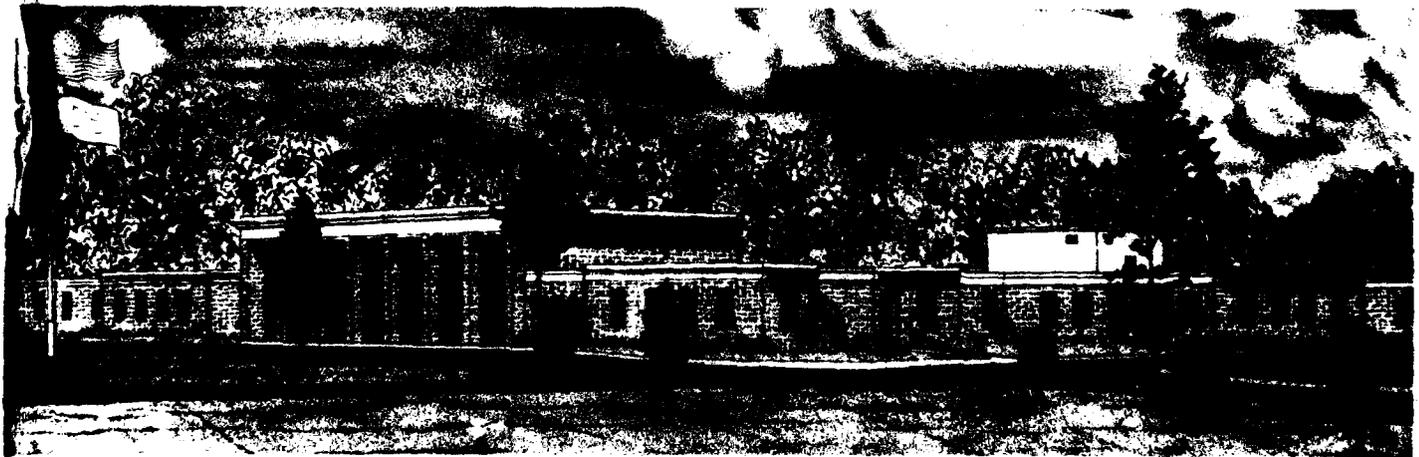
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A surface vibratory investigation was conducted at two proposed damsites (Dutch Gulch and Tehama) in connection with the Cottonwood Creek Project near Redding, California. From this investigation, Rayleigh-wave (R-wave) velocities (analogous to shear-wave velocities) were determined for the materials at the sites to a depth of approximately 50 ft.

Results of the investigation conducted at the Dutch Gulch site indicated that R-wave velocities generally fell within an 850- to 1000-fps → (Continued)

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20. ABSTRACT (Continued)

range and were relatively constant (for a particular test location) with depth. Minimum and maximum velocity values determined at the site were 550 and 1130 fps at depths of 8 and 26 ft, respectively.

At the Tehama site, R-wave velocities generally ranged from 1000 to 1300 fps and exhibited a slightly increasing trend from near ground surface to about a 20-ft depth where they become relatively constant with depth. Minimum and maximum velocity values determined at the site were 630 and 1450 fps at depths of 6 and 27 ft, respectively.

Preface

Tests reported herein were conducted by the U. S. Army Engineer Waterways Experiment Station (WES) and authorized by the U. S. Army Engineer District, Sacramento, under Inter-Agency Agreement No. SPKED-F-7-3 dated 16 October 1978.

The field investigation was conducted during the period 6-18 November 1978 by Messrs. J. R. Curro, Jr., R. E. Wahl, and D. H. Douglas of the Field Investigations Group (FIG), Earthquake Engineering and Geophysics Division (EE&GD), Geotechnical Laboratory (GL), WES. The work was performed under the direct supervision of Mr. R. F. Ballard, Jr., Chief, FIG, and under the general supervision of Dr. P. F. Hadala, Chief, EE&GD, and Mr. J. P. Sale, Chief, GL.

Commanders and Directors of the WES during the conduct of this study were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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Contents

Conversion Factors, U. S. Customary to Metric (SI)
Units of Measurement

U. S. customary units of measurement used in this report can be con-
verted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
inches per second	25.4	millimetres per second
miles (U.S. statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms

RAYLEIGH-WAVE VELOCITY DETERMINATIONS FOR
COTTONWOOD CREEK PROJECT, CALIFORNIA

Introduction

1. To evaluate the dynamic response of a site or a structure founded on soil to earthquake shaking specified at the top of bedrock, knowledge of stress-strain properties of the foundation materials is required. When current dynamic computerized finite-element analyses are used, shear-wave (S-wave) velocities (at very low strains, generally 10^{-4} in./in.* or less) are necessary input parameters to the codes. These S-wave velocities are usually determined in situ using the cross-hole and downhole seismic methods.

2. The Cottonwood Creek Project is located approximately 150 miles north of Sacramento, California, and consists of the proposed construction of two dams (Figure 1). Since the project is in the preliminary stage, it was desired to make a quick and economical initial assessment of S-wave velocities of the foundation materials at the two proposed damsites (Dutch Gulch and Tehama). To accomplish this, surface Rayleigh-wave (R-wave) vibratory tests were conducted at the sites from which velocities (analogous to S-wave velocities**) were determined. A limited foundation and geologic study that encompassed drilling and trenching operations and a refraction seismic survey were performed by J. H. Kleinfelder and Associates (1978).†

3. The primary purpose of investigations reported herein was to determine R-wave velocities of the material at the damsites to a depth of approximately 50 ft and report any anomalies inferred from the data.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

** A. A. Maxwell, and Z. B. Fry. 1967. "A Procedure for Determining Elastic Moduli of In Situ Soil by Dynamic Techniques," Proceedings, International Symposium on Wave Propagation of Dynamic Properties of Earth Materials, Albuquerque, N. Mex.

† J. H. Kleinfelder and Associates. 1978. "Geological and Foundation Report, Cottonwood Creek Project, Tehama County, California," Contract Report A-1749-1 (unpublished), Sacramento, Calif.

Site Description

4. The damsites are located approximately 8 miles west of
Cottonwood, California, which is about 15 miles south of Redding on
Interstate Highway 5 as shown in the general locality map (Figure 1).
The topography at both sites exhibited gently rolling surfaces. Vege-
tation consisted of thick annual grass (1 to 2 ft tall) and trees
(sparse to medium dense). The geology of the tested areas was comprised
of Terrace materials (Pleistocene to Recent age) overlying the Pliocene
Tehama formation.* From boring and outcrop data, the Terrace deposits
consist of a silty and clayey coarse-grained gravelly sand and sandy
gravel. The Tehama formation is composed of sandy clay and fine to
coarse clayey sand with occasional silty sand and gravel layers. Cobbles
were also encountered in several borings at various depths during
drilling operations.

Equipment and Test Procedure

5. The surface vibratory tests were conducted utilizing a 4000-lb
force (peak) electrohydraulic vibrator as the wave source. Associated
instrumentation to operate and monitor the vibrator is described by
Ballard (1964)** and Maxwell and Fry (1967).† The surface wave gener-
ated by the vibrator was detected by 24 vertical, velocity-type trans-
ducers (geophones) and recorded using a portable, battery-operated,
24-channel seismograph and oscillograph. The oscillograph displayed
the data on light-sensitive paper while operating at a speed of 16 ips.
Resolution time at this speed is about 1 msec. Timing lines were pro-
duced on the oscillograph at 10-msec intervals.

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* Kleinfelder and Associates, op. cit., p. 4.
** R. F. Ballard, Jr. 1964. "Determination of Soil Shear Moduli at
   Depths by In Situ Vibratory Techniques," Miscellaneous Paper 4-691,
   U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
† A. A. Maxwell, and Z. B. Fry, op. cit., p. 4.

6. The test procedure consisted of positioning the vibrator at a selected location and placing the geophones in a straight line (starting at and extending away from the vibrator) at selected intervals (5 and 10 ft) along the surface of the ground. The vibrator was then operated at discrete selected frequencies with the surface R-wave being monitored by the transducers (geophone nearest the vibrator served as zero time). The time lag, referenced to the zero time geophone, is determined and plotted versus the respective distances that the geophones were from the vibrator. The R-wave velocity for the source frequency is determined from the slope of the line obtained in the plot. When the frequency and R-wave velocity are known, a corresponding wavelength can be computed by dividing the velocity by the frequency. Wave velocities thus derived are considered to be average values* for an effective depth of one-half the wavelength.** As mentioned previously, R-wave velocities are numerically close to S-wave velocities. For the range of Poisson's ratios commonly found in soil materials, the maximum difference between R- and S-wave velocities is less than 10 percent.**

Tests Conducted and Discussion of Results

Dutch Gulch site

7. At this site, 12 surface vibratory lines, designated as V-1 through V-12, were run as shown in the test layout (Figure 2). The selection of these locations was determined by judgment based on the results of surface refraction seismic tests conducted by Kleinfelder and Associates (1978).† The vibratory lines, two (in opposite

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 * R-wave velocities that are determined near a high velocity contrast interface, such as a soil-rock boundary, will probably be influenced by both the higher and lower velocity materials and thus provide weighted average velocities dependent on the physical properties of the two layers.
** Ballard, op. cit., p. 5.
 † Kleinfelder and Associates, op. cit., p. 4.

directions) for each vibrator location, were generally 230 ft in length.
The vibratory tests were performed using various discrete frequencies,
usually between 8 and 50 Hz, which provided the necessary depth coverage.
It will be noted that the geophone data obtained from frequencies below
about 20 Hz were not purely sinusoidal ground motions of the propagated
frequency. This probably resulted from the inherent characteristics of
the vibratory system, such as the engine and hydraulic noise and the
vibrator design that deteriorated the sinusoidal signal. Since the data
should be sinusoidal and of the propagated frequency to confidently be
reduced manually (as most reductions were made in the field), questions
may arise as to the validity of the data. Therefore, selected data
records were digitized and subjected to Fourier analysis and filtering.
Cross-correlation techniques were then applied to the processed data
(to determine time lag mentioned in paragraph 6). These procedures re-
sulted in the same velocity and depth values as those computed by manual
means, which validated the manually reduced data.

