SITE DEPENDENT RESPONSE SPECTRA

BEAVER VALLEY POWER STATION - UNIT 2

Prepared for

Duquesne Light Company
Pittsburgh, Pennsylvania

Reviewed and Approved

by

Duquesne Light Company
Seismic Advisory Panel

Dr. I.M. Idriss (Chairman)
Woodward-Clyde Consultants

Dr. J.A. Jan
Duquesne Light Company

Dr. J.T. Christian
Stone & Webster Engineering Corporation

Mr. D.E. Shaw
Consultant

Dr. C.W. Lin
Westinghouse Electric Corporation

Prepared

by

STONE & WEBSTER ENGINEERING CORPORATION
BOSTON, MASSACHUSETTS

FEBRUARY 1985

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

LIST OF TABLES

LIST OF FIGURES

SECTION 1

EXECUTIVE SUMMARY

The Final Safety Analysis Report (SWEC, 1983) presents the seismic design basis for the Beaver Valley Power Station - Unit 2 (BVPS-2). In response to questions from the U.S. Nuclear Regulatory Commission (NRC), the BVPS-2 design response spectra were supported with additional analyses submitted in a report to the NRC in June, 1984 (SWEC, 1984). The present report supplements the June, 1984, report.

The analyses described in the present report clearly demonstrate that the BVPS-2 design response spectra are appropriate when compared to response spectra determined by current state-of-the-art procedures. Two suites of actual strong motion accelerograms, one recorded at stations with soil conditions matching those of the site and the other recorded on rock and amplified analytically through the soil profile, give estimates of the anticipated response spectra due to a Safe Shutdown Earthquake (SSE) with a body-wave magnitude of 4.75. A combined estimate considering the results of both methods together gives the site dependent response spectra for 5 percent damping shown in Figure 1-1. The 50th percentile response spectrum falls well below the BVPS-2 design spectrum. The 84th percentile response spectrum closely matches the design response spectrum above 6Hz and falls below it for all other frequencies, sometimes substantially.

Probabilistic analyses of seismic hazard show that the annual probability of equalling or exceeding the 50th percentile response spectrum is on the order of 10^{-4} and is on the order of 10^{-5} for the 84th percentile response spectrum. The annual probability associated with the 50th percentile spectrum is comparable to values usually acceptable for the SSE; the probability for the 84th percentile is substantially lower. A conventional seismic hazard analysis gives an annual probability of about 2×10^{-4} for the SSE acceleration of 0.125g.

This report responds to the additional issues outlined in Appendix 1 that were identified by the NRC during its review of the June, 1984 report. The results of the investigations performed are described in the subsequent sections and are summarized below:

- The effect on the maximum earthquake potential for the site resulting from including the southeastern Ohio, Intensity VI-VII (MM) event of November, 1926, within the Appalachian Plateau tectonic province is examined. The effects of shallow focal depth earthquakes on the intensity of the SSE is also considered. Neither of these issues affects the seismic hazard or the site dependent response spectra.

- The site matched response spectra analysis presented in SWEC (1984) is re-examined to evaluate the effects of (1) the use of a revised, magnitude dependent scaling law, and (2) the difference in shear wave velocity contrast between the soil and the rock at the site matched recording stations compared to that at BVPS-2. The 50th percentile and 84th percentile site matched response spectra computed using the revised scaling law are about 10-percent lower than those presented in SWEC (1984). The difference in shear wave velocity contrast at BVPS-2 and at the site matched recording stations is accounted for by increasing the revised 50th percentile and 84th percentile site matched response spectra at each frequency. The increase ranges between 1-percent and 49-percent and averages about 16-percent for all frequencies.

- The soil response analysis presented by SWEC (1984) is revised to include a larger, more recent earthquake record data base, and a revised, magnitude dependent scaling law is used to scale the amplified ground surface motions.

- The site matched response spectra adjusted for velocity contrast and the soil response analysis response spectra are combined statistically to determine the site dependent response spectra shown in Figure 1-1.

- Two related probability analyses are performed to estimate the annual probability of exceeding the 50th and 84th percentile site dependent response spectra. The first is a conventional seismic hazard analysis using three seismic source models: two tectonic province models and a seismic source zone model. The analyses lead to a general understanding of the seismic hazard at BVPS-2. The tectonic province model approach concludes that almost all of the hazard at the site is contributed by the portion of the Appalachian Plateau province in the site region. Similarly, with the seismic source zone approach, background seismicity is the major contributor. Based on the results of the conventional seismic hazard analysis, a second, more detailed, analysis is made to consider the seismicity of only the region around the site. The 50th percentile response spectrum has an annual probability of exceedence that is lower than values that have been accepted for the safe shutdown earthquake (SSE), and, therefore, represents an acceptable level of conservatism. The 84th percentile has an annual probability of exceedence that is very much lower.

- The site matched response spectra analysis approach also demonstrates that the use of two-thirds as the ratio of vertical to horizontal response spectra is conservative. The ratio of vertical to horizontal site matched response spectra, shown in Figure 1-2, is less than two-thirds for all frequencies.

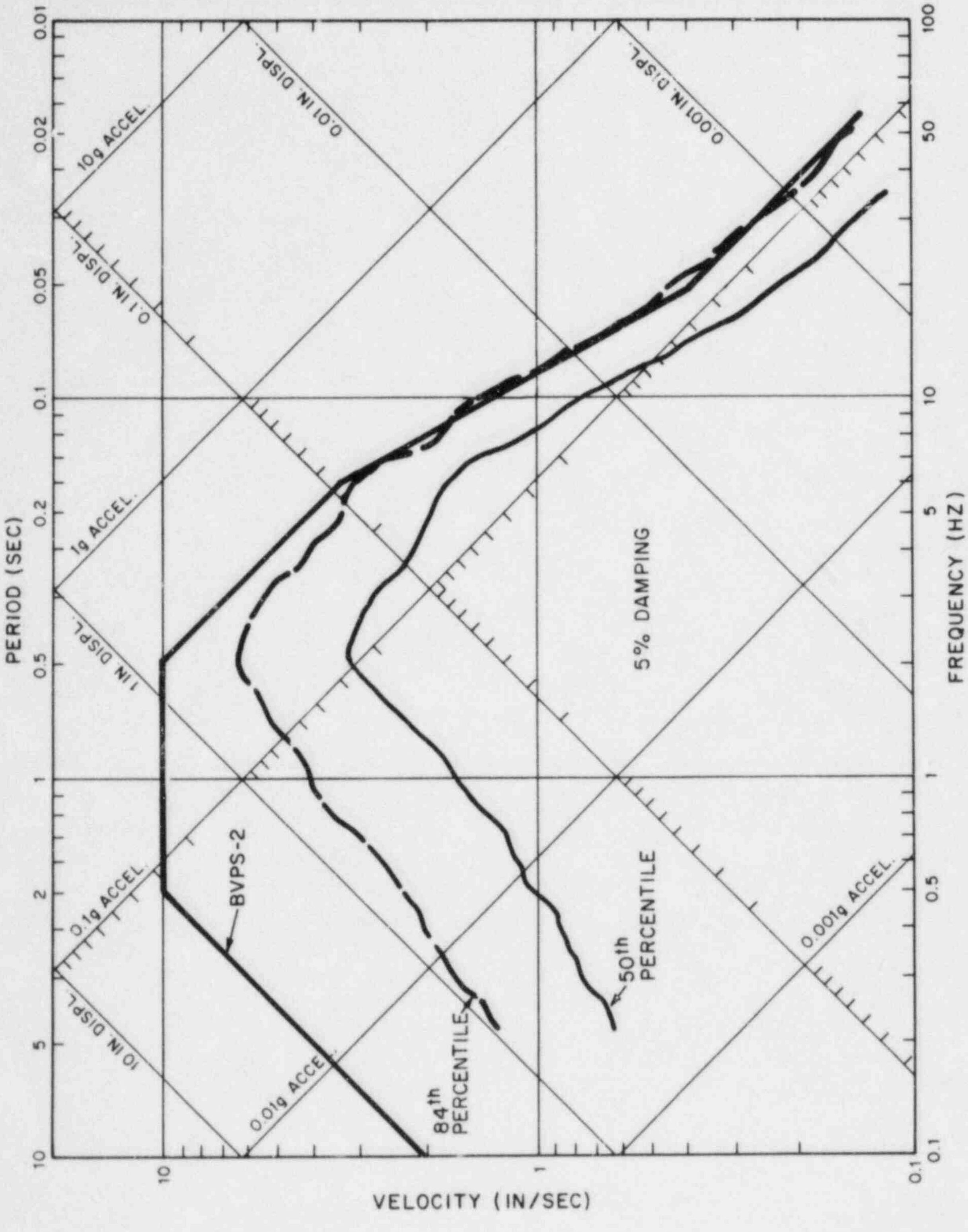


FIGURE 1-1

SITE DEPENDENT
RESPONSE SPECTRA

BEAVER VALLEY POWER STATION-UNIT 2

STONE & WEBSTER ENGINEERING CORPORATION

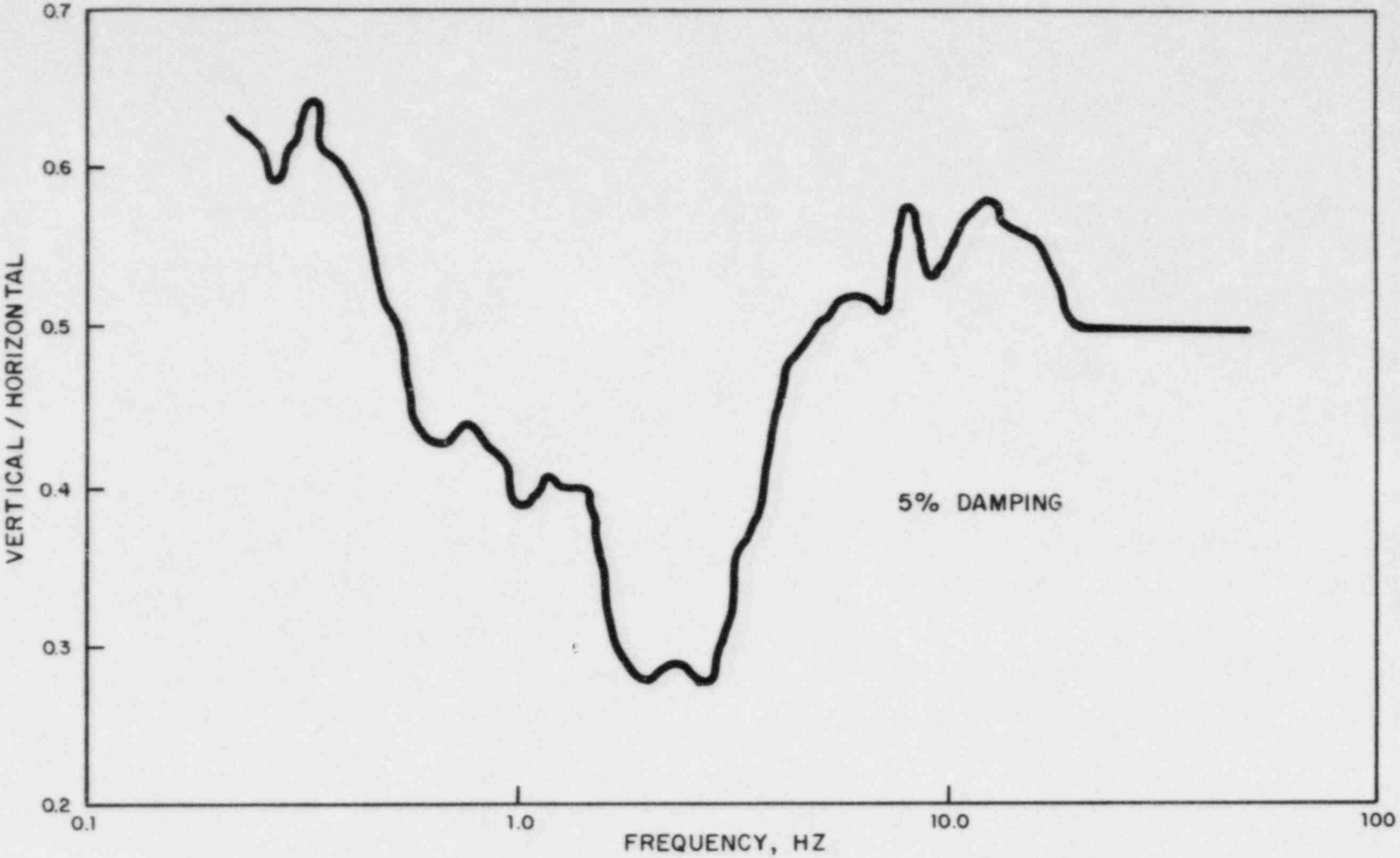


FIGURE 1-2
RATIO OF VERTICAL TO HORIZONTAL SITE MATCHED RESPONSE SPECTRA
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

SECTION 2

RESPONSE SPECTRA METHODOLOGY

Two approaches were used to determine horizontal, ground surface response spectra for the safe shutdown earthquake (SSE) taking into consideration the geology, seismicity and local soil conditions at BVPS-2. The approaches were:

- Site matched response spectra analysis
- Soil response analysis

The site matched response spectra analysis used ground surface records from earthquakes that were recorded at accelerograph stations with subsurface conditions matched as closely as possible to the BVPS-2 site. Response spectra for 5-percent damping were computed from these ground surface earthquake records and statistically analyzed to determine a 50th and an 84th percentile response spectrum.

The soil response analysis used records from earthquakes recorded at accelerograph stations founded on rock outcrops. These recordings were amplified through the BVPS-2 in situ soil profile using the computer program SHAKE (Schnabel et al, 1972). Ground surface response spectra for 5-percent damping were determined and statistically analyzed to obtain a 50th and an 84th percentile response spectrum. The earthquake record data base used in the soil response analysis included more recent earthquakes than had been used in the original analysis presented by SWEC (1984).

Statistical analysis of individual response spectra from both approaches was performed assuming that the response spectra ordinates were log-normally distributed.

A magnitude dependent, earthquake scaling law, developed from the attenuation relationships presented by Nuttli (1984), was used to scale the earthquake records to the magnitude corresponding to the BVPS-2 SSE for both the site matched analysis and the soil response analysis.