8. As mentioned previously, the data from the surface vibratory
tests were plotted as R-wave time versus distance for each frequency.
Figure 3 shows a typical plot with the corresponding velocity, wave-
length, and depth. When this had been accomplished for all frequencies
from a vibratory line, a plot of R-wave velocity versus depth was made.
Figures 4 through 9 present these plots from lines V-1 through V-12
for the Dutch Gulch site. It will be noted that boring and Standard
Penetration Test (SPT) data* have been superimposed on the plots where
the borings and vibratory lines were in proximity.

9. Referring to Figures 4 through 9, R-wave velocities generally
can be banded between 850 and 1000 fps and were relatively constant
with depth, particularly below about 15 ft. There were two major excep-
tions to the above velocity range, and several individual data points
fell outside the band. The notable differences occurred from lines V-9
through V-12 (Figures 8 and 9). The data shown in Figure 8 indicate

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* Kleinfelder and Associates, ibid.

velocities slightly greater than 1000 fps (reaching a high of 1130 fps) below a depth of approximately 19 ft. The data from lines V-11 and V-12 (Figure 9) exhibit velocities considerably less than 850 fps, ranging from a low of 550 fps at an 8-ft depth to a high of 845 fps at 20 ft (very high SPT blow counts were noted near this depth) and then showing a decrease to 685 fps at 57 ft. The reason for the lower velocities may be due to these vibratory lines being located in a transitional material, since floodplain deposits (Q_f) were exposed nearby and the elevation of the ground surface was approximately 60 ft less than that at other tested locations as shown in Figure 2. At any rate, the R-wave velocities measured at lines V-11 and V-12 were significantly lower than all others measured at this site, and some cause for this difference should be sought in the detailed geologic studies for the project. No anomalous features were noted in any of the data from this site.

Tehama site

10. Eighteen surface vibratory lines (V-13 through V-30) were run at this site. Their locations (Figure 10) were referenced to surface refraction seismic tests conducted by Kleinfelder and Associates (1978).* The vibratory lines ranged from 200 to 230 ft in length. Various frequencies in the 8- to 50-Hz range were run to provide velocities at reasonable depth intervals. As mentioned in paragraph 7, selected data were subjected to digitizing, Fourier analysis, and cross-correlation techniques to establish the validity of the manually reduced data.

11. Figures 11 through 19 present the R-wave velocity versus depth plots from lines V-13 through V-30. Boring and SPT data*,** have been superimposed on the plots where the borings and vibratory lines were in proximity.

12. Referring to Figures 11 through 19, R-wave velocities generally fell in a 1000- to 1300-fps range, particularly below a depth of

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* Ibid.

** U. S. Army Engineer District, Sacramento. 1970. "Cottonwood Creek Site Geology Report," Sacramento, Calif.

about 10 ft (approximate top of the Pliocene Tehama formation) and were relatively constant (for a particular test location) below a depth of 20 ft. Velocities generally exhibited an increasing trend from near ground surface to 20 ft. There are three notable exceptions to the velocity range given above (aside from individual data points that fell outside the range). The data from lines V-21 and V-22 (Figure 15) indicate velocities that slightly exceed 1300 fps in the 26- to 39-ft depth interval and below 70 ft. A maximum site value of 1450 fps was noted at 27 ft from line V-21. Conversely, data from lines V-15, V-16, and V-27 (Figures 12 and 18) exhibit velocities considerably less than the 1000- to 1300-fps band. Data from line V-15 (Figure 12) indicate an average velocity of about 800 fps from 10 to 56 ft deep. Velocities from line V-16 range from a low of 750 fps at a depth of 14 ft to a high of 1090 fps at 34 ft where there is a decreasing trend to 880 fps at 44 ft. The higher velocity values at 34 and 38 ft correlate well with high blow count values noted at these depths in a nearby boring. This could be only coincidental as there is an indication from the boring data that gravel is present. As noted in Figure 10, lines V-15 and V-16 were run in the vicinity of the contact between the Q_f and Terrace deposits (Q_t); therefore, the lower velocities may be attributed to a transitional change in materials. In addition, Figure 10 shows companion lines V-13 and V-14, which exhibit considerably higher velocities, to be in proximity to a "finger" of the Pliocene Tehama formation (Pte). Boring data* in Figure 11 indicate the Pte, beginning at a 13-ft depth, to be lightly to moderately cemented, which may account for the higher velocities. Data from line V-27 (Figure 18) exhibit a velocity range of 630 to 800 fps (6- to 34-ft depth) except for an 870-fps velocity at 10 ft. The 630 fps was the lowest velocity determined at the Tehama site. Also, line V-28 (Figure 18) exhibited velocities considerably higher than those from line V-27, and no explanation can be given for this difference. Therefore, future detailed

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* U. S. Army Engineer District, Sacramento, op. cit., p. 8.

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geological and geophysical studies should address this area of the site to determine the reason for the velocity contrasts.

13. A prominent anomalous feature at the site consisted of the highest velocities (for a particular test location) being exhibited in the approximate depth interval of 25 to 35 ft. This was particularly noticeable on all vibratory lines except lines V-15, V-17, V-18, and V-30.

Conclusions

14. Based on the results of the surface vibratory investigation conducted at Dutch Gulch and Tehama damsites, the following conclusions were drawn:

Dutch Gulch site

a. R-wave velocities generally fell within an 850- to 1000-fps range and were relatively constant (for a particular test location) with depth.

b. Two exceptions to the 850- to 1000-fps velocity range existed. Data from vibratory lines V-9 and V-10 indicated slightly higher velocities (maximum of 1130 fps) below a depth of about 19 ft. Data from lines V-11 and V-12 exhibited velocities (550 to 845 fps), which were considerably less than the range. The lower velocities may be attributed to the vibratory lines being located in a transitional material since the Q_f and Q_t contact was in proximity.

c. Minimum and maximum velocity values determined at this site were 550 and 1130 fps at depths of 8 and 26 ft, respectively.

d. No anomalous features were noted from the data.

Tehama site

a. R-wave velocities generally ranged from 1000 to 1300 fps and exhibited a slightly increasing trend from near ground surface to about a 20-ft depth where they became relatively constant with depth.

b. Three exceptions to the 1000- to 1300-fps velocity range were noted. Data from vibratory lines V-21 and V-22 indicated velocities slightly exceeding the zone in the 26- to 39-ft depth interval and below 70 ft. Data from lines V-15, V-16, and V-27 exhibited velocities considerably

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less than 1000 fps, generally ranging from a low of 630 fps to a high of 880 fps.

c. Minimum and maximum velocity values determined at the site were 630 and 1450 fps at depths of 6 and 27 ft, respectively.

d. Anomalous features at the site appeared to be zones of higher velocities (for a particular test location) in about the 25- to 35-ft depth interval. These velocities usually correlated with higher blow counts from SPT tests (where available) although boring data normally indicated gravel to be present in or near the high blow-count zones.

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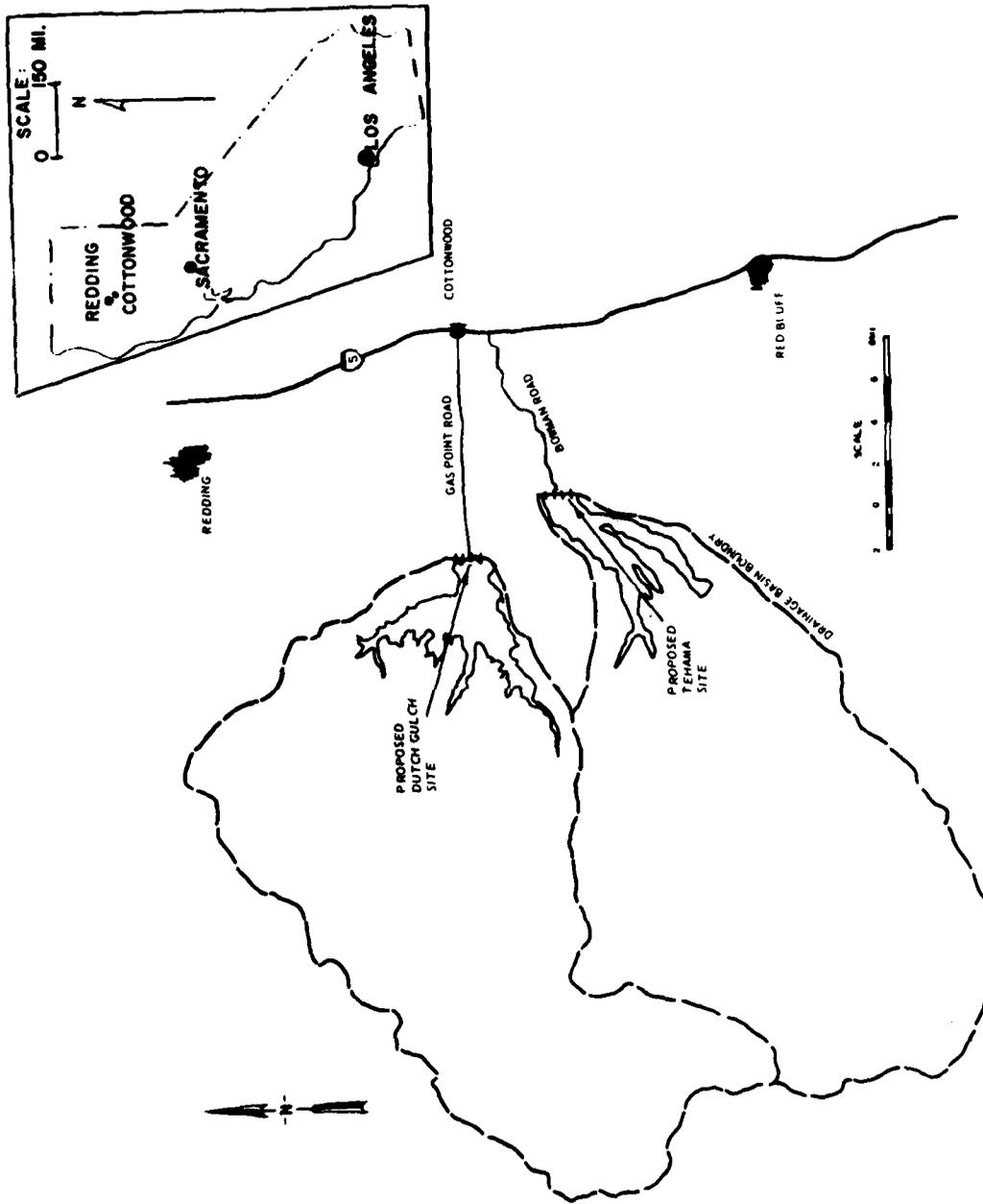
Figure 1. General locality map, Dutch Gulch and Tehama damsites, California

Figure 2. Geophysical test layout, Dutch Gulch site
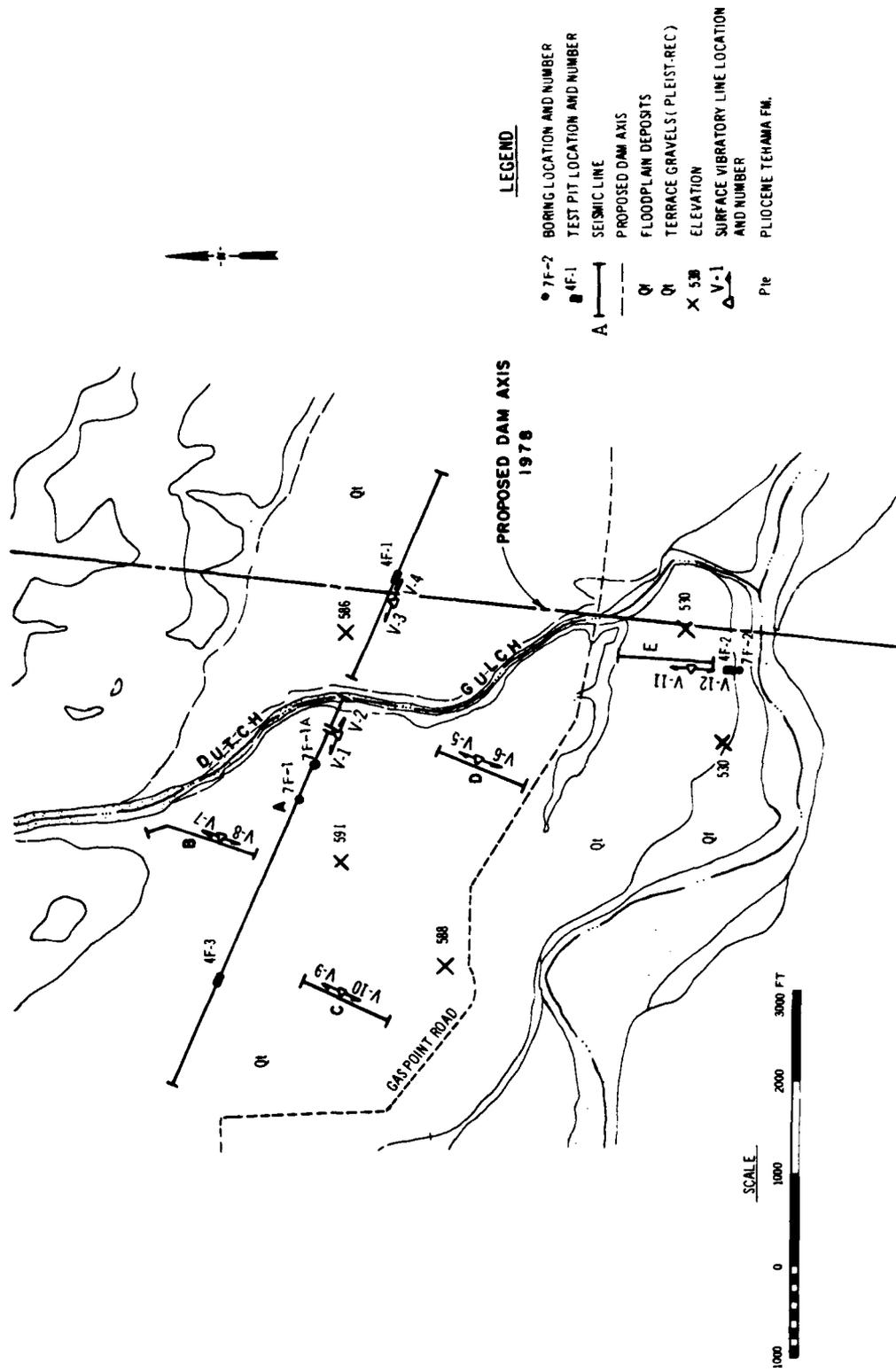
LEGEND

● 7F-2   BORING LOCATION AND NUMBER
■ 4F-1   TEST PIT LOCATION AND NUMBER
A ⊢——⊣   SEISMIC LINE
- - -   PROPOSED DAM AXIS
Qt   FLOODPLAIN DEPOSITS
Qt   TERRACE GRAVELS (PLEIST-REC)
× 530   ELEVATION
△ V-1   SURFACE VIBRATORY LINE LOCATION
          AND NUMBER
Pte   PLIOCENE TEHAMA FM.

LEGEND:

f= frequency, Hz
v= velocity, fps
λ= wavelength, ft.
d= depth, ft

f = 25 Hz   V = (1135 fps)   λ = 45.3'   d = 22.7')