2.1 EARTHQUAKE MAGNITUDE

The BVPS-2 design earthquake (SSE) was established to be equivalent to an intensity VI (MM) event occurring near the site (SWEC, 1983). Since magnitude, rather than intensity, is a more reliable measure of earthquake source strength, the earthquake records used in both the site matched analysis and the soil response analysis were selected on the basis of magnitude. The SSE intensity was, therefore, converted to a corresponding eastern United States body-wave magnitude. The convention of using local magnitude for western United States earthquakes required an additional relationship to establish a western local magnitude equivalent to the eastern SSE body-wave magnitude.

The design earthquake intensity was established considering the historical seismicity and the tectonic provinces around the BVPS-2 site (SWEC, 1983). The NRC raised the issue, during their review of SWEC (1984), that the western boundary of the Appalachian Plateau tectonic province, in which the site is located, should not exclude an intensity VI-VII (MM) earthquake that occurred in southeastern Ohio in November, 1926. The NRC also requested that the possible effects of shallow focal depth earthquakes on the selection of the design earthquake be evaluated. Neither of these concerns affects the design earthquake.

2.1.1 Design Earthquake

The design earthquake intensity was converted to magnitude using the empirical correlation given by Nuttli and Herrmann (1978):

$$m_b = 0.5I_o + 1.75 \qquad (m_b \pm 0.5 \text{ units}) \qquad \text{(Eq 2-1)}$$

where: m_b = body-wave magnitude
I_o = epicentral intensity

The SSE Intensity VI (MM) event is thus converted to a body-wave magnitude of 4.75 ± 0.5.

Most of the currently available strong motion records are for western United States earthquakes. Chung and Bernreuter (1980) found that the body-wave magnitudes of western United States earthquakes were about 0.3 units lower than similar eastern United States earthquakes. Since local magnitude, rather than body-wave magnitude, is generally used as an indicator of western earthquake source strength, Chung and Bernreuter (1980) developed the following empirical correlation between the body-wave magnitude of an eastern earthquake and the local magnitude of an equivalent western earthquake:

$$M_L(\text{west}) = 0.57 + 0.92m_b\,(\text{east}) \qquad \text{(Eq 2-2)}$$

Therefore, the SSE body-wave magnitude of 4.75 ± 0.5 is equivalent to a western local magnitude of 4.95 ± 0.5. Records of the 1976 Friuli, Italy earthquakes were considered to be similar to western United States earthquakes.

2.1.2 Appalachian Plateau Tectonic Province

The western boundary of the Appalachian Plateau tectonic province (Figure 6-5) was established as the westernmost limit of known structural geologic features associated with the Allegheny orogeny of Permian age (SWEC, 1983). Occurring about 250 million years ago, this is the most recent tectonic episode to have affected the site region.

The maximum earthquake potential (SSE) for the site was determined from the tectonic province approach to be equivalent to an intensity VI (MM) event. The western boundary of the Appalachian Plateau tectonic province excluded the November, 1926 intensity VI-VII (MM) earthquake that occurred in southeastern Ohio. However, there is no effect on the design earthquake even if the November 1926 event is assumed to have occurred in the Appalachian Plateau tectonic province, rather than in the adjacent Central Stable Region.

The November, 1926 earthquake has been identified by Nuttli and Brill (1981) to be a shallow focal depth event (<3 km). It was estimated to have a body-wave magnitude of 3.4 and a felt area of only 350 square miles, suggesting that it was not felt beyond about 10 miles from the epicenter. It is shown in Section 2.1.3 that shallow focal depth earthquakes do not present a seismic hazard to BVPS-2. Furthermore, this earthquake was conservatively included in the probabilistic assessment of seismic risk at the site presented in Section 6.

2.1.3 Effects of Shallow Earthquakes

Earthquakes with shallow focal depths, having lower magnitudes and smaller felt areas than other earthquakes with the same epicentral intensity, have occurred within 200 miles of the site and within the Appalachian Plateau tectonic province. Similar earthquakes could occur in the future in the vicinity of BVPS-2; however, the occurrence of these events is expected to be infrequent and the resulting ground motions are not expected to present a seismic hazard to BVPS-2 plant structures. Appendix 2 contains a more detailed discussion of the effects of shallow earthquakes.

Analysis of several strong motion records from shallow events that occurred in the eastern United States in 1978 and 1979 indicated that peak accelerations resulted from high frequency spikes of short duration which do not represent significant energy input to typical power plant structures (McGuire, 1982). Damage results predominantly from long duration shaking (Trifunac, 1972). Brady et al (1981) found that the peak accelerations in the records occurred at frequencies as high as 25-30 Hz, and that the duration of strong ground motion was between 1/2 and 1 second. The lack of correlation between the high peak accelerations for these shallow events and damage to any facility within one or two kilometers of the epicenter suggests that high accelerations alone are not indicative of potential damage.

While shallow earthquakes may occur in the vicinity of BVPS-2, the likelihood is very low and the maximum expected body-wave magnitude is 3.8, which is less than the SSE body-wave magnitude of 4.75. Predicted accelerations at the site range from 0.024g to 0.214g but these predictions are very uncertain. Given that shallow eastern earthquakes produce high accelerations of short duration at predominantly high frequencies which do not damage engineered structures, and that BVPS-2 structures are designed for a normal focal depth type of earthquake with a peak ground acceleration of 0.125g, the design is conservative for the effects of shallow earthquakes.

2.2 EARTHQUAKE RECORD SCALING PROCEDURE

Ideally, records of earthquakes having magnitudes within the limits defined for the design earthquake would be used directly, without scaling, in the site matched or soil response analyses. However, the number of suitable recordings meeting this criterion was too small to represent a valid statistical sample, and therefore, a magnitude scaling law and procedure were developed so that records of earthquakes having magnitudes outside of the limits could be used.

2.2.1 Eastern United States Earthquakes

The scaling law was developed from the attenuation relationship presented by Nuttli (1984) for South Carolina earthquakes which has the form:

$$\log a_h = A + Bm_b - 0.83\ (R^2 + h^2)^{1/2} - CR \qquad \text{(Eq 2-3)}$$

where: a_h = peak horizontal acceleration in cm/sec²
m_b = body-wave magnitude
R = epicentral distance in km
h = focal depth in km
A, B and C = empirical constants
B = 0.5 for $m_b \geq 4.5$ and
0.25 for $m_b < 4.5$

The form of this relationship is generally the same as that presented by Nuttli and Herrmann (1984) for Mississippi Valley earthquakes. The values for the constant term, B, are valid for central and eastern United States earthquakes (Nuttli, 1984a).

Assuming that all of the variables in Equation 2-3 are constant except for magnitude leads to the following relations for the change in acceleration as a function of the change in magnitude:

$$\Delta\log a_h = 0.5\ \Delta m_b \qquad \text{for } m_b \geq 4.5 \qquad \text{(Eq 2-4a)}$$

$$\Delta\log a_h = 0.25\ \Delta m_b \qquad \text{for } m_b < 4.5 \qquad \text{(Eq 2-4b)}$$

These relations were used to scale eastern United States earthquake records to the SSE body-wave magnitude of 4.75.

2.2.2 Equivalent Western United States Earthquakes

Comparing two eastern events with two equivalent western events using Equation 2-2 leads to the following expression:

$$\Delta m_b \text{ (east)} = 1.09\ \ \Delta M_L \text{ (west)} \qquad \text{(Eq 2-5)}$$

Substituting Equation 2-5 into Equations 2-4a and 2-4b leads to the scaling law used to scale equivalent western United States earthquake records to a local magnitude of 4.95:

$$\Delta \log a_h = 0.54 \ \Delta M_L \qquad \text{for } M_L \geq 4.7 \qquad \text{(Eq 2-6a)}$$

$$\Delta \log a_h = 0.27 \ \Delta M_L \qquad \text{for } M_L < 4.7 \qquad \text{(Eq 2-6b)}$$

Equation 2-6a is the same scaling law presented by SWEC (1984) and used to scale earthquakes regardless of local magnitude; however, differentiation between local magnitudes greater than or less than 4.7 was not made by SWEC (1984). The use of Equation 2-6b for earthquakes with local magnitudes less than 4.7 results in smaller scaling factors than those used in the original analyses.

2.2.3 Scaling Procedure

In the site matched response spectra analyses, ground surface time histories were scaled to the design magnitude and then response spectra were computed. In the soil response analysis, rock outcrop records were input to the SHAKE model without scaling, and amplified through the BVPS-2 soil profile. The resulting ground surface time histories were then scaled to the design magnitude, and response spectra were computed.

The scaling procedure for the soil response analysis is appropriate for two reasons. First, the Nuttli (1984) attenuation relationships used to develop the scaling law were determined from ground motion data obtained at soil sites and may not be appropriate for scaling rock records directly (Nuttli and Hermann, 1984). Scaling the output of the soil response analyses, rather than the input rock motion, is, therefore, consistent with the use of the Nuttli attenuation relationships.

Second, scaling the ground surface time histories from the soil response analyses is consistent with scaling the site matched, ground surface time histories prior to computing response spectra. The site matched approach used recorded ground surface time histories which were the result of bedrock motions amplified through a subsurface profile comparable to that of BVPS-2. These time histories were scaled to the design magnitude prior to computing response spectra and as a result, scaling the output is implied in the site matched approach.

SECTION 3

SITE MATCHED RESPONSE SPECTRA

The site matched response spectra analysis presented in SWEC (1984) was re-examined to evaluate the effects of: (1) the revised, magnitude dependent scaling law represented by Equations 2-6a and 2-6b, and (2) the difference in shear wave velocity contrast between the soil and rock at the site matched recording stations compared to that at BVPS-2. The site matched response spectra analysis was also used to demonstrate that the use of two-thirds as the ratio of vertical to horizontal response spectra is conservative for all frequencies.

The 50th percentile and the 84th percentile response spectra computed using the revised scaling law are about 10 percent lower than those presented in SWEC (1984).

The revised 50th percentile and 84th percentile response spectra were increased at each frequency by a factor which accounts for the difference between the shear wave velocity contrast at BVPS-2 and the average shear wave velocity contrast at the California site matched recording stations. The percentage increase varied between about one percent and 49-percent and averaged about 16-percent for all frequencies.

The ratio of vertical to horizontal site matched response spectra was shown to be less than two-thirds for all frequencies. The ratio varies between 0.28 and 0.64 and averages about 0.5.

3.1 EFFECT OF REVISED SCALING LAW

The 50th percentile and 84th percentile site matched response spectra presented by SWEC (1984), and shown in Figure 3-1, were determined from the suite of eighteen site matched earthquake records shown in Table 3-1. These records were scaled to a local magnitude of 4.95 using Equation 2-6a for all magnitudes. For comparison, scaling factors determined using the revised, magnitude dependent scaling law, namely Equations 2-6a and 2-6b, are also shown in Table 3-1. The scaling factors of 6 component recordings out of a total of 18 were lowered by using the revised scaling law.

To evaluate the effect of the new scaling law, individual response spectra were recomputed for the earthquake records listed in Table 3-1 using the revised scaling factors. The 50th percentile and the 84th percentile response spectra are shown in Figure 3-2, which also shows those presented in SWEC (1984) for comparison. The effect of the revised scaling law was to reduce the 50th percentile and the 84th percentile response spectra shown by SWEC (1984) by about 10 percent for all frequencies.

3.2 EFFECT OF VELOCITY CONTRAST

A study was made to evaluate the change in ground surface response spectra caused by changes in the shear wave velocity contrast between the rock and the overlying soil. The purpose of the analysis was to adjust the 50th percentile and the 84th percentile site matched response spectra to account for the difference between the shear wave velocity contrast at the "site matched" California recording stations and BVPS-2.

A normalizing parameter called velocity contrast ratio (VCR) was defined as the ratio of the shear wave velocity of the rock or rock-like layer divided by the shear wave velocity of the immediately overlying soil layer. The average VCR for the site matched California recording stations is about 2.0 (Appendix 3), and the VCR at BVPS-2 is 4.2 (Figure 4-1).

To quantify the effect on ground surface response spectra caused by changes in velocity contrast ratio, a soil response analysis was performed. Each rock outcrop time history listed in Table 3-2 was amplified through the BVPS-2 in situ soil profile and a ground surface response spectrum for 5-percent structural damping was computed.[1] A 50th percentile response spectrum was computed from the suite of individual response spectra assuming a log-normal distribution of the spectral ordinates.

Three values of VCR were investigated: 4.2, corresponding to BVPS-2; 2.0, corresponding to the average VCR for the site matched recording stations; and 1.0 as the limiting value. The resulting 50th percentile response spectra, shown in Figure 3-3, indicate that as the VCR decreases, the spectral ordinates decrease, as expected. With a decrease in the VCR; i.e., as the shear wave velocity of the rock approaches that of the soil, more of the energy of the waves reflected at the free surface of the soil is reabsorbed by the rock. This effect is referred to as radiation or geometric damping. Conversely, as the VCR increases, more of the energy remains in the soil layer.

Figure 3-4 shows the percentage change in spectral ordinates as a function of frequency and change in VCR. The curves are shown for a change in VCR from 1.0 to 4.2, the limiting case, and from 2.0 to 4.2. Each curve represents the 50th percentile percent change

---

[1]The records and scaling factors shown in Table 3-2 were used in the soil response analysis presented in SWEC (1984). The rock outcrop time histories were scaled prior to amplifying them through the BVPS-2 in-situ profile in contrast to the procedure described in Section 2.2.3. The scaling procedure is, however, not important since the objective of the analysis was to evaluate the effect on ground surface spectra due to changes in the shear wave velocity of the rock.

computed at each frequency for each earthquake record used in the analysis.

Since the average VCR for the site matched recording stations is about 2.0 and the VCR at BVPS-2 is 4.2, the 50th and 84th percentile site matched response spectra computed using the revised scaling law (Figure 3-2) were increased at each frequency by the percent change appropriate for an increase in VCR from 2.0 to 4.2. The resulting adjusted site matched response spectra are shown in Figure 3-5. The BVPS-2 design response spectrum envelopes the adjusted site matched response spectra at all frequencies.

3.3 VERTICAL RESPONSE SPECTRA

BVPS-2 vertical design response spectra are taken as two-thirds of the corresponding horizontal design response spectra and SWEC (1984) demonstrated that this is consistent with available earthquake data from the United States and Japan. The site matched response spectra approach was used to provide additional support for the use of two-thirds as the ratio of vertical to horizontal response spectra.

Response spectra for 5 percent structural damping were computed from the vertical components of the site matched ground surface records listed in Table 3-1. The earthquake records were scaled according to the scaling law used in SWEC (1984) and given by Equation 2-6a[2]. The 50th percentile and the 84th percentile vertical, site matched response spectra are shown in Figure 3-6, compared to the corresponding BVPS-2 vertical design spectrum. The BVPS-2 vertical design response spectrum conservatively envelopes the vertical site matched spectra at all frequencies.