DISTANCE, FT

0 20 40 60 80 100 120 140 160 180 200 220 240

TIME, MSEC

0 20 40 60 80 100 120 140 160 180 200 220

Figure 3. R-wave time versus distance, Tehama site, line V-25
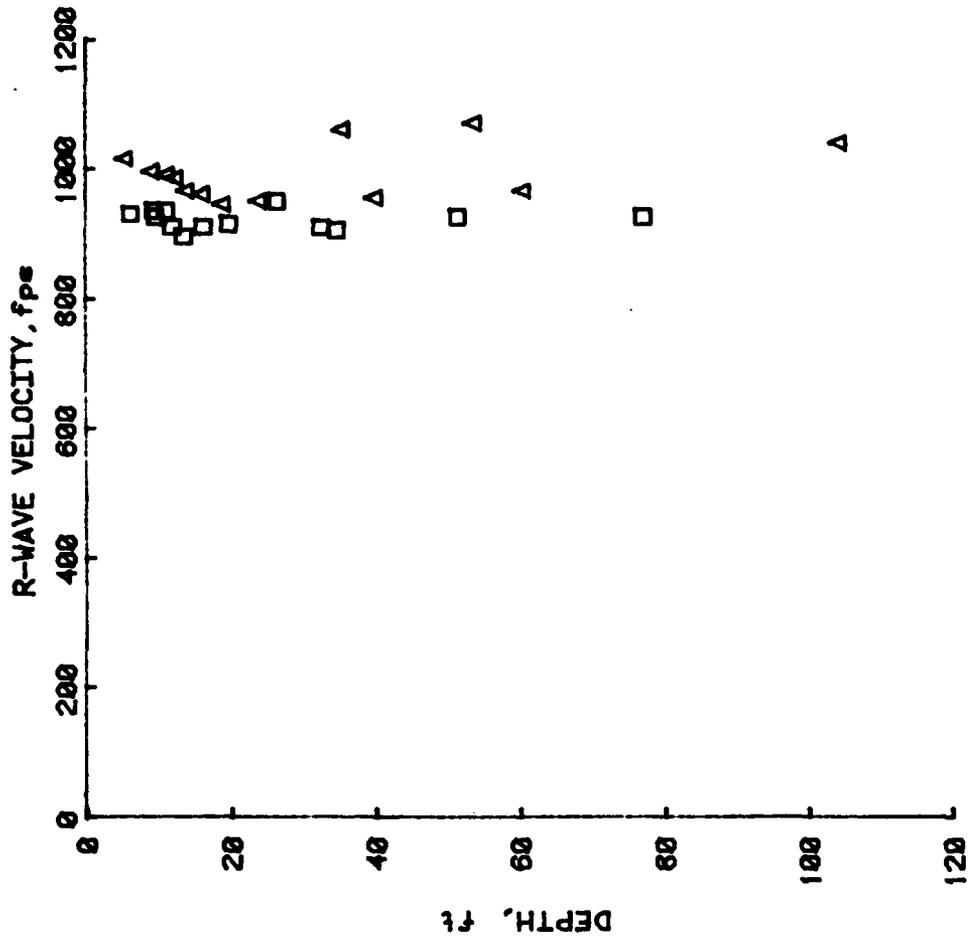
Figure 4. R-wave velocity versus depth, Dutch Gulch site, lines V-1 and V-2
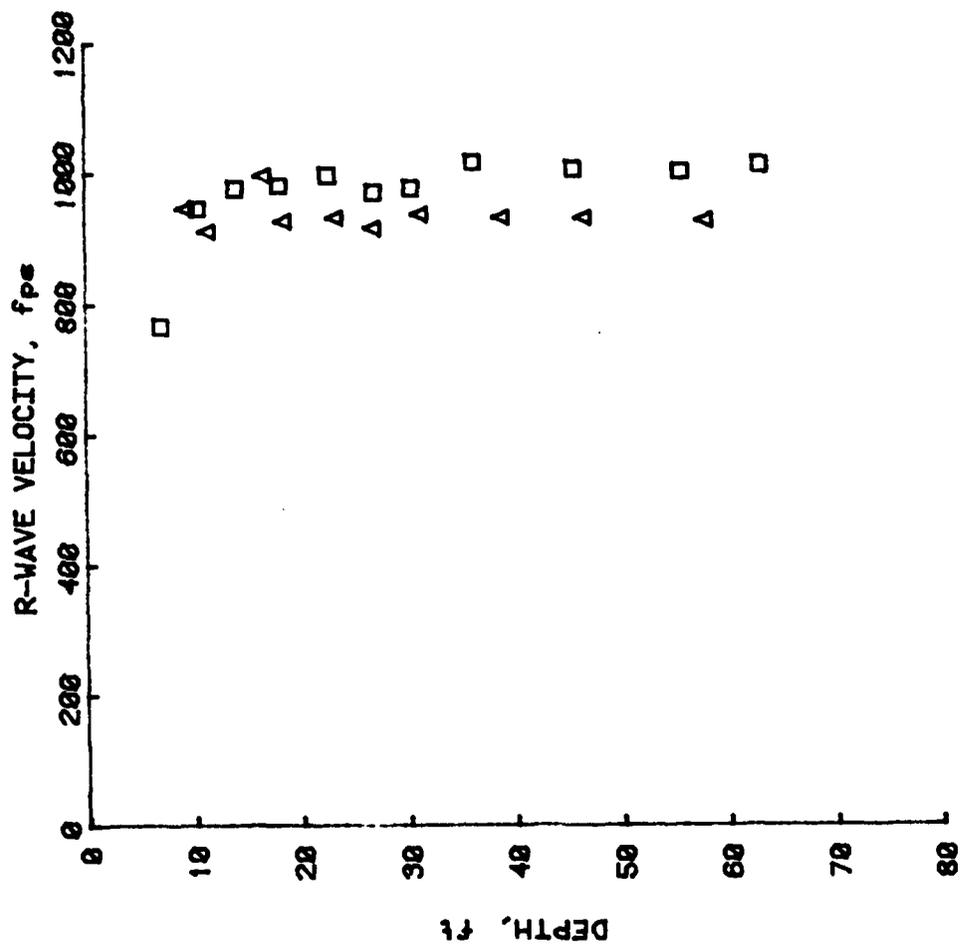
Figure 5. R-wave velocity versus depth, Dutch Gulch site, lines V-3 and V-4
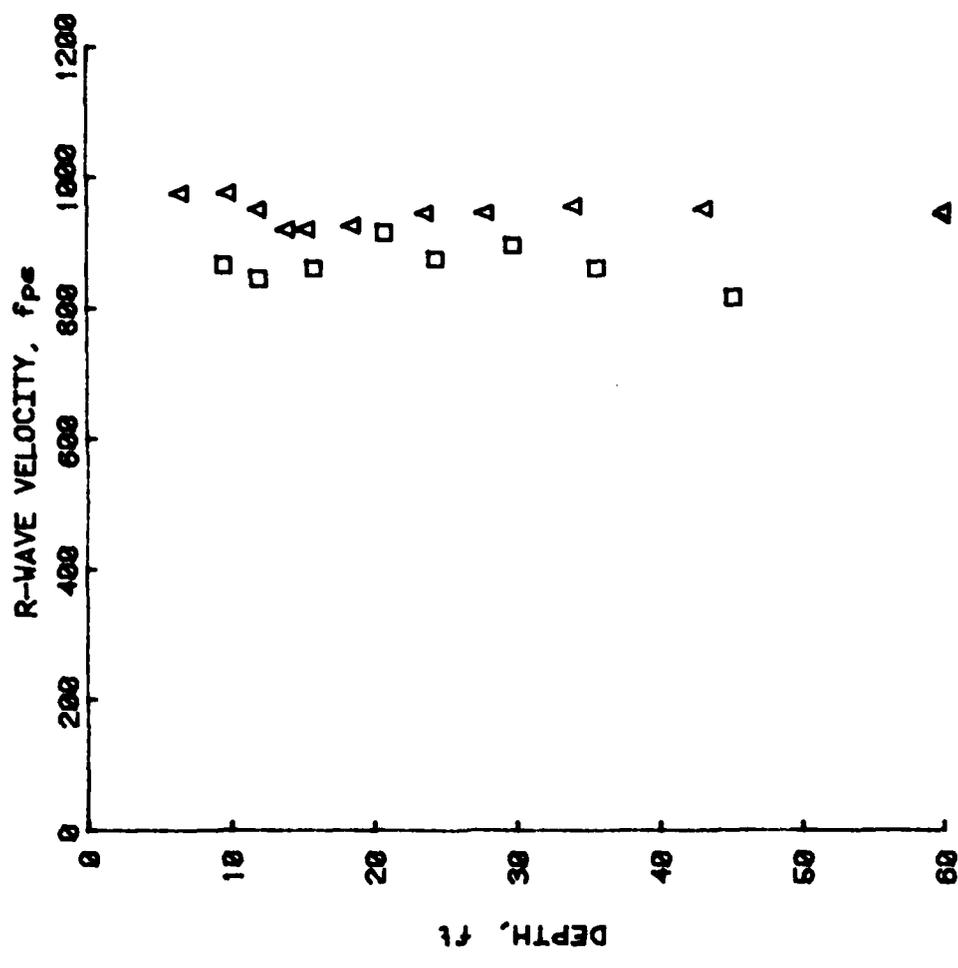
Figure 6. R-wave velocity versus depth, Dutch Gulch site, lines V-5 and V-6
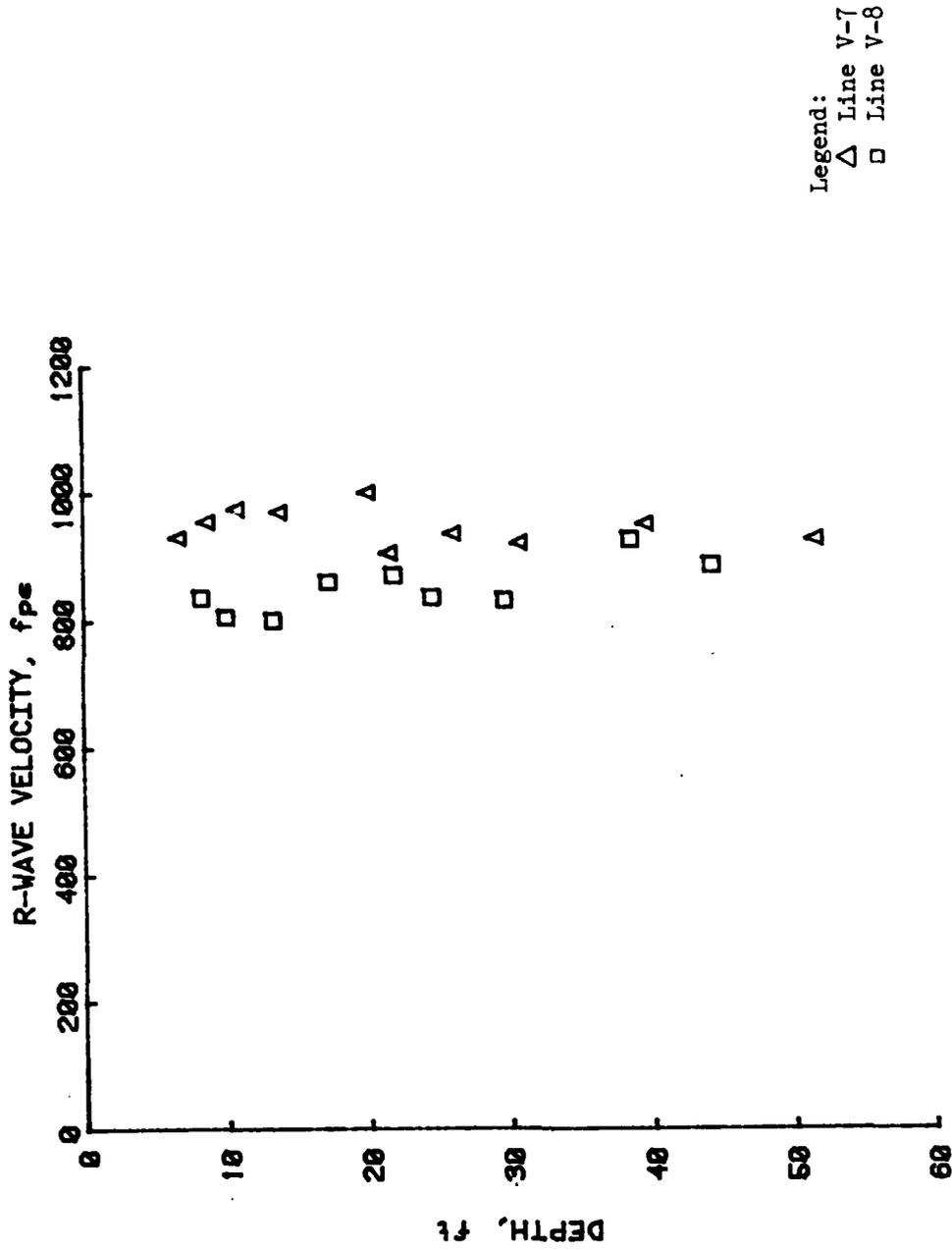
Figure 7. R-wave velocity versus depth, Dutch Gulch site, lines V-7 and V-8
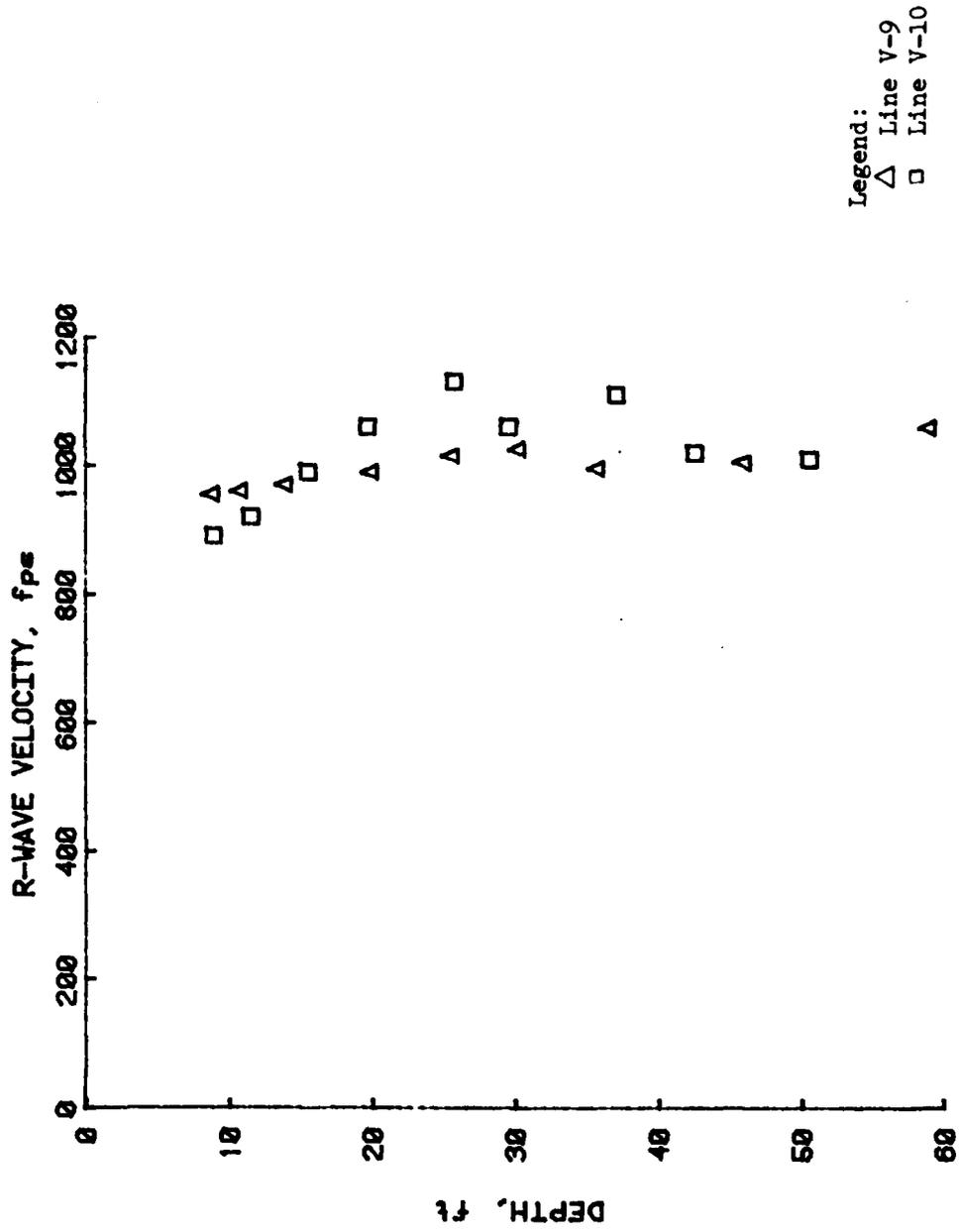
Figure 8. R-wave velocity versus depth, Dutch Gulch site, lines V-9 and V-10
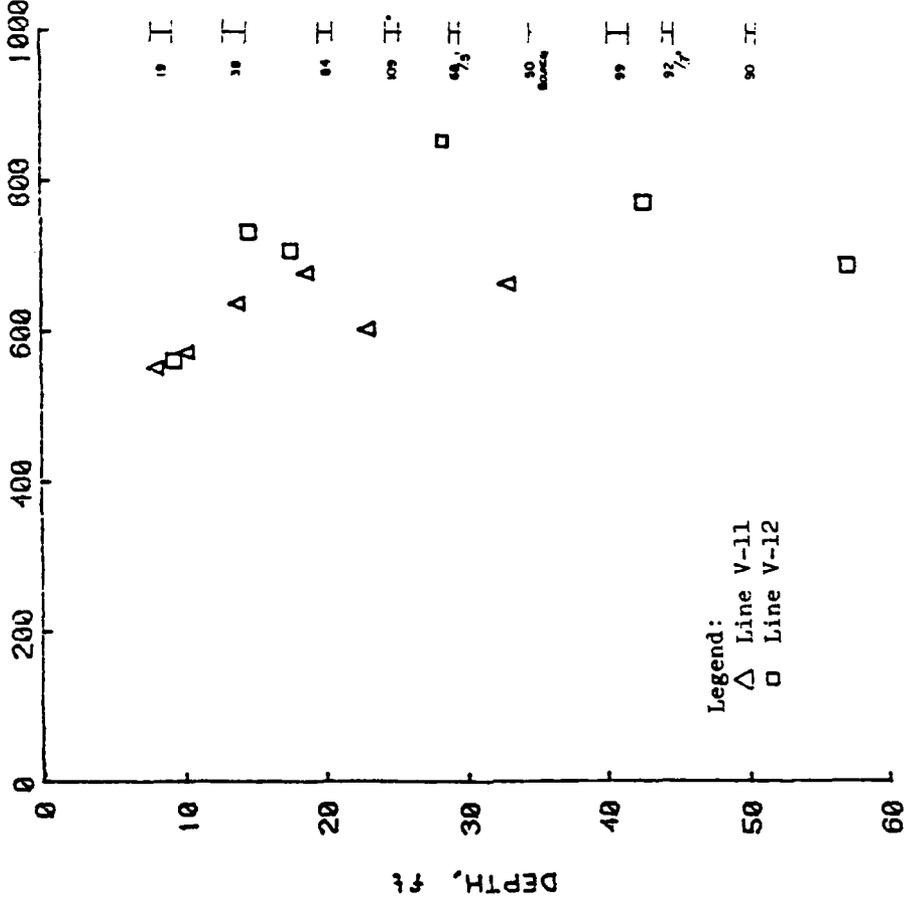
Figure 9. R-wave velocity versus depth, Dutch Gulch site, lines V-11 and V-12

Figure 10. Geophysical test layout, Tehama site
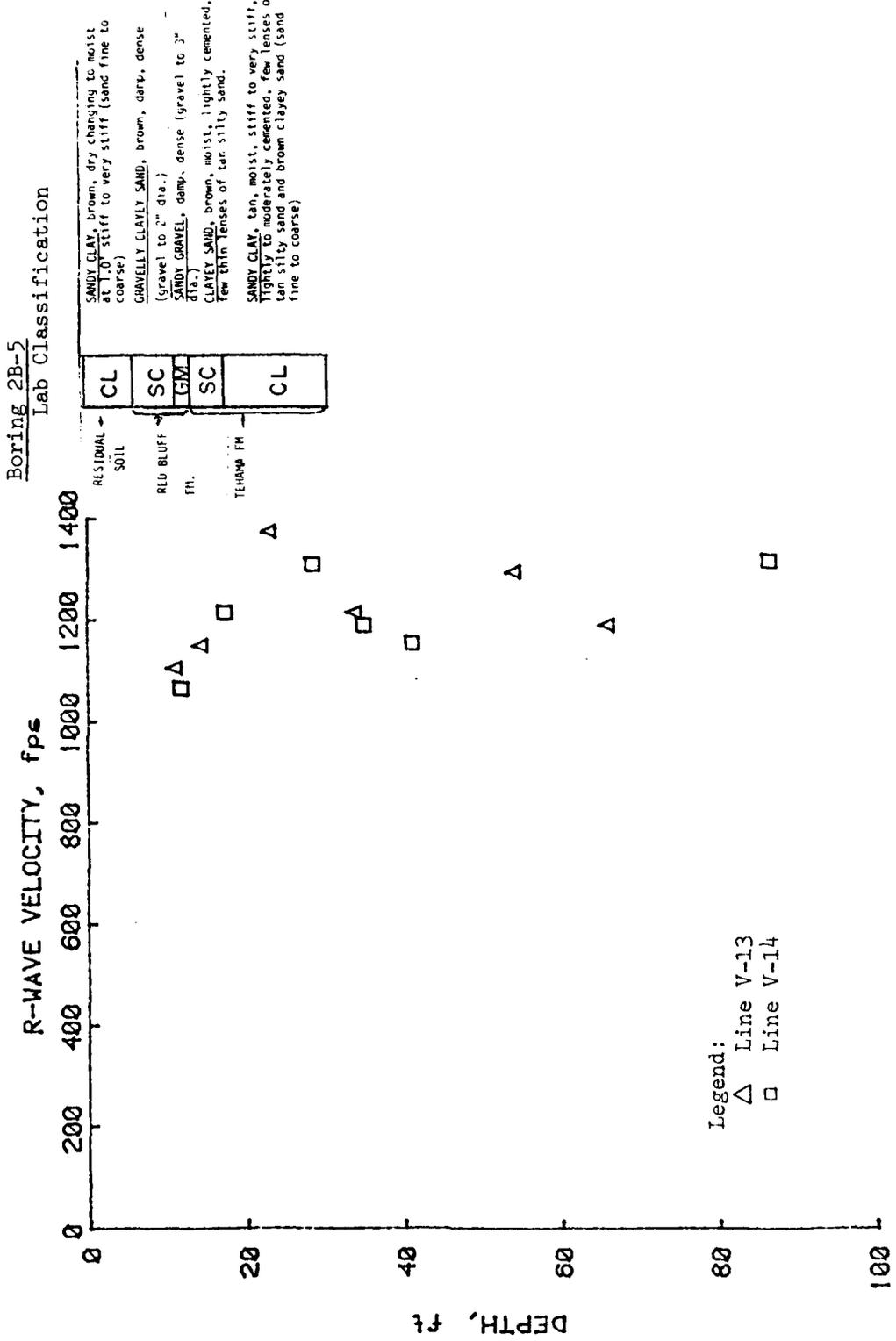
Figure 11. R-wave velocity versus depth, Tehama site, lines V-13 and V-14
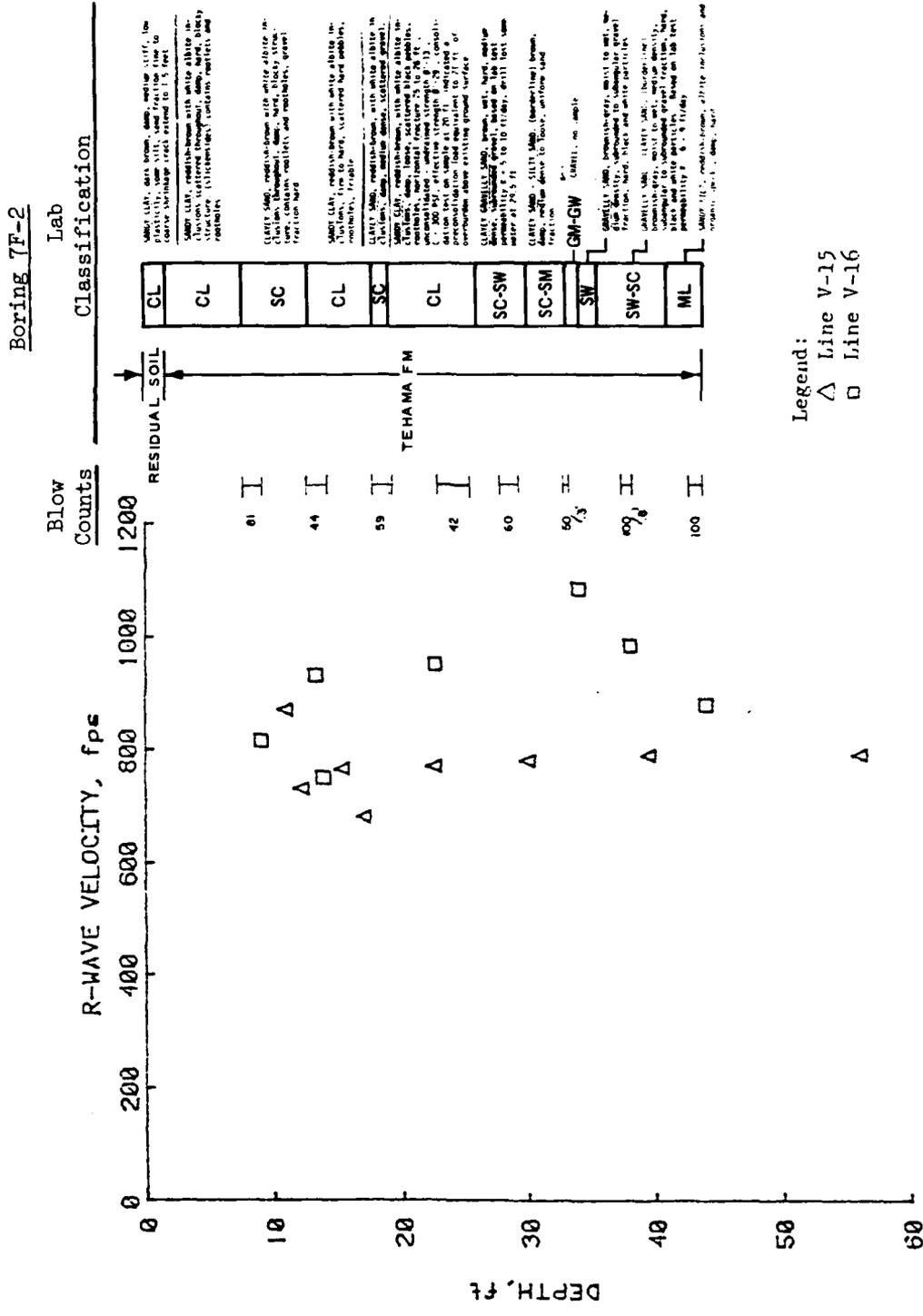
Figure 12. R-wave velocity versus depth, Tehama site, lines V-15 and V-16