Ratios of the vertical to the horizontal site matched response spectra are shown in Figure 3-7 as a function of frequency. They were computed from the 50th percentile vertical response spectrum shown in Figure 3-6 and the 50th percentile horizontal response spectrum shown in Figure 3-1. The ratios vary between 0.28 and 0.64 and average about 0.5 for all frequencies.

In conclusion, the results indicate that the selection of two-thirds as the ratio of vertical to horizontal response spectra is a conservative one.

[2]Section 3.1 shows that the use of the original scaling factors for this suite of records is conservative. Also, the objective of this analysis was to compute the ratio of vertical to horizontal response spectra. Since the vertical and horizontal components of the same event were scaled using the same scaling factor, the ratio of response spectra is not affected by not using the revised scaling law.

TABLE 3-1

SITE MATCHED GROUND SURFACE EARTHQUAKE RECORDS
SCALED TO A LOCAL MAGNITUDE OF 4.95

Date Year	Date Month	Date Day	Epicentral Location	Local Magnitude	Recording Station	Epicentral Distance (km)	Component	Scaling Factor SWEC (1984)	Scaling Factor EQN. 2-6a&b	CIT Record No.(1)
1954	12	21	Eureka, CA	6.5	Federal Bldg. Eureka, CA	6	N79E S11E	0.146	0.146	A-008
1957	03	22	San Francisco, CA	5.3	State Bldg. San Francisco, CA	13	N09E S81W	0.65	0.65	A-016
					Alexander Bldg. San Francisco, CA	14	N09W N81E	0.65	0.65	A-014
1957	03	22	San Francisco, CA	4.4	Alexander Bldg. San Francisco, CA	16	N09W N81E	1.98	1.65	V-323
					City Hall, Oakland, CA	24	N26E S64E	1.98	1.65	A-017
1962	09	04	Northern CA	5.0	Federal Bldg. Eureka, CA	18	N79E S11E	1.0(2)	0.94	V-330
1965	07	15	Southern CA	4.0	Old Ridge Rte. Castaic, CA	14	E S	3.26	2.11	V-331
1970	09	12	Lytle Creek, CA	5.4	6074 Park Dr. Wrightwood, CA	14	S65E S25W	0.572	0.572	W-334
1971	02	09	San Fernando, CA	6.4	Old Ridge Rte. Castaic, CA	29	N21E N69W	0.165	0.165	D-056

NOTE:
(1) California Institute of Technology reference number, Trifunac and Lee (1973)
(2) This scaling factor should have been 0.94 and has been revised for the present analysis

TABLE 3-2

ROCK OUTCROP RECORDS SCALED TO A LOCAL MAGNITUDE OF 4.95

USED TO EVALUATE EFFECT OF SHEAR WAVE VELOCITY CONTRAST
ON SITE MATCHED RESPONSE SPECTRA

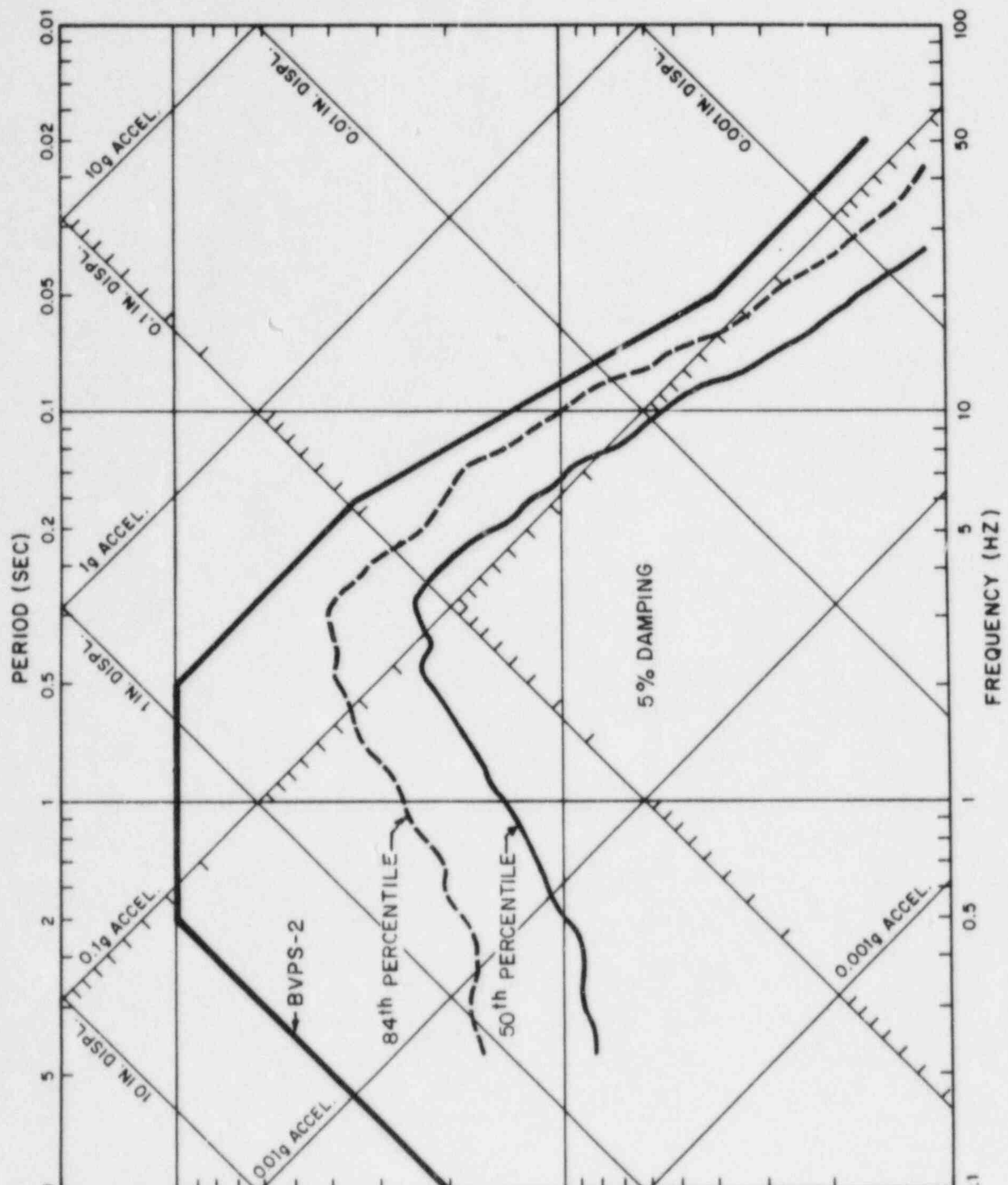
Date Year	Month	Day	Epicenter Location	Local Magnitude	Recording Station	Epicentral Distance (km)	Component	Scaling Factor(2)	CIT Record No.(3)
1935	10	31	Helena, MT	6.0	Carroll College Helena, MT	6	EW NS	0.271	B-025
1935	10	31	Helena, MT	4.0(1)	Federal Bldg. Helena, MT	6	NS EW	3.26	U-295
1935	11	21	Helena, MT	3.8(1)	Federal Bldg. Helena, MT	6	EW NS	4.18	U-296
1935	11	28	Helena, MT	5.0(1)	Federal Bldg. Helena, MT	6	NS EW	1.0	U-297
1957	03	22	San Francisco, CA	5.3	Golden Gate Pk. San Francisco, CA	11	S80E N10E	0.65	A-015
1970	09	12	Lytle Creek, CA	5.4	Allen Ranch Cedar Springs, CA	19	S05W S85E	0.572	W-335
1971	02	09	San Farnando, CA	6.4	Array No. 4 Lake Hughes, CA	29	S69E S21W	0.165	J-142
					Array No. 9 Lake Hughes, CA	29	N21E N69W	0.165	J-143
					Array No. 12 Lake Hughes, CA	24	N69W N21E	0.165	J-144

NOTES:

(1) Estimated by Kanomori and Jennings (1978)

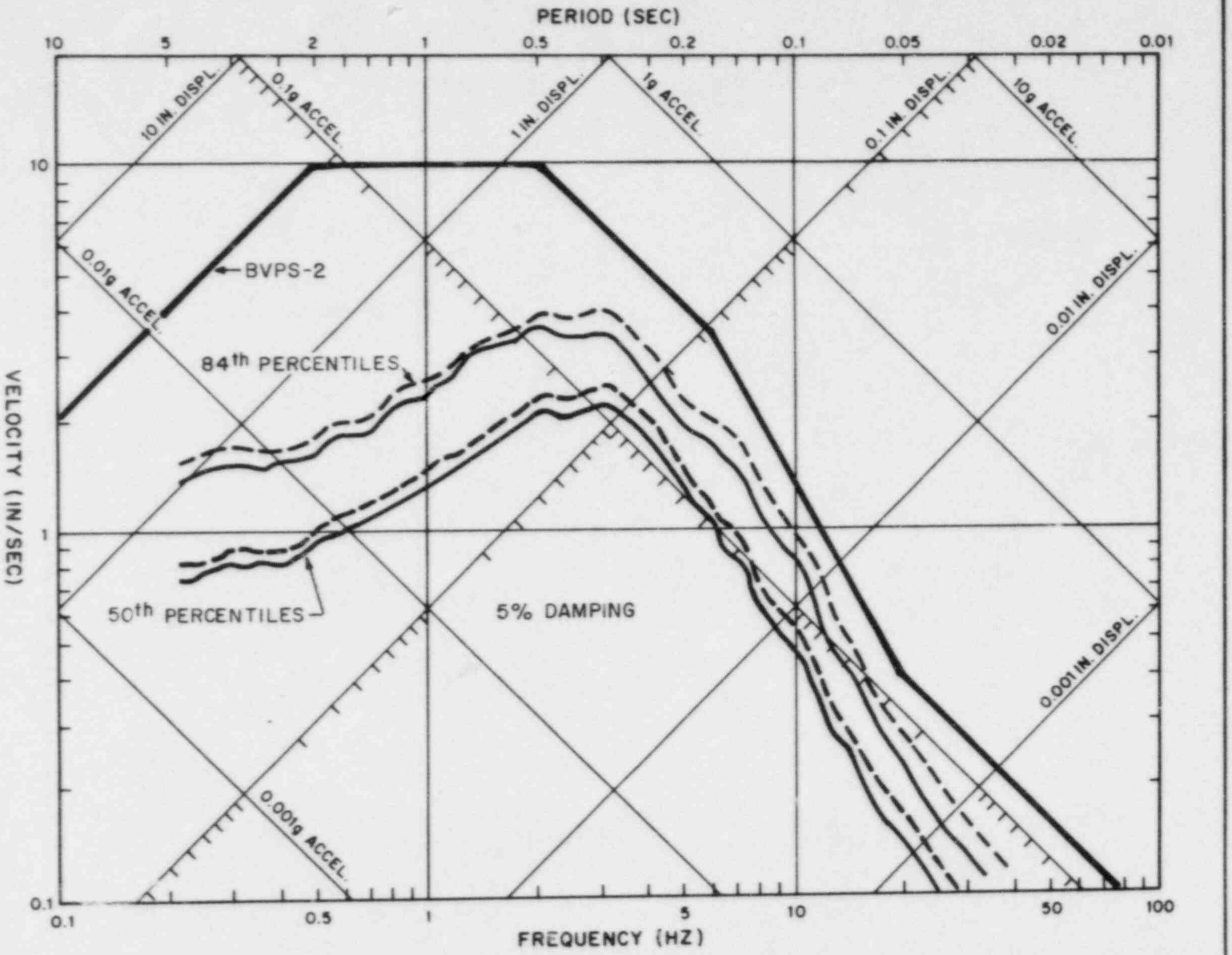
(2) From SWEC (1984)

(3) California Institute of Technology reference number, Trifunac and Lee (1973)



NOTE:
TAKEN FROM FIGURE 6-9 SWEC (1984)

FIGURE 3-1
SITE MATCHED RESPONSE
SPECTRA: SCALED
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

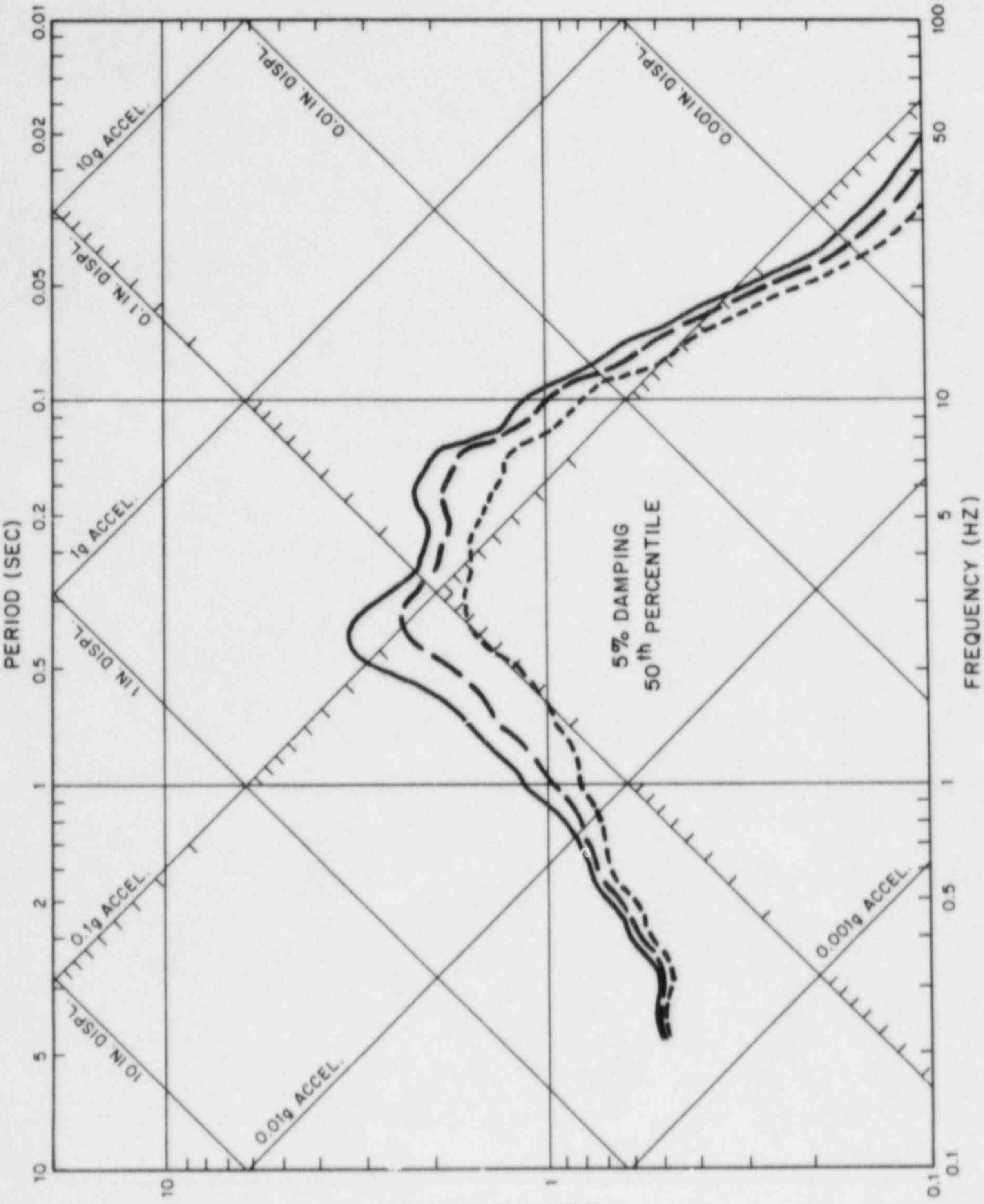


LEGEND:

- - - - OLD SCALING LAW, EQUATION 2-6a FOR ALL MAGNITUDES FIGURE 6-9, SWEC (1984)

——— NEW SCALING LAW EQUATIONS 2-6a AND 2-6b

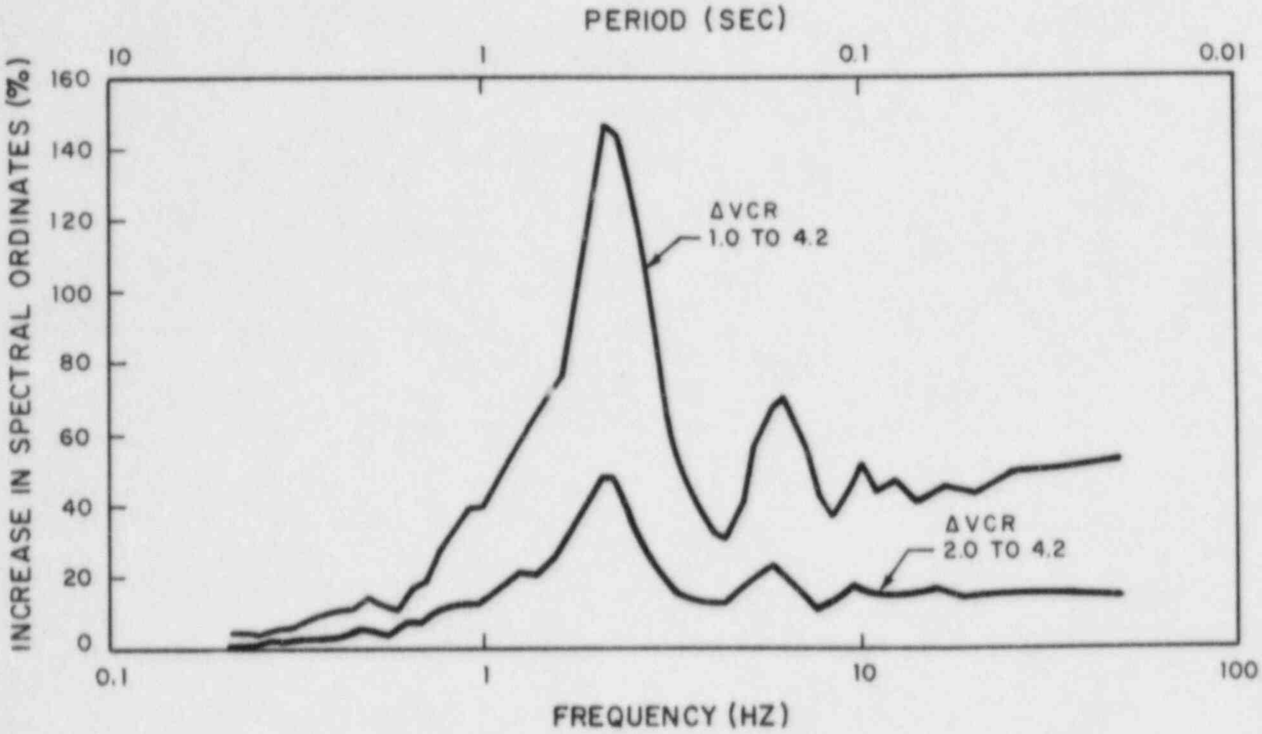
FIGURE 3-2
SITE MATCHED RESPONSE SPECTRA
EFFECT OF REVISED SCALING LAW
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION



LEGEND:

- VCR = 4.2 (solid line)
- VCR = 2.0 (long dashes)
- VCR = 1.0 (short dashes)

FIGURE 3-3
EFFECT OF VELOCITY CONTRAST ON GROUND SURFACE RESPONSE SPECTRA
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION



NOTE:

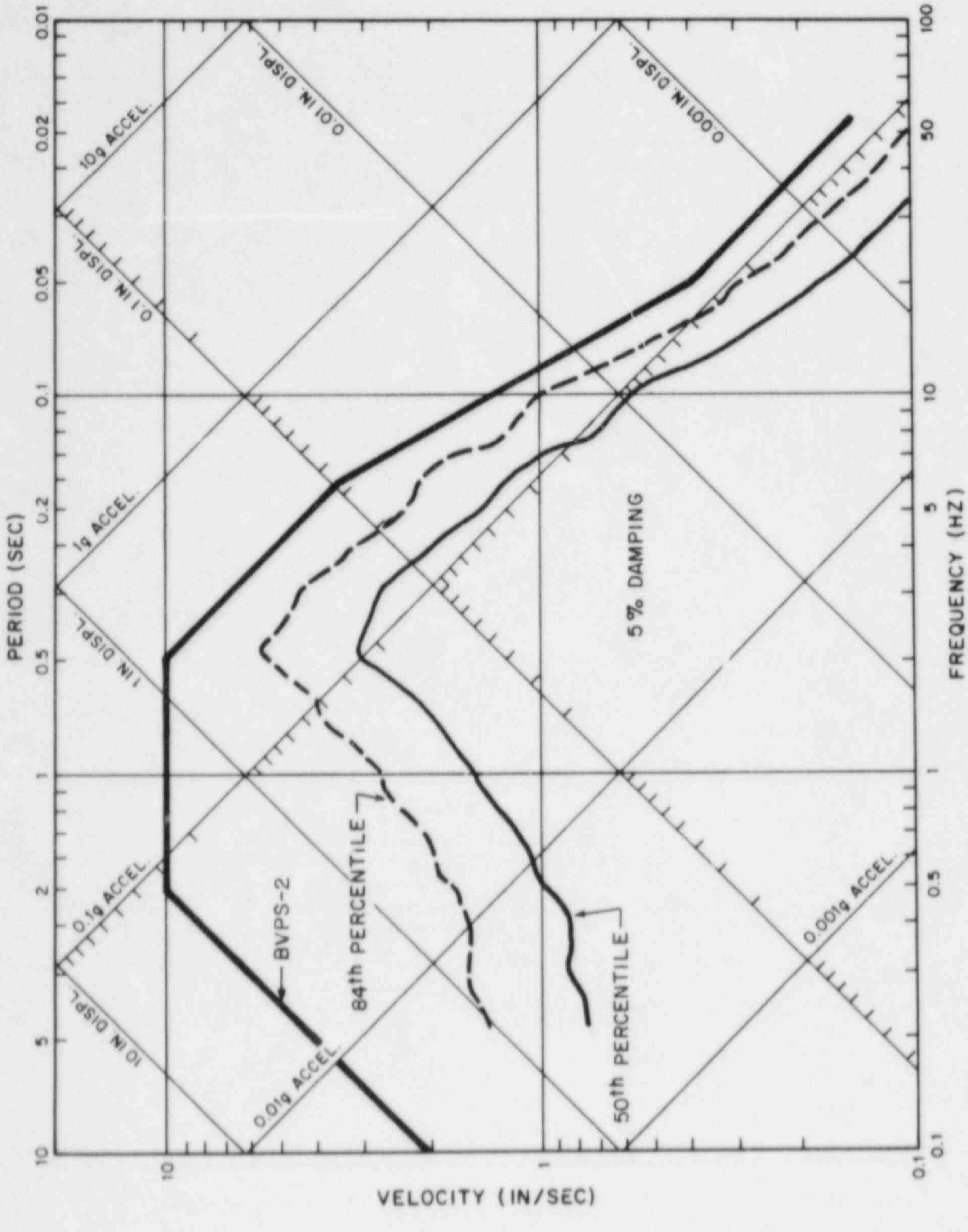
EACH CURVE REPRESENTS THE 50TH PERCENTILE PERCENT CHANGE IN SPECTRAL ORDINATES FOR THE NOTED CHANGE IN VELOCITY CONTRAST RATIO (VCR)