Boring 2F-5
Lab Classification

SANDY SILT, tan, dry, firm (some fine gravel)

SILTY SANDY GRAVEL, dry (gravel to 3"dia. and a few cobbles to 4" dia.)

CLAYEY SANDY GRAVEL, dry, dense, well-graded (gravel to 3' dia. and a few cobbles to 4" dia.)

CLAYEY GRAVELLY SAND, brown, moist with water content increasing with depth, dense, well-graded (gravel to 3' dia.)

SANDY CLAY, tan, moist, lightly to moderately cemented (minor gravel to 1/2" dia.)

SILTY SAND, tan, moist, dense (minor gravel to 1/2" dia.)

SANDY CLAY, brown to 35' then tan moderately cemented (minor gravel to 2" dia.)

CLAYEY SAND, gray, moist, dense (sand fraction fine to coarse)

SANDY CLAY, tan to 55' then brown, moist to wet, moderately cemented, few thin lenses of sandy silt and silty sand (sand fraction fine to coarse and minor gravel to 1/2" dia. from 55 to 62')

SILTY SAND, gray, saturated - Water Zone (minor gravel to 1/2" dia.)

SANDY CLAY, tan, moist, stiff, fines exhibit medium plasticity (sand fraction mostly fine grained and minor gravel to 2" dia.)

CLAYEY SAND, gray from 67 to 68' and then tan, moist, dense, fines increase below 68' (sand fraction fine to coarse)

SANDY CLAY, tan, moist, stiff (sand fraction fine to coarse)

R-WAVE VELOCITY, fps

DEPTH, ft

Legend:
△ Line V-17
□ Line V-18

RESIDUAL SOIL

TERRACE DEPOSITS

TEHAMA FM.