FIGURE 3-4

PERCENT INCREASE IN RESPONSE SPECTRA ORDINATES DUE TO CHANGE IN VELOCITY CONTRAST RATIO

BEAVER VALLEY POWER STATION - UNIT 2

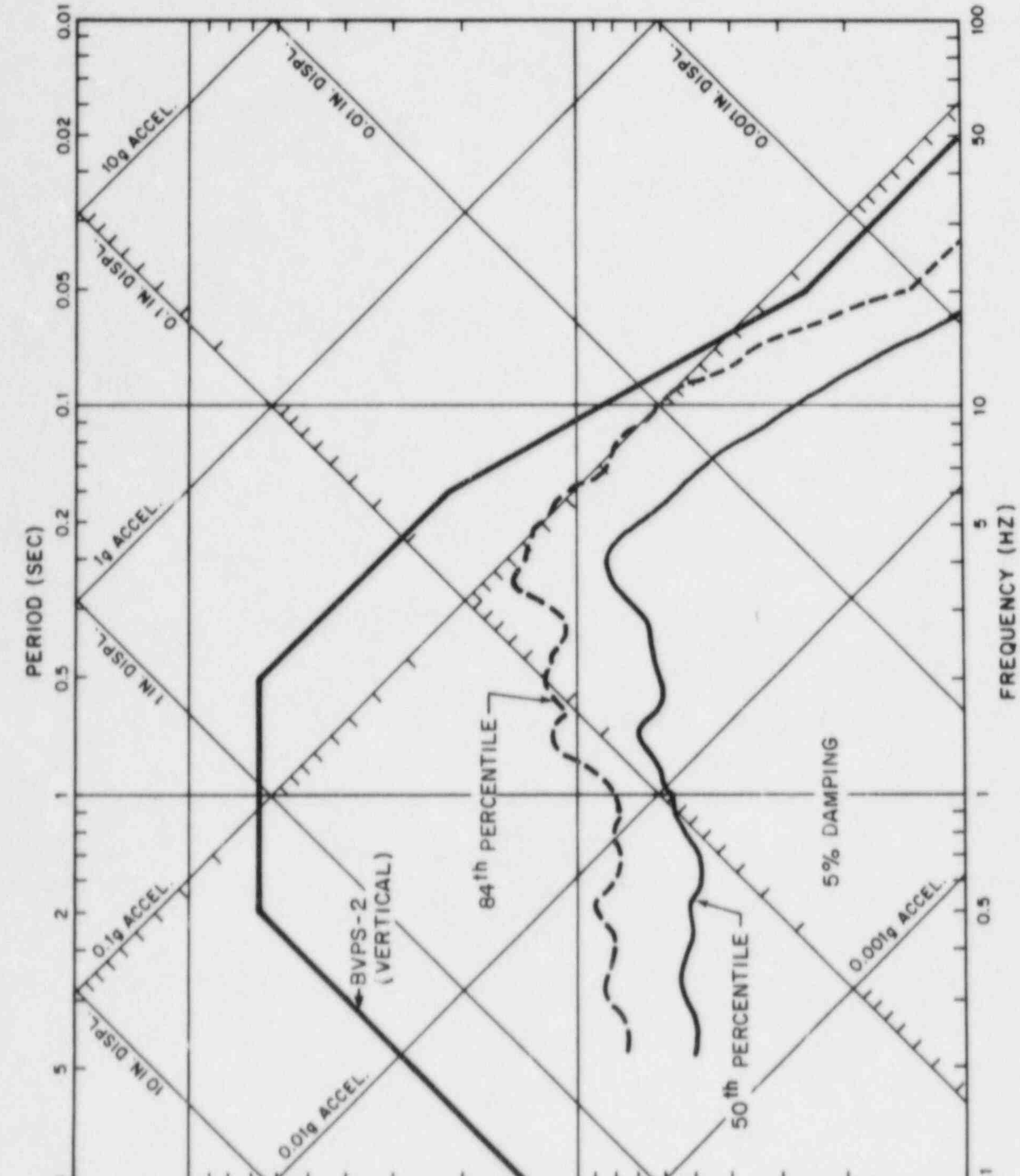
STONE & WEBSTER ENGINEERING CORPORATION



NOTE

RESPONSE SPECTRA
FROM EVENTS SCALED ACCORDING TO
REVISED SCALING LAW - EQ 2-6

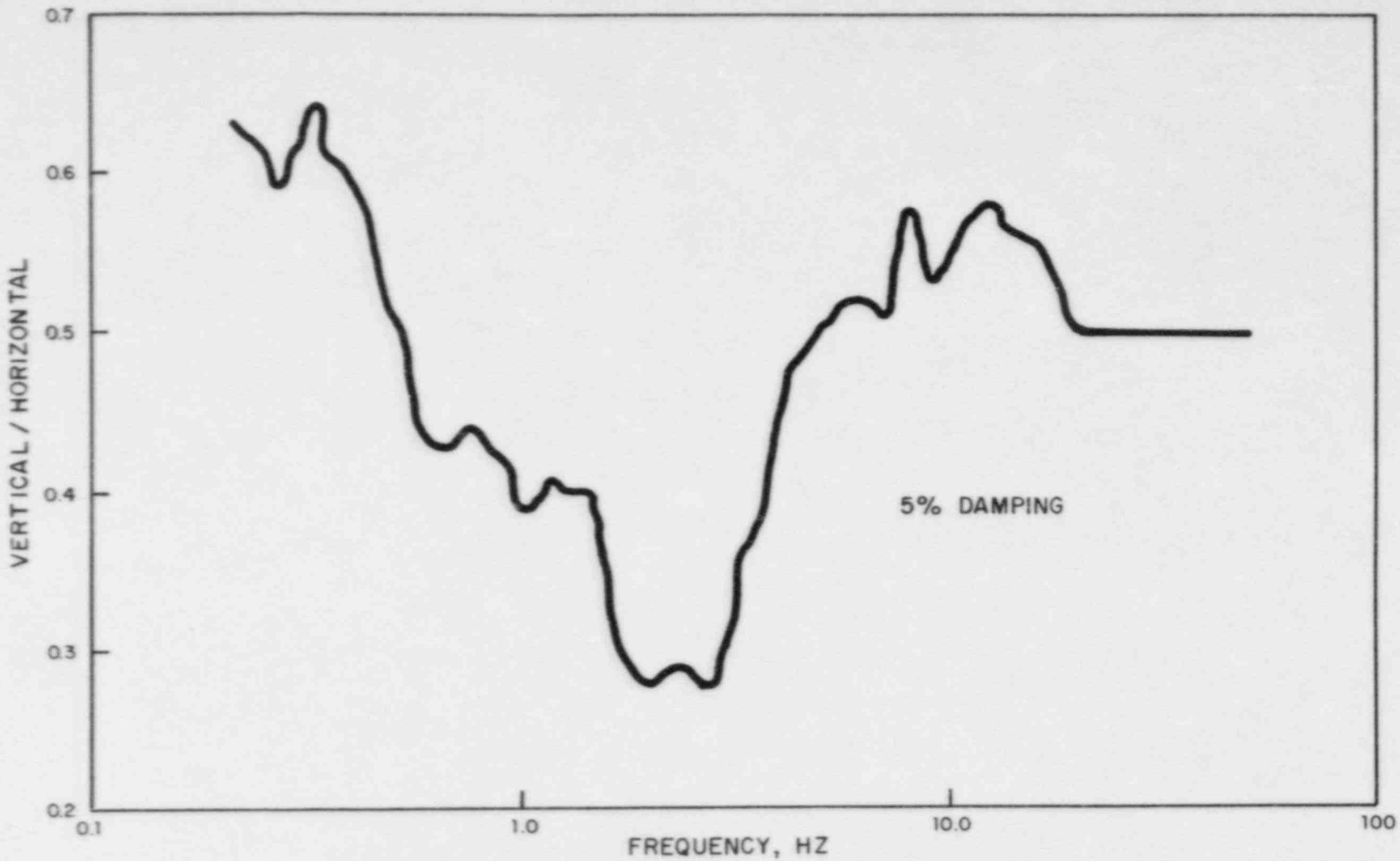
FIGURE 3-5
SITE MATCHED RESPONSE SPECTRA ADJUSTED FOR SHEAR WAVE VELOCITY CONTRAST
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION



NOTES:

1. FROM VERTICAL COMPONENTS OF RECORDS LISTED IN TABLE 3-1
2. SCALED USING EQUATION 2-6a

FIGURE 3-6
SITE MATCHED VERTICAL RESPONSE SPECTRA
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION



NOTE:

COMPUTED AS THE RATIO OF THE 50th PERCENTILE VERTICAL (FIG. 3-6) TO THE 50th PERCENTILE HORIZONTAL (FIG. 3-1) SITE MATCHED RESPONSE SPECTRA.

FIGURE 3-7
RATIO OF VERTICAL TO HORIZONTAL SITE MATCHED RESPONSE SPECTRA
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

SECTION 4

SOIL RESPONSE ANALYSIS

The soil response analysis presented by SWEC (1984) was performed using 18 component recordings of 9 earthquakes which were made at accelerograph stations founded on sites described as rock. Following its review of SWEC (1984), the NRC suggested a number of additional earthquake records which might be included in the earthquake record data base. Accordingly, the original soil response analysis was revised to include a larger and more recent set of earthquake records.

The computer program SHAKE (Schnabel, et al, 1972) was used to determine the ground surface response caused by earthquake records input at the bedrock surface and amplified through the BVPS-2 in-situ soil profile. Ground surface response spectra for 5-percent structural damping were determined for each earthquake record and then statistically analyzed to determine 50th percentile and 84th percentile response spectra for comparison with the BVPS-2 design response spectrum.

4.1 EARTHQUAKE RECORD DATA BASE

The earthquake record data base used by SWEC (1984) is given in Table 4-1. The recordings were made at accelerograph stations described as rock sites by SW-AA (1980). Table 4-2 lists the earthquakes suggested by the NRC for consideration. Tables 4-1 and 4-2 were combined chronologically to form Table 4-3.

The earthquakes listed in Table 4-3 and the site conditions at the associated accelerograph stations were reviewed and documented. The magnitude and epicentral distance associated with each record were verified, as well as whether or not the recording station was founded on rock and represented free-field rock motion which would be suitable for input to the soil response analysis. Details of this effort are provided in Appendix 4. Table 4-3 includes a summary of the additional information obtained and some minor corrections to the original data shown in Tables 4-1 and 4-2.

4.1.1 Selection Criteria

Based on the magnitude of the SSE established in Section 2.1, the earthquakes considered for use without scaling had magnitudes falling within the following limits:

- For eastern United States earthquakes: $4.25 \le m_b \le 5.25$
- For western United States and Italian earthquakes: $4.45 \le M_L \le 5.45$

To increase the number of earthquakes in the data base, the scaling law described in Section 2.2 was used to scale records up or down to a magnitude corresponding to the BVPS-2 SSE. Thus, two earthquake data bases were formed: one containing records within 0.5 magnitude units of the BVPS-2 SSE, which were used without scaling, and another containing those same records plus additional records for events falling more than 0.5 magnitude units from the BVPS-2 SSE. All of the records in the latter data base were scaled to the BVPS-2 SSE.

To limit the diminution of the strength of the earthquake due to attenuation effects, the selection process chose earthquake records recorded at accelerograph stations with epicentral distances of about 25 km. or less.

Earthquake records selected were those recorded at accelerograph stations founded on rock outcrops. A criterion of free field rock motion was used to remove any bias created by either geometric effects or rock-structure interaction effects.

4.1.2 Earthquake Records Selected

The final earthquake data base was compiled by selecting the records listed in Table 4-3 which met the selection criteria. Thirty-six component recordings of 17 earthquakes were eliminated for the following reasons:

- Three of the 1935 Helena, Montana earthquakes were removed because the magnitudes were estimated and not computed instrumentally (Ref. Nos. 2,3, and 4).

- The March 22, 1957, San Francisco earthquake recorded at Golden Gate Park was removed because of the fractured nature of the rock at the site (Ref. No. 5).

- The records of the February 9, 1971, San Fernando earthquake made at Lake Hughes Array No. 9 and No. 12 were removed because of 9 to 10 ft. of soil underlying the recording stations (Ref. Nos. 9 and 10).

- The January 12 and June 7, 1975, Cape Mendocino earthquakes are considered to be subduction plate border events and were removed because they had very disimilar mechanisms than the remaining western United States events (Idriss, 1984) (Ref. Nos. 11 and 12).

- The August 1, 1975, Oroville, CA, earthquake recorded at the Oroville Dam was removed since the recording station was located on the crest of the earthfill dam and not on rock (Ref. No. 13).

- Three of the 1975 Oroville Aftershocks recorded at Johnson Ranch were removed because the station was founded on 10 meters of sediments (Ref. Nos. 15, 16 and 18).

- Records of the 1976 Friuli, Italy events obtained at Somplago (D) were removed because the station was located in a tunnel 260 meters below the ground surface and the records could not be considered outcrop recordings (Ref. Nos. 20, 23 and 24).

- The August 13, 1978, Santa Barbara earthquake was removed because the recording station was founded on a floor slab supported on caissons extending through 13 ft of soil and founded in rock, rather than directly on rock (Ref. No. 26).

- The January 26, 1980, Livermore, CA earthquake is currently being digitized by the USGS and will not be available. (Ref. No. 30).

- The records of the March 31, 1982 New Hampshire earthquake recorded on the right abutment of the Franklin Falls dam may have been significantly affected by the site geometry and were, therefore, removed.

Table 4-4 lists the 12 earthquakes with 28 component recordings remaining in the data base. They represent the total set of records which were scaled to a magnitude corresponding to the BVPS-2 SSE.

Table 4-5, a subset of Table 4-4, lists five earthquakes with 10 component recordings that were available for use directly without scaling. The number of records is, however, too small and does not represent a statistically significant data base for a soil response analysis.

4.2 SOIL MODEL

The original soil response analysis presented in SWEC (1984) considered two soil profile models: one for soils within the portion of the main plant area affected by the soil densification program and one for in-situ soils outside of the densified area. In the revised soil response analysis, only the in-situ soil profile, shown in Figure 4-1, was used as representative of free field soil conditions appropriate for determining response spectra applicable to the BVPS-2 site. The densified area profile was not used because it reflects localized soil conditions beneath only the northern 50 percent of the main plant area and is not representative of soil conditions throughout the site.

The SHAKE program iterates to obtain values of soil shear modulus and damping that are compatible with the strain levels induced by earthquake motions. The shear moduli corresponding to the shear wave velocities shown in Figure 4-1 represent low strain or maximum values. The strain dependent variations of shear modulus and damping used in the analysis were based on the data presented by Seed and Idriss (1970), and are shown in Figure 4-2.

4.3 RESULTS

The suite of scaled earthquake records listed in Table 4-4 was used to compute 50th and 84th percentile ground surface response spectra. The number of unscaled earthquake records listed in Table 4-5 is too small to be statistically significant. Additional discussion of the unscaled analysis is provided in Appendix 5.

The results of the scaled soil response analysis are shown in Figure 4-3. The 50th percentile response spectrum is less than the BVPS-2 design response spectrum for all frequencies. The 84th percentile response spectrum is less than the BVPS-2 design response spectrum for frequencies less than 4 Hz and exceeds the BVPS-2 design response spectrum above 4 Hz.

Section 6 shows that the annual probability of exceeding the 50th percentile response spectrum is approximately 10^{-4} and represents an acceptable margin of seismic safety that is commensurate with generally accepted probability levels of seismic safety. The probability of exceeding the 84th percentile is approximately an order of magnitude smaller.

TABLE 4-1

EARTHQUAKE DATA BASE
FROM SWEC (1984)

Year	Mo.	Day	Epicenter Location	Local Magnitude	Epicenter Distance (km)	CIT Record No.(2)	Recording Station
1935	10	31	Helena, MT	6.0	6.6	B-025	Carroll College Helena, MT
1935	10	31	Helena, MT	4.0(1)	5.8	U-295	Federal Bldg. Helena, MT
1935	11	21	Helena, MT	3.8(1)	5.8	U-296	Federal Bldg. Helena, MT
1935	11	28	Helena, MT	5.0(1)	5.8	U-297	Federal Bldg. Helena, MT
1957	03	22	San Francisco, CA	5.3	11.2	A-015	Golden Gate Pk. San Francisco, CA
1970	09	12	Lytle Creek. CA	5.4	19.2	W-335	Allen Ranch Cedar Springs, CA
1971	02	09	San Fernando, CA	6.4	28.8	J-142	Array No. 4 Lake Hughes, CA
					28.6	J-143	Array No. 9 Lake Hughes, CA
					24.0	J-144	Array No. 12 Lake Hughes, CA

NOTES:

(1) Estimated by Kanamori and Jennings (1978)
(2) California Institute of Technology reference number, Trifunac and Lee (1973)

TABLE 4-2

ROCK SITES(1)

	Date	Station Code and Name	M_L	Dist (km)
1)	10/31/35	U295 - Helena Feder. Bldg.	(5.0)	6
2)	10/31/35	B025 - Helena Carroll Coll.	6.0	7
3)	11/28/35	U297 - Helena Feder. Bldg.	(5.0)	6
4)	6/28/66	B037 - Temblor	5.6	(20)
5)	9/12/70	W335 - Allen Ranch	5.4	19
6)	1/12/75	PC175 - Cape Mendocino	5.2	27
7)	6/7/76	PC675 - Cape Mendocino	5.2	22
8)	8/1/75	OD875 - Oroville Dam	5.7	11
9)	8/1/75	OS875 - Oroville Seis. Stat.	5.7	12
10)	8/6/75	J350 - (Johnson Ranch)	4.7	13
11)	8/8/75	J700 - (Johnson Ranch)	4.9	11
12)	8/8/75	6700 - Oroville #6	4.9	(5)
13)	9/27/75	J234 - (Johnson Ranch)	4.6	(13)
14)	9/27/75	8234 - Oroville #8	4.6	(11)
15)	9/11/76	I142 - Somplago	5.9	6
16)	9/11/76	I139 - San Rocco	5.9	14
17)	9/11/76	I132 - San Rocco	5.5	15
18)	9/11/76	I134 - Somplago	5.5	10
19)	9/15/76	I159 - Somplago	5.0	11
20)	9/15/76	I169 - San Rocco	6.0	19
21)	8/13/78	North Hall (Goleta)	5.1	(4)
22)	8/6/79	San Martin, C.C.	5.9	1
23)	8/6/79	(Gilroy #1)	5.9	8

TABLE 4-2 (Cont)

Date	Station Code and Name	M_L	Dist (km)
	Gilroy #6		
3/31/82	Mitchell Lake, Aftershock New Brunswick	4.8	
1/18/82	Franklin Falls Dam	4.7	
1/26/80	Livermore, CA Morgan Territory Park		

NOTE:

(1) Provided by Geosciences Branch, U.S. NRC at August 16, 1984 meeting with DLC and SWEC.