ML GM GC SC CL SM CL SC CL SM CL SC CL

Figure 13. R-wave velocity versus depth, Tehama site, lines V-17 and V-18
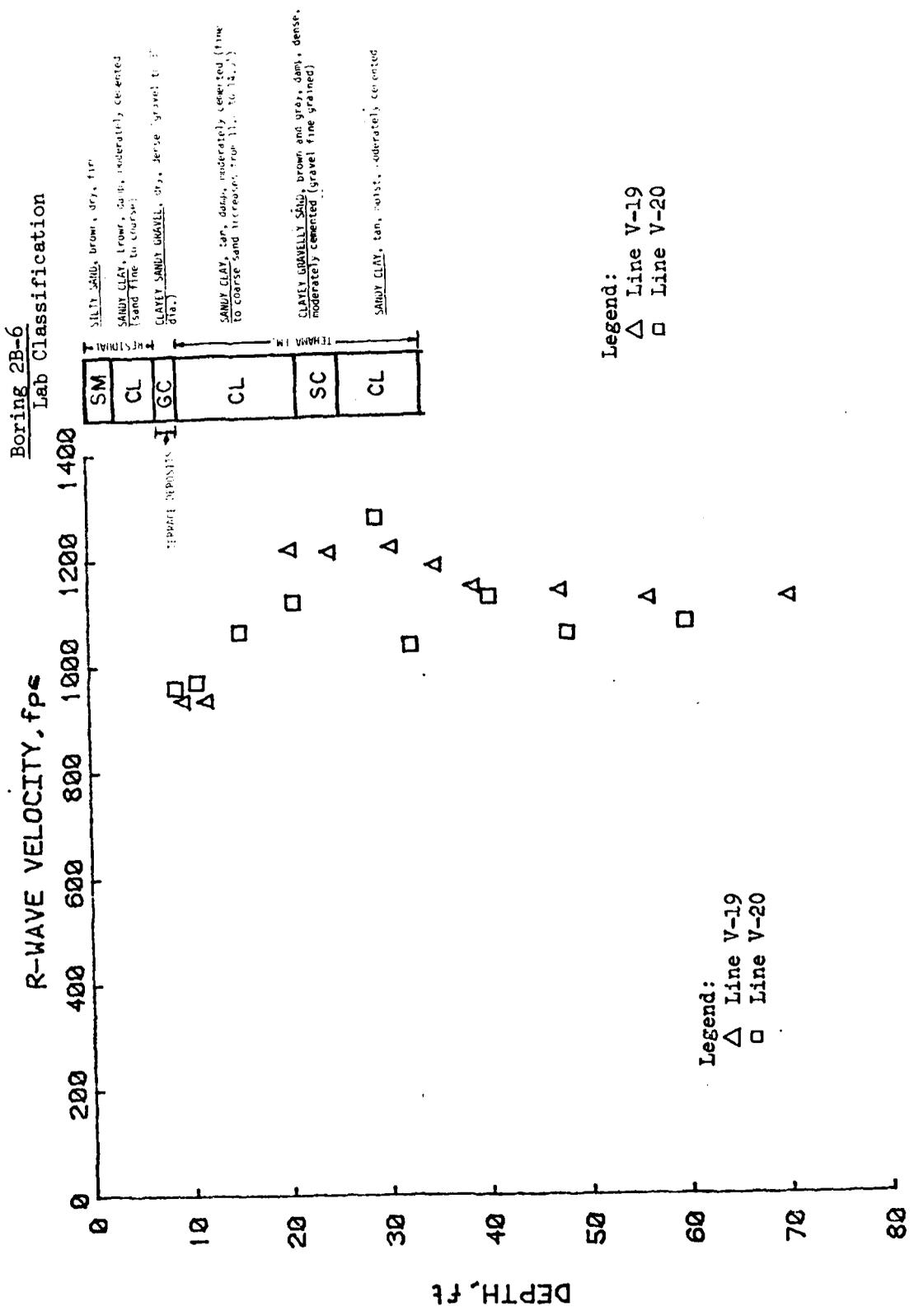
Figure 14. R-wave velocity versus depth, Tehama site, lines V-19 and V-20