TABLE 4-3

EARTHQUAKE RECORDS CONSIDERED

Ref. No.	Date Year	Mo.	Day	Earthquake Name	Local Magnitude	Epicentral Distance (km)	Record No.	Recording Station	Site Conditions at Recording Station
1.	1935	10	31	Helena, MT	6.0	6	B-025	Carroll College Helena, MT	Limestone
2.**	1935	10	31	Helena, MT	4.0*	6	U-295	Federal Bldg. Helena, MT	Limestone
3.**	1935	11	21	Helena, MT	3.8*	6	U-296	Federal Bldg. Helena, MT	Limestone
4.**	1935	11	28	Helena, MT	5.0*	6	U-297	Federal Bldg. Helena, MT	Limestone
5.**	1957	03	22	San Francisco, CA	5.3	11	A-015	Golden Gate Pk. San Francisco, CA	Chert and Shale
6.	1966	06	28	Parkfield, CA	5.6	39(7)	B-037	Cholame-Shandon Array, Temblor	Serpentine and serpentinized peridotite
7.	1970	09	12	Lytle Creek, CA	5.4	19	W-335	Allen Ranch Cedar Springs, CA	Granite bedrock
8.	1971	02	09	San Fernando, CA	6.4	29	J-142	Array No. 4 Lake Hughes,CA	Weathered granite bedrock
9.**						29	J-143	Array No. 9 Lake Hughes, CA	9 ft of silty and gravelly sand overlying granite gneiss
10.**						24	J-144	Array No. 12 Lake Hughes, CA	5-10 ft of landslide debris overlying sandstone, conglomerate and shale
11.**	1975	01	12	Cape Mendocino, CA	4.4	16	PC-175	Cape Mendocino Petrolia, CA	Cretaceous Franciscan volcanic sandstone (graywacke)
12.**	1975	06	07	Cape Mendocino, CA	5.2	30	PC-675	Cape Mendocino Petrolia, CA	Cretaceous Franciscan volcanic sandstone (graywacke)

TABLE 4-3 (Cont)

EARTHQUAKE RECORDS CONSIDERED

Ref. No.	Date Year	Mo.	Day	Earthquake Name	Local Magnitude	Epicentral Distance (km)	Record No.	Recording Station	Site Conditions at Recording Station
13.**	1975	08	01	Oroville, CA	5.7	11	OD-875	Oroville Dam Crest	Earthfill dam
14.						12	OS-875	Oroville Dam Seismograph Sta.	Metavolcanic rock
15.**	1975	08	06	Oroville, CA Aftershock	4.7	8	J-350	Johnson Ranch	10 meters of sediments overlying greenstone
16.**	1975	08	08	Oroville, CA Aftershock	4.9	8	J-700	Johnson Ranch	10 meters of sediments overlying greenstone
17.						6	6-700	Oroville, CA CDMG No. 6	Mesozoic greenstone
18.**	1975	09	27	Oroville, CA Aftershock	4.6	11	J-234	Johnson Ranch	10 meters of sediments overlying greenstone
19.						11	8-234	Oroville, CA CDMG No. 8	Mesozoic greenstone
20.**	1976	09	11	Friuli, Italy Aftershock	5.9	6	I-142	Samplago (D)	Triassic limestone and dolomite. Installed 260 meters below surface.
21.						14	I-139	San Rocco	Limestone
22.	1976	09	11	Friuli, Italy Aftershock	5.5	16	I-132	San Rocco	Limestone
23.**						10	I-134	Samplago (D)	Triassic limestone and dolomite. Installed 260 meters below surface.
24.**	1976	09	15	Friuli, Italy Aftershock	5.0	11	I-159	Samplago (D)	Triassic limestone and dolomite. Installed 260 meters below surface.
25.	1976	09	15	Friuli, Italy Aftershock	6.0	19	I-169	San Rocco	Limestone

TABLE 4-3 (Cont)

EARTHQUAKE RECORDS CONSIDERED

Ref. No.	Date Year	Mo.	Day	Earthquake Name	Local Magnitude	Epicentral Distance (km)	Record No.	Recording Station	Site Conditions at Recording Station
26.**	1978	08	13	Santa Barbara, CA	5.1	13	-	UCSB-North Hall Goleta, CA	Floor slab on caissons extending through 13 ft of soil and founded in siltstone
27.	1979	08	06	Coyote Lake, CA	5.9	2	SM-879	Coyote Creek San Martin, CA	Conglomerate, sandstone and shale
28.						16	G1-879	Gilroy No. 1 Gavilan College Water Tower	Sandstone, shale, and chert
29.						10	G6-879	Gilroy No. 6 San Ysidro, CA	Conglomerate, sandstone and shale
30.**	1980	01	26	Livermore, CA	5.2-5.8	11	-	Livermore - Morgan Territory Park	Sandstone and shale (Digitized record not available)
31.**	1982	01	18	New Hampshire	4.7 (m_b = 4.4)	8	-	Franklin Falls Dam, Rt. abutment	Rock
32.	1982	03	31	New Brunswick Aftershock	4.8 (m_b = 5.0)	4	-	Mitchell Lake Rd.	Rock

NOTES:

* Magnitude estimate by Kanamori and Jennings (1978)

** Removed from data base

TABLE 4-4

ROCK OUTCROP RECORDS

USED IN SCALED SOIL RESPONSE ANALYSIS

Year	Mo.	Day	Earthquake Name	Local Magnitude	Scaling Factor	Recording Station	Epicentral Distance (km)	Component	Record No.
1935	10	31	Helena, MT	6.0	0.271	Carroll College Helena, MT	6	EW NS	B-025
1966	06	28	Parkfield, CA	5.6	0.446	Cholame-Shandon Array, Temblor	39(7)	N65W S25W	B-037
1970	09	12	Lytle Creek, CA	5.4	0.572	Allen Ranch Cedar Springs, CA	19	S05W S85E	W-335
1971	02	09	San Fernando, CA	6.4	0.165	Array No. 4 Lake Hughes, CA	29	S69E S21W	J-142
1975	08	01	Oroville, CA	5.7	0.394	Oroville Dam Seismograph Station	12	N53W N37E	OS-875
1975	08	08	Oroville, CA Aftershock	4.9	1.064	Oroville, CA CDMG No. 6	6	S55E N35E	6-700
1975	09	27	Oroville, CA Aftershock	4.6	1.452	Oroville, CA CDMG No. 8	11	N90W S00E	8-234
1976	09	11	Friuli, Italy Aftershock	5.9	0.307	San Rocco	14	NS EW	I-139
1976	09	11	Friuli, Italy Aftershock	5.5	0.505	San Rocco	16	NS EW	I-132
1976	09	15	Friuli, Italy Aftershock	6.0	0.271	San Rocco	19	NS EW	I-169
1979	08	06	Coyote Lake, CA	5.9	0.307	Coyote Creek San Martin, CA	2	250° 160°	SM-879
						Gilroy No. 1 Gavilan College Water Tower	16	320° 230°	G1-879
						Gilroy No. 6 San Ysidro, CA	10	320° 230°	G6-879
1982	03	31	Miramichi, New Brunswick	4.8 (m_b = 5.0)	0.750	Mitchell Lake Road	4	118° 28°	ML-382

TABLE 4-5

ROCK OUTCROP RECORDS

AVAILABLE FOR UNSCALED SOIL RESPONSE ANALYSIS

Year	Mo.	Day	Name	Local Magnitude	Epicenter Distance (km)	Record No.	Component	Recording Station
1970	09	12	Lytle Creek, CA	5.4	19	W-334	S05W S85E	Allen Ranch Cedar Springs, CA
1975	08	08	Oroville, CA (Aftershock)	4.9	6	6-700	S55E N35E	Oroville, CA CDMG No. 6
1975	09	27	Oroville, CA (Aftershock)	4.6	11	8-234	N90W S00E	Oroville, CA CDMG, No. 8
1976	09	11	Friuli, Italy	5.5	16	I-132	NS EW	San Rocco
1982	03	31	Miramichi, New Brunswick	4.8 (m_b = 5.0)	4	ML-382	118° 28°	Mitchell Lake Road

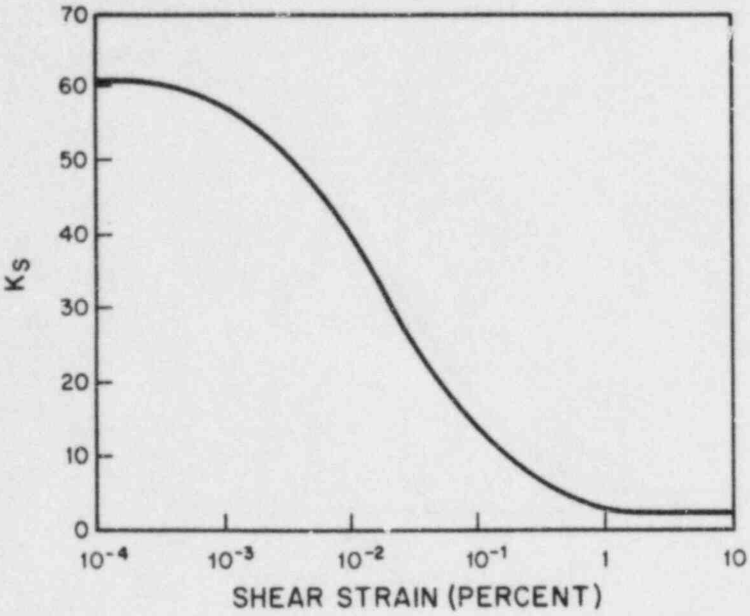
ELEV. (FT.)	LAYER No.	LAYER THICKNESS (FT.)	UNIT* WEIGHT (PCF)	SHEAR WAVE VELOCITY** (FT./SEC.)	DEPTH (FT.)	
735 – 725	1	10	125	600	0 – 10	SAND & GRAVEL
725 – 715	2	10	125	800	10 – 20	SAND & GRAVEL
715 – 705	3	10	125	950	20 – 30	SAND & GRAVEL
705 – 695	4	10	125	950	30 – 40	SAND & GRAVEL
695 – 685	5	10	125	1100	40 – 50	SAND & GRAVEL
685 – 675	6	10	125	1100	50 – 60	SAND & GRAVEL
675 – 665	7	10	125	1100	60 – 70	SAND & GRAVEL
665 – 657.5	8	7.5	136	1200	70 – 77.5	SAND & GRAVEL
657.5 – 650	9	7.5	136	1200	77.5 – 85	SAND & GRAVEL
650 – 640	10	10	136	1200	85 – 95	SAND & GRAVEL
640 – 630	11	10	136	1200	95 – 105	SAND & GRAVEL
630 – 620	12	10	136	1200	105 – 115	SAND & GRAVEL
	BASE LAYER	HALF SPACE	160	5000		ROCK

NOTES

* UNIT WEIGHT FROM BVPS-2 FSAR SECTION 2.5.4.

** SHEAR WAVE VELOCITY FROM FIGURE 6-2 (SWEC, 1984)
IN SITU: NATURAL FREQUENCY = 2.3 H_z

FIGURE 4 - 1
SOIL MODEL
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

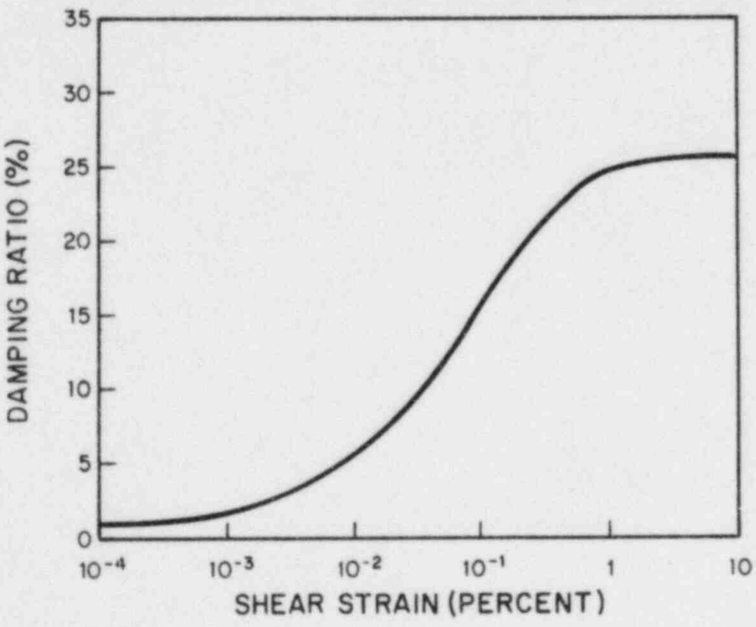


$G = 1000 K_S (\sigma'_m)^{0.5}$ (PSF)

WHERE G = SHEAR MODULUS

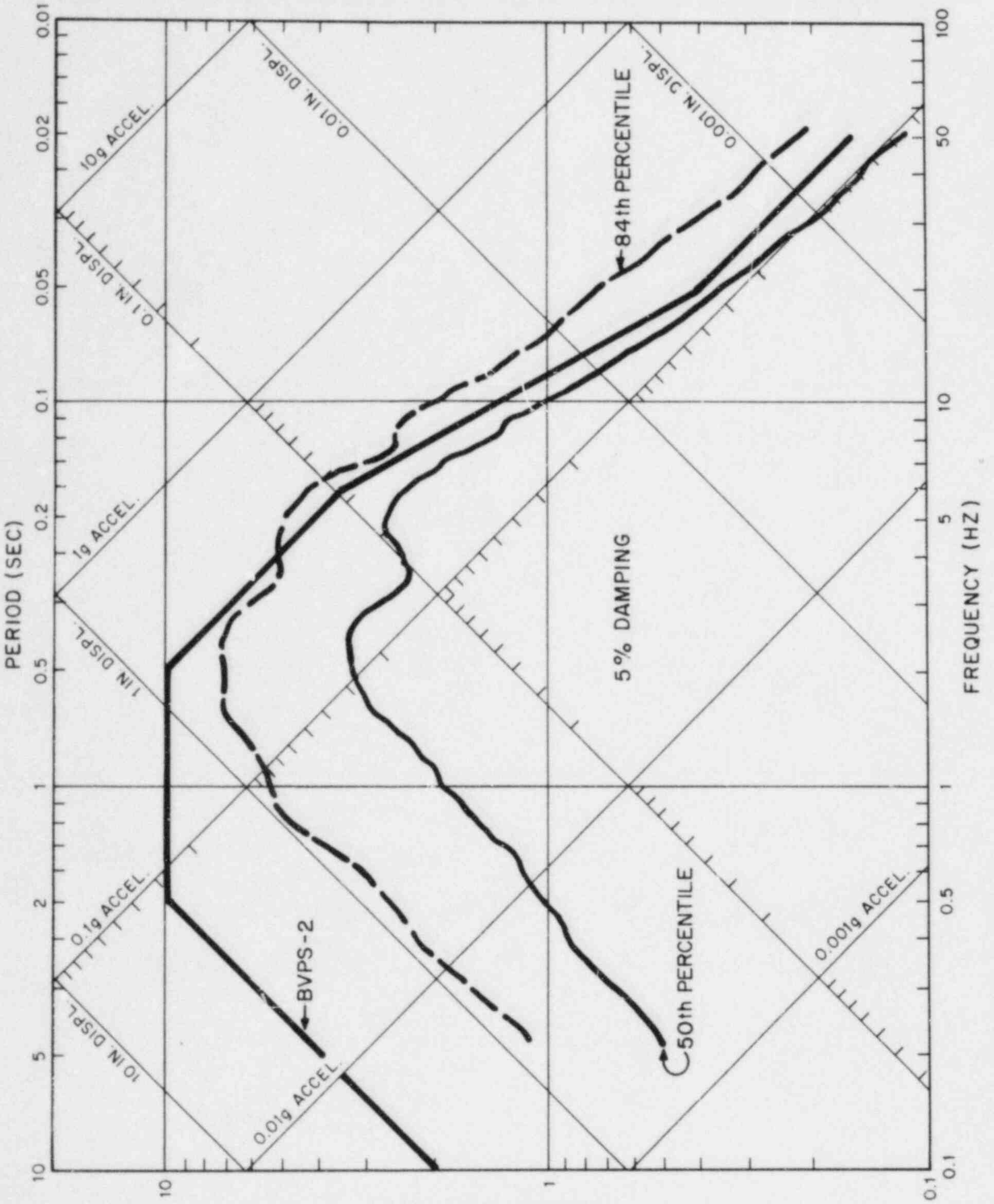
σ'_m = MEAN EFFECTIVE SOIL PRESSURE

a. VARIATION OF SHEAR MODULUS OF SAND WITH STRAIN



b. VARIATION OF DAMPING RATIO OF SAND WITH STRAIN

FIGURE 4-2
STRAIN DEPENDENT SOIL PARAMETERS
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION



NOTE:

RESPONSE SPECTRA COMPUTED
FROM RECORDS LISTED IN TABLE 4-4

FIGURE 4-3
HORIZONTAL RESPONSE SPECTRA FROM SOIL RESPONSE ANALYSIS: SCALED
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

SECTION 5

SITE DEPENDENT RESPONSE SPECTRA

Two approaches have been used to determine ground surface response spectra, taking into consideration the geology, seismicity and local soil conditions at BVPS-2. They were (1) the site matched response spectra approach, the results of which are discussed in Section 3 and shown in Figure 3-5, and (2) the soil response analysis approach, the results of which are discussed in Section 4 and shown in Figure 4-3.

The site matched and soil response analyses provide two separate statistical estimates of the site dependent response spectra. Advantages and limitations can be ascribed to each method, and it cannot be stated with certainty which of the two gives the best estimate. Since the two approaches augment one another, to obtain the best estimates of the 50th and 84th percentile site dependent response spectra, the results were combined statistically. The resulting site dependent response spectra for BVPS-2 are shown in Figure 5-1.

5.1 PROCEDURE

The statistical analysis procedure used to combine the site matched and soil response analyses results is fully described in Appendix 6 and briefly summarized below.

The response spectra pseudo-velocities are log-normally distributed. The best estimate of the 50th percentile site dependent response spectrum was determined as the linear combination of the results of the two approaches according to the expressions:

$$\mathrm{MEANLOGV} = W_{sm}(\mathrm{MEANLOGV}_{sm}) + W_{sr}(\mathrm{MEANLOGV}_{sr}) \qquad \text{(EQ 5-1a)}$$

$$\mathrm{MEDIANV} = 10^{\mathrm{MEANLOGV}} \quad \text{(in/sec)} \qquad \text{(EQ 5-1b)}$$

where:

W_{sm}, W_{sr} = weighting factors for the site matched analysis and the soil response analysis, respectively

The weighting factors were chosen to minimize the variance of the estimate of the mean of the underlying distribution. Expressions for the weighting factors are provided in Appendix 6.

The calculations described by Equation 5-1 were carried out for each frequency at which the two sets of spectra had been evaluated.

The best estimate of the variance of the $\log_{10}$ pseudo-velocities was determined assuming that the variances of the individual data sets were chi-square distributed. This resulted in a combination of the individual variances that was weighted according to the number of observations (earthquake records) in each data set. The governing equation was:

$$VARLOGV = 0.3864\,(VARLOGV_{sm}) + 0.6136\,(VARLOGV_{sr}) \quad \text{(EQ 5-2)}$$

It then follows that the 84th percentile value of the pseudo-velocities is calculated for each frequency according to the equations:

$$MSDLOGV = MEANLOGV + (VARLOGV)^{1/2} \quad \text{(EQ 5-3a)}$$

$$MSDV = 10^{MSDLOGV} \quad \text{(in/sec)} \quad \text{(EQ 5-3b)}$$

5.2 RESULTS

The 50th and the 84th percentile site dependent response spectra for 5 percent damping are plotted in Figure 5-1. The 50th percentile response spectrum falls well below the BVPS-2 design response spectrum. The 84th percentile response spectrum closely matches the design spectrum above 6 Hz and falls below it for all other frequencies, sometimes substantially.

Section 6 demonstrates that the annual probability of exceeding the 50th percentile site dependent response spectrum is about 10^{-4} and is about 10^{-5} for the 84th percentile spectrum. The annual probability associated with the 50th percentile spectrum is comparable to values usually accepted for the SSE; the probability for the 84th percentile is substantially lower. The BVPS-2 design response spectrum, therefore, has an annual probability of exceedence that is very low and in the frequency range of interest to BVPS-2 plant structures (2-10 Hz) is about 10^{-5}.

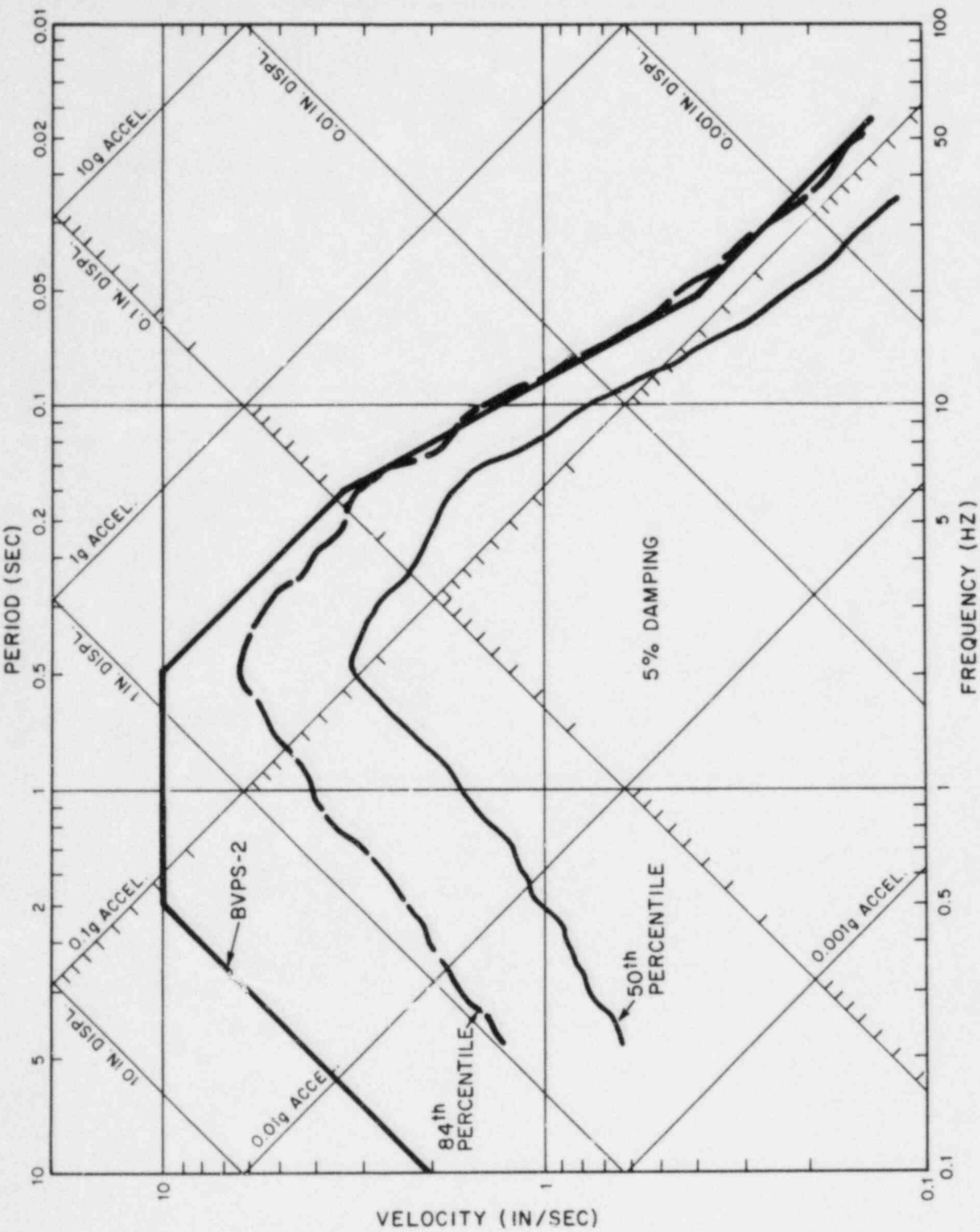


FIGURE 5-1
SITE DEPENDENT
RESPONSE SPECTRA
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

SECTION 6

PROBABILISTIC ANALYSIS

Exceeding a given response spectrum at BVPS-2 depends on the interaction of several factors: earthquake magnitude, epicentral distance, attenuation characteristics of the region, and the time history of motion. An earthquake of sufficient size must occur near enough to the site so that the attenuated motions will cause a significant ground shaking at the site. The resulting time history of motion at the site and the corresponding set of response spectra are, of course, unique for each earthquake. All of these factors have uncertainty associated with their potential effects at the site, which suggests a probabilistic approach to evaluating response spectra.

Accordingly, two related probabilistic analyses were performed. The first consisted of three conventional seismic hazard analyses performed using two tectonic province models and a seismic source zone model. The analyses considered the contribution to the seismic hazard at BVPS-2 due to those parts of the United States and Canada lying east of 84°W, north of 34°N, and south of 47°N as well as local sources at New Madrid, MO; Charleston, SC; Anna, OH; La Malbaie, PQ; and the Wabash Valley. It led to a general understanding of the seismic hazard at the site and to the conclusion that almost all of the hazard is contributed by the Appalachian Plateau tectonic province or by background seismicity for the seismic zone model. Based upon the results of the conventional seismic hazard analysis, a more detailed examination of the region near the site was made which resulted in an estimate of the annual probability of exceeding the 50th and 84th percentile site dependent response spectra.

6.1 Seismic Hazard Analysis

The annual probability of exceeding a given level of shaking at a site, more simply, the annual seismic hazard, is usually calculated by methods based on the work of Cornell (1968), and implemented in the widely used program developed by McGuire (1976). In this approach, earthquakes are allowed to occur at random throughout the different zones of seismicity and are governed by the annual rate of occurrence of events equal to or greater than a given magnitude (the activity rate) and by the relation between magnitude and number of events (the recurrence relation). Their effects are evaluated at the site according to an attenuation relation. Thus, a seismic hazard analysis requires: (a) establishing a geometric pattern of seismic sources; (b) for each source, determining the activity rate, the recurrence relation, and upper bound limits on earthquake size; and (c) choosing an appropriate attenuation relation. The annual probability of exceeding various levels of shaking at the site is then computed.

6.1.1 Contributions of Tectonic Provinces and Seismic Source Zones

The historic earthquake catalogue that was used for this analysis covered the period from 1871 to 1976. The catalogue had been processed to retain all events of epicentral intensity greater than or equal to V (MM). A map of epicentral locations is shown in Figure 6-1.

For the present case, two approaches were used to establish seismic sources. The first method used the tectonic provinces and concentrated, local seismic sources shown in Figure 6-2. The local sources include New Madrid, Missouri; Anna, Ohio; Charleston, SC; the Wabash Valley area; and the La Malbaie area in Quebec. Surrounding the site is the Appalachian Plateau tectonic province, which is distinguished from the Central Stable Region and the Northern Valley and Ridge tectonic province. The precise locations of the boundaries between the provinces are not significant factors in the analysis. The western boundary of the Appalachian Plateau tectonic province shown in Figure 6-2 is located somewhat to the west of that shown in Figure 6-5; this has the effect of including within the Appalachian Plateau tectonic province the 1926 intensity VI-VII(MM) event in southeastern Ohio. Several earthquakes in the historical record occurred near a tectonic province boundary, so that they could have occurred in either province. The alternative choices resulted in two distributions of historic activity in the provinces, which are called Provinces I and Provinces II in the subsequent discussion.

The second method is based on the work done on seismic source zones by Chiburis (1979) and expanded with data developed by Nuttli (1979) and Bollinger (1975). Chiburis (1979) identified sources of seismic activity by applying pattern recognition techniques to the historic seismic record. This led to a set of seismic source zones and an overall background seismic activity that accounts for seismicity not included in specific zones. Figure 6-3 shows the configuration of the seismic source zones used in the analysis. The tectonic provinces and seismic source zones used in this analysis are the same as those presented by Acharya, Lucks, and Christian (1984), from which Figures 6-1, 6-2 and 6-3 were adapted.

All of the events in the earthquake catalogue were described in terms of body-wave magnitude, and annual activity rates were evaluated for each province for time intervals before 1976 ranging from 10 to 100 years. The most reasonable values of average activity were chosen for each tectonic province. The recurrence relation predicting the number N of events per year equal to or greater than magnitude m_b is of the form:

$$\text{Log } N = a - bm_b \qquad \text{(Eq 6-1)}$$

The parameters a and b are empirical: a describes the activity rate and b is the slope of the recurrence relation. For this analysis, b was selected to be 0.9.

The following attenuation relation, proposed by Hermann and Nuttli (1984), was used with a standard deviation of 0.6 to account for uncertainty:

$$\log a_h = 0.57 + 0.50\, m_b - 0.83 \,\mathrm{Log}\, (R^2 + h^2)^{1/2} - 0.00069\, R + \varepsilon$$
$$\text{with } \sigma_\varepsilon = 0.6 \qquad \text{(Eq. 6-2)}$$

6.1.2 Seismic Hazard at BVPS-2

Figure 6-4 and Table 6-1 summarize the results for all three models. The annual probability of equaling or exceeding a horizontal ground surface acceleration greater than or equal to 0.125g, which is the zero period acceleration for the SSE, ranges from 1.32×10^{-4} to 2.47×10^{-4}.

Table 6-1 shows that the overwhelmingly major portion of the seismic hazard at BVPS-2 is contributed by the Appalachian Plateau tectonic province (for Provinces I and II) or background seismicity (for seismic zones). One can see in the computer output that it is the portion of the Appalachian Plateau tectonic province or background zone immediately surrounding the site that contributes to the seismic hazard. For a_h equal to or greater than 0.125g, these contribute between 92 percent and 96 percent of the total seismic hazard. Almost all of the remaining seismic hazard derives from the local source near Anna, Ohio.