Figure 15. R-wave velocity versus depth, Tehama site, lines V-21 and V-22
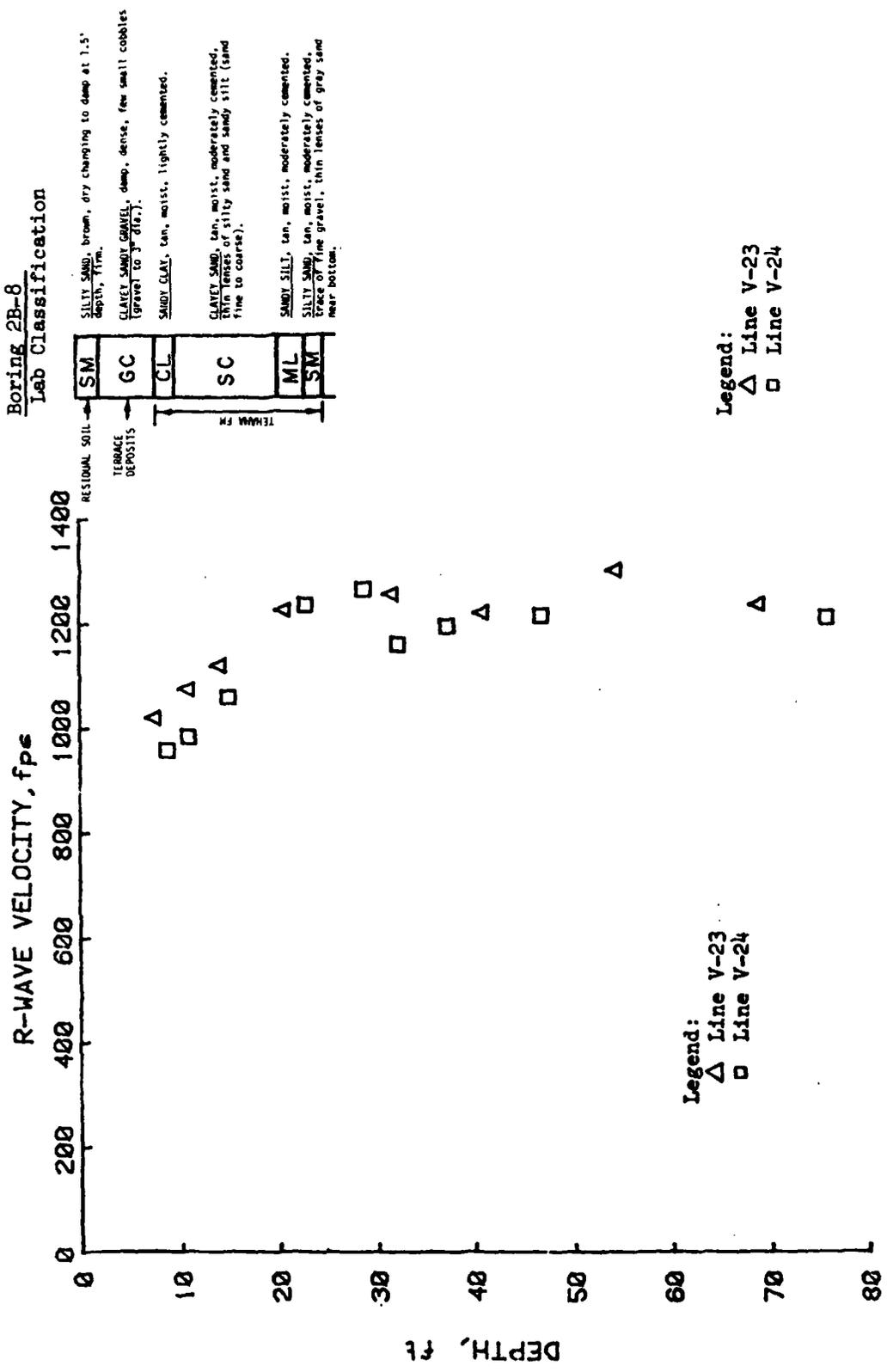
Figure 16. R-wave velocity versus depth, Tehama site, lines V-23 and V-24
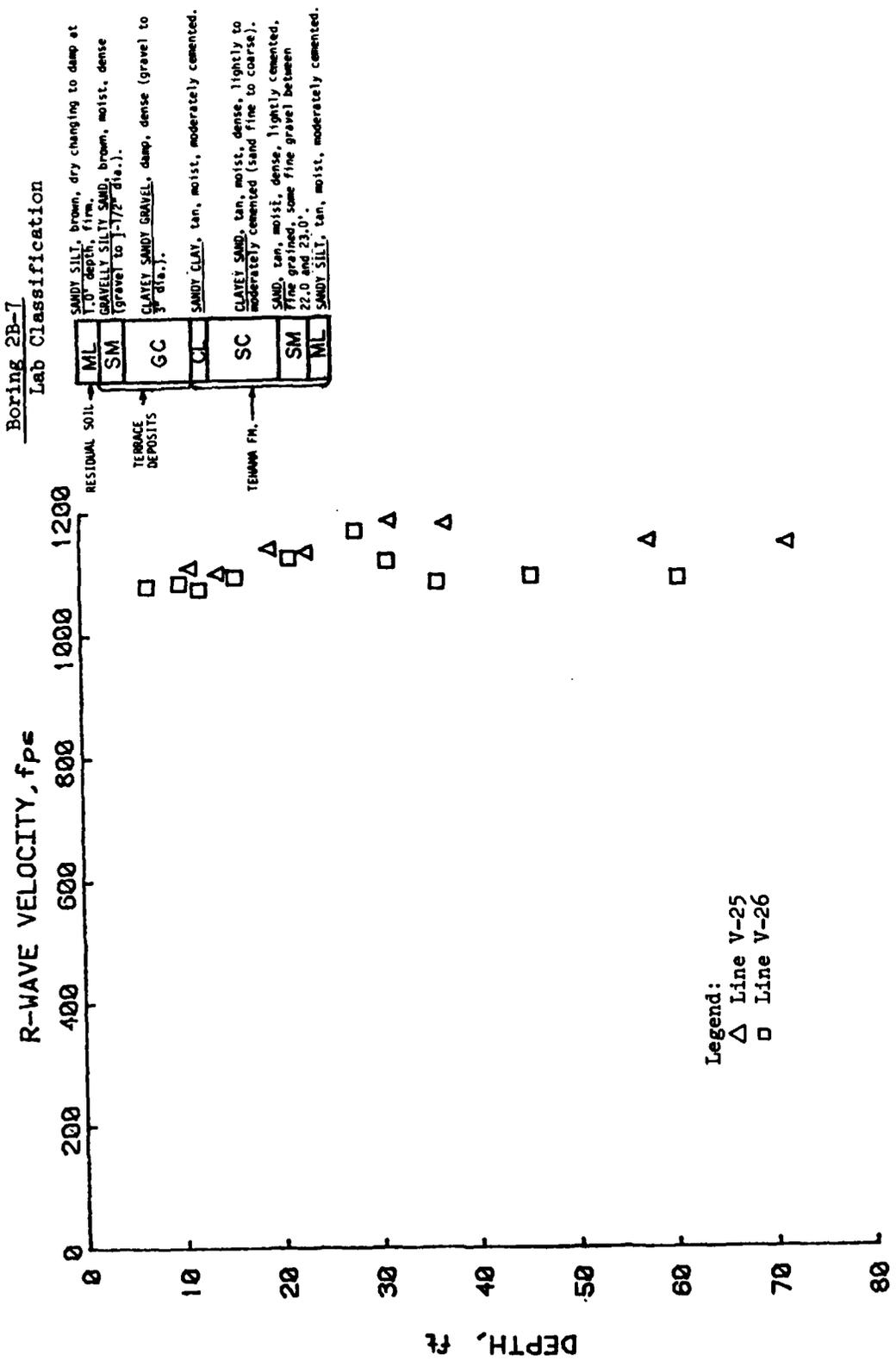
Figure 17. R-wave velocity versus depth, Tehama site, lines V-25 and V-26
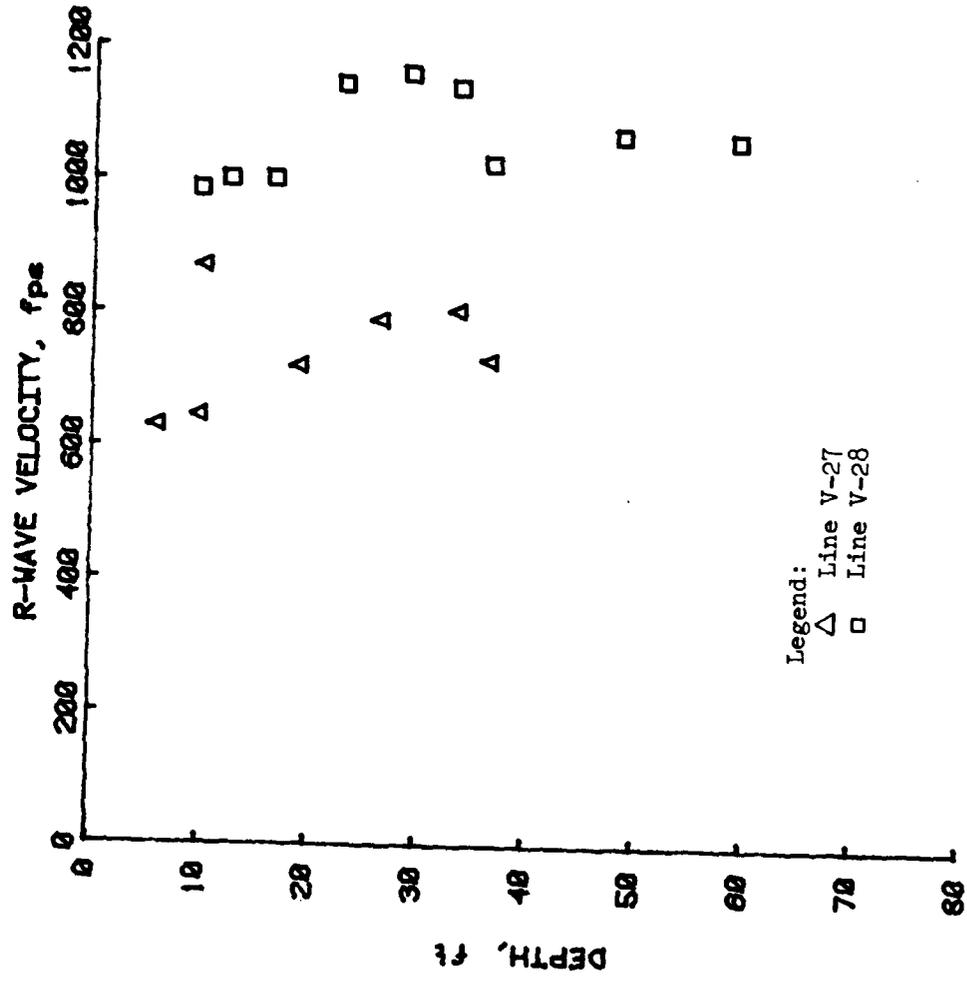
Figure 18. R-wave velocity versus depth, Tehama site, lines V-27 and V-28
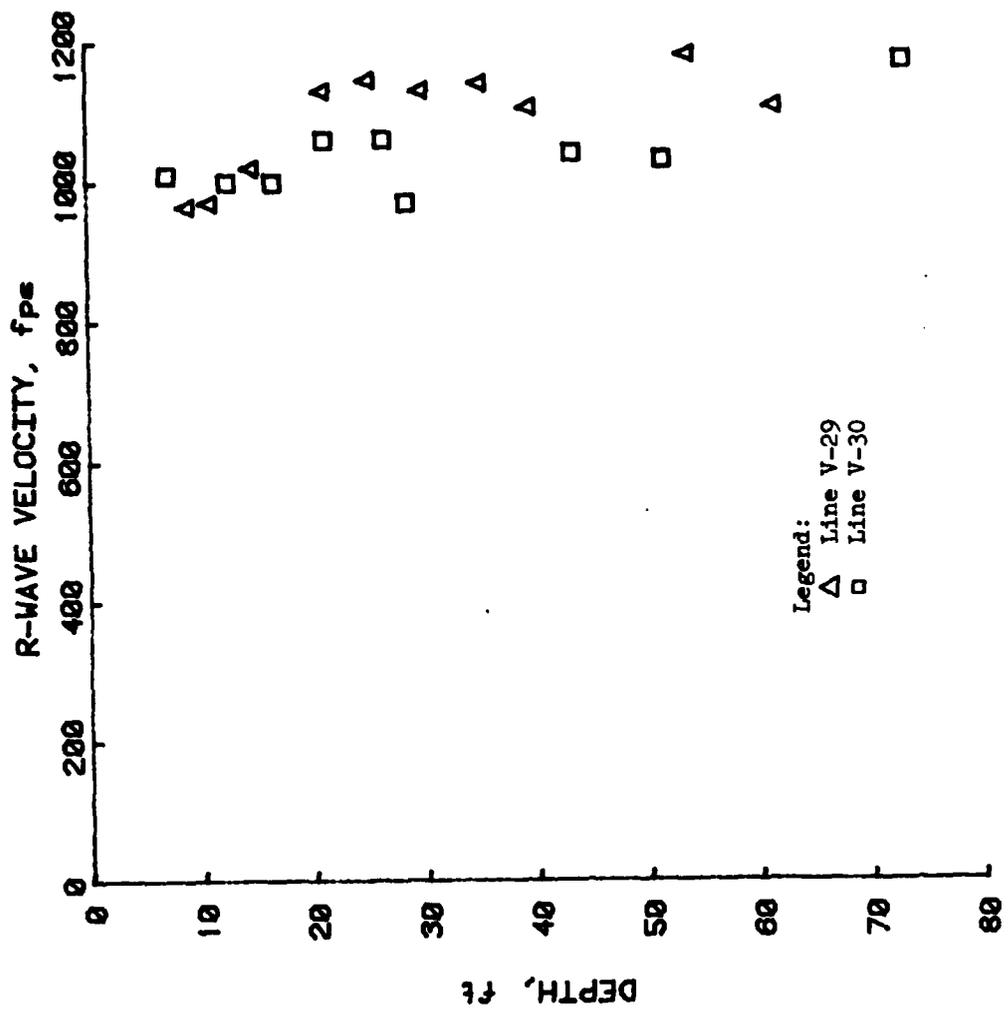
Figure 19. R-wave velocity versus depth, Tehama site, lines V-29 and V-30

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