The activity rates and recurrence relations include the effects of both shallow and normal focal depth earthquakes. Since shallow earthquakes are typically felt over much smaller areas than normal focal depth earthquakes of similar magnitudes, the attenuation of the shallow events must be more severe. Consequently, the computed seismic hazard would be reduced by distinguishing between the two types of events. Since this was not done in this analysis, the results include some conservatism.

6.1.3 Summary

A seismic hazard analysis performed using conventional procedures results in an annual seismic hazard of about 10^{-4} for a horizontal ground surface acceleration, a_h, equal to or greater than 0.125g, which corresponds to the SSE. The annual seismic hazard is slightly larger for a_h equal to or greater than about 0.12g, which is the 84th percentile value at frequencies above 50 Hz from Figure 5-1. This hazard is very strongly dominated by the region around the site, and therefore, a refinement of the hazard analysis should emphasize this region. In addition, the shapes of response spectra associated with this local activity can be studied by examining historical strong motion recordings.

6.2 Probability of Exceeding Response Spectra

The conventional analysis described in the preceding section showed that the seismic hazard at BVPS-2 is almost completely dominated by the portion of the Appalachian Plateau tectonic province around the site. Consequently, the second analysis developed a more detailed description of the recurrence relation in that region. Also, in the site matched response spectra analysis and in the soil response analysis, all of the earthquake records used to compute ground surface response spectra were recorded within 29 km of the epicenters of the respective earthquakes. Therefore, the second probabilistic analysis accounted for the occurrence of an event within 29 km of BVPS-2. This approach incorporates the effects of attenuation in that the records themselves reflect the effects of attenuation. The earthquake records also include the effects of near field motions.

6.2.1 Methodology

The probabilities were computed from the product of the yearly probability of the design or greater earthquake occurring anywhere in the Appalachian Plateau tectonic province, the conditional probability of its occurring within a 29 km radius of the site given that it occurs in the province, and the percentile probability associated with the site dependent response spectra.

The probability that the site dependent response spectrum would be exceeded was determined from the joint and conditional probability equation:

$$P(A_2 \& A_3) = P(A_2)\, P(A_3) = P(A_1)\, P(A_2|A_1)\, P(A_3) \qquad \text{(Eq 6-3)}$$

where:

A_2 and A_3 are stochastically independent

$P(A_2 \& A_3)$ = probability of an event of $m_b \geq 4.75$ occurring within 29 km of the BVPS-2 site and causing a response spectrum exceeding a given percentile site dependent response spectrum

$P(A_1)$ = probability of an event of $m_b \geq 4.75$ occurring in the Appalachian Plateau tectonic province

$P(A_2)$ = probability of an event of $m_b \geq 4.75$ occurring within 29 km of BVPS-2 site

$P(A_2|A_1)$ = conditional probability of an event of $m_b \geq 4.75$ occurring within 29 km of BVPS-2 given that the event occurs within the Appalachian Plateau tectonic province

$P(A_3)$ = probability that an earthquake with $m_b \geq 4.75$ occurring within 29 km of a site with site characteristics similar to BVPS-2 produces a response spectrum that exceeds a given percentile site dependent response spectrum.

6.2.1.1 Recurrence Interval for Design Earthquake

As discussed in Section 2.1, the SSE for BVPS-2 has been estimated to be equivalent to an event with a body-wave magnitude of 4.75. $P(A_1)$, the annual probability of exceeding the SSE within the Appalachian Plateau tectonic province, was determined from the observed historical seismicity of the province within 200 miles of the site.

A recurrence relation that predicts the numbers of events, N, with body-wave magnitude, m_b, greater than a given value is similar to Equation 6-1. Nuttli (1974) presented a recurrence relation for the Mississippi Valley region. His relation, however, defines N as the annual number of events having magnitudes within a given interval, rather than as the number of events having magnitudes equal to or greater than a given value. When his data were reexamined to obtain a recurrence relation in which the latter definition of N was used, the parameter b in Equation 6-1 was found to be 1.03. This value was used in subsequent calculations since the intent was to determine the probability of exceeding a given level of shaking, namely, $m_b \geq 4.75$.

Figure 6-5 shows the historical earthquake epicenters and tectonic province boundaries within 200 miles of the site (SWEC, 1984a). From the earthquake catalog for BVPS-2 presented in SWEC (1984b), 50 events have occurred in the portion of the Appalachian Plateau tectonic province within 200 miles of the site. This subset of events from the BVPS-2 earthquake catalog is provided in Table 6-2. Statistical evaluation of the data in Table 6-2 was performed using the methods described by Nuttli (1974). Two magnitude limits were considered, $m_b \geq 2.9$ and $m_b \geq 3.4$, as being the most likely to be completely reported over a limited time period in an area of limited sesimicity. For those events in Table 6-2 for which magnitudes were not reported, they were estimated from the epicentral intensities.

The annual numbers of events, N, for $m_b \geq 2.9$ and for $m_b \geq 3.4$ were found to be 0.36 and 0.27, respectively. From these data and the recurrence relation given by Equation 6-1 with b equal to 1.03, the following estimates of the annual number of occurrences of events having an $m_b \geq 4.75$ were obtained:

if $N = 0.36$ for $m_b \geq 2.9$, then $N = 0.0045$ for $m_b \geq 4.75$

if $N = 0.27$ for $m_b \geq 3.4$, then $N = 0.0110$ for $m_b \geq 4.75$

Therefore, a high estimate of $P(A_1)$ is 0.0110 and a low estimate is 0.0045. Alternatively, the seismicity data for 100 years in the Appalachian Plateau tectonic province within 200 miles of the site give the recurrence relation plot shown in Figure 6-6. This yields an estimated $P(A_1)$ of 0.006.

The inclusion or exclusion of the 1926 event in southeastern Ohio has little effect on these numbers.

6.2.1.2 Conditional Probability of Design Earthquake Within 29 km of the Site

The probability of an earthquake with an $m_b \geq 4.75$ occurring within a 29 km radius of the BVPS-2 site, given that the event has occurred in the Appalachian Plateau tectonic province, is the ratio of the area of a circle with a radius of 29 km to the area of the Appalachian Plateau tectonic province within 200 miles of the site. The choice of a 29 km radius around the BVPS-2 site was based on the fact that all of the earthquake records used for the scaled site matched analyses (Table 3-1) and the scaled soil response analyses (Table 4-4) were recorded at epicentral distances ranging from approximately 4 km to approximately 29 km. Determining the probability in this manner implicitly assumes that the probability distribution for an earthquake occurring anywhere within the Appalachian Plateau tectonic province is uniform. This is a reasonable assumption based on the geology of a tectonic province model possessing no unique seismological features that would be more or less preferential for earthquake hypocenters.

The area of a circle with a 29 km radius is 2642.1 sq km. From Figure 6-5, the area of the Appalachian Plateau tectonic province within 200 miles of the site is 136,863 sq km. Therefore:

$$P(A_2|A_1) = 2642.1/136{,}863 = 0.0193$$

6.2.1.3 Probability of Exceeding Site Dependent Response Spectra

The site dependent response spectra were calculated assuming that the individual response spectrum pseudo-velocity values for a given frequency were log-normally distributed; i.e., that the logarithm of the pseudo-velocities were normally distributed. For this case, the probability of exceeding the median value is 0.5. Therefore, the probability of an earthquake with an $m_b \geq 4.75$ occurring within 29 km of a site similar to BVPS-2 which produces a response spectrum that exceeds the 50th percentile site dependent response spectrum is:

$$P(A_3) = 0.5 \qquad \text{(For 50th percentile)}$$

Likewise, the probability of an earthquake with an $m_b \geq 4.75$ occurring within 29 km of a site similar to BVPS-2 which produces a response spectrum that exceeds the 84th percentile site dependent response spectrum is:

$$P(A_3) = 0.16 \qquad \text{(For 84th percentile)}$$

6.2.2 Results

The probability that an earthquake with an $m_b \geq 4.75$ will occur within the Appalachian Plateau tectonic province and within 29 km of the site and will produce a response spectrum greater than the site dependent response spectrum was determined as the product of the independent and conditional probabilities previously discussed. From equation 6-2, for the 50th percentile response spectrum:

$$P(A_2 \& A_3) = (0.0045 \text{ or } 0.0110)\ (0.0193)\ (0.5)$$

This gives an annual probability of exceedence between 4.4×10^{-5} and 1.1×10^{-4}. For the 84th percentile response spectrum:

$$P(A_2 \& A_3) = (0.0045 \text{ or } 0.0110)\ (0.0193)\ (0.16)$$

This gives an annual probability of exceedence between 1.4×10^{-5} and 3.4×10^{-5}.

As described in Section 6.2.1, the value of $P(A_1)$ estimated directly from the recurrence relation within 200 miles of the site is 0.006. This gives an annual probability of exceedence of 5.8×10^{-5} for the mean response spectrum and 1.9×10^{-5} for the 84th percentile spectrum.

These calculations have not included the contributions of events with $m_b < 4.75$ to the probability of exceeding the various response spectra. Approximate extrapolation of the present results using Herrmann and Nuttli's relation (Equation 6-2) indicates that the smaller earthquakes may increase the computed annual probability of exceeding the response spectra to about 2.3×10^{-4} for the 50th percentile spectrum and 5.3×10^{-5} for the 84th percentile spectrum.

6.3 Discussion

The seismic hazard analysis led to the conclusion that the seismic hazard at the site is overwhelmingly dominated by the seismicity of the Appalachian Plateau tectonic province. A more detailed examination of that province provides an estimate for the annual probability of an earthquake with a body-wave magnitude greater than or equal to 4.75 occurring within 29 km of BVPS-2. The response spectra for earthquakes within this radius, normalized to a body-wave magnitude of 4.75, provide statistical estimates of the distribution of response spectra. These, combined with the computed annual probability for the earthquakes, give an annual probability of exceeding the 50th percentile response spectrum of between 4.4×10^{-5} and 2.0×10^{-4}. The annual probability of exceeding the 84th percentile response spectrum is 1.4×10^{-5} to 4.4×10^{-5}.

A significant conclusion is that the 50th percentile response spectrum computed from a suite of actual accelerograms has an annual probability of exceedence that is lower than values usually accepted for the SSE and, therefore, represents an acceptable degree of conservatism. The 84th percentile response spectrum has an annual probability of exceedence that is very much lower.

TABLE 6-1

SEISMIC HAZARD ANALYSIS

Case No.	Description	For $a_h = 0.125g$: Annual Exceedence Probability	Contribution of Appalachian Province
A-1	Tectonic Province I $m_b \geq 4.0$	$1.68x10^{-4}$	$1.58x10^{-4}$ (94%)
A-2	Tectonic Province II $m_b \geq 4.0$	$2.47x10^{-4}$	$2.37x10^{-4}$ (96%)
B-1	Seismic Zones $m_b \geq 4.0$	$1.32x10^{-4}$	$1.21x10^{-4}$ (92%)

TABLE 6-2

EARTHQUAKES WITHIN 200 MILES OF THE SITE
AND WITHIN THE APPALACHIAN PLATEAU TECTONIC PROVINCE

Date			Origin	Latitude	Longitude	Intensity	Depth		Felt Area	
Year	Month	Day	Time	(°N)	(°W)	(MM)	(km)	Magnitude	($\times 10^2$ mi^2)	Location
1823	05	30		41.5	81.0	IV		3.8		
1824	07	15	1620	39.7	80.5	IV				
1836	07	08		41.5	81.7	IV		3.8		
1857	03	01		41.7	81.2	IV-V		4.0		
1857	12	10	2200	37.8	80.4					
1857	12	11	0300	37.8	80.5					
1858	04	16	1200	41.7	81.3	IV		3.8		
1867	01	13		41.5	81.7	III		3.4		
1872	07	23		41.4	82.1	IV		3.8		
1873	08	17	1400	41.2	80.5	III				Sharon, PA
1885	01	18	1030	41.1	81.4	(IV)		(3.8)		
1885	01	18	1130	41.3	81.1	III		3.4		
1885	08	15	0505	41.3	81.1	II		3.2		
1885	09	26	2030	40.3	80.1	III				
1898	10	24		41.5	81.7	III-IV		3.6		
1900	04	09	1400	41.4	81.8	VI*		4.7 (3.8)		
1902	[illegible]	14	0700	40.3	81.4	IV-V		4.0		
1906	04	20	1730	41.5	81.7	(III)		(3.4)		
1906	04	20	1830	41.5	81.7	IV		3.8		
1906	06	27	1210	40.4	81.6	V*		4.2 (3.4)	0.4	
1906	06	27	2210	41.4	81.6	V				
1907	01	10	1000	41.2	77.1	IV				Williamsport, PA

TABLE 6-2 (Cont)

Date Year	Month	Day	Origin Time	Latitude (°N	Longitude (°W)	Intensity MM)	Depth (km)	Magnitude	Felt Area ($\times 10^2$ mi^2)	Location
1907	04	12		41.5	81.7	III		3.0		
1927	10	29		40.9	81.2	V		4.2		
1928	09	09	2100	41.5	82.0	V		4.2	1.5	
1929	09	17	1900	41.5	81.5	III		3.0		
1932	01	22		41.1	81.5	V*		4.2 (3.6)		
1934	10	29	2007	42.0	80.2	V				Erie, PA
1934	11	05	2000	41.8	80.3	III				
1935	07	13		40.5	78.5	VI				Blair Co., PA
1935	11	01	0330	38.9	79.9	V				
1935	11	01	2030	39.9	79.9	V				
1936	08	26	0900	41.4	80.4	III				Greenville, PA
1938	07	15	2245	40.7	78.4	V-VI				Blair Co., PA
1940	05	31	1700	41.1	81.5	II		3.0		
1951	12	03	0200	41.6	81.4	IV		3.8	0.1	
1951	12	03	0702	41.6	81.4	(IV)		(3.2)	(0.1)	
1951	12	07		41.6	81.4	II		3.0		
1951	12	21	2100	41.6	81.5	II				
1951	12	22	0400	41.6	81.4	II		3.0		
1955	05	26	1809	41.5	81.7	V (IV-V)*		3.8 (3.6)		
1955	06	29	0116	41.5	81.7	V (IV)*		3.8 (3.6)		
1958	05	01	2247	41.5	81.7	IV-V		4.0		
1965	10	08	0217	40.1	79.8			3.3		Southwestern PA
1966	09	28	2059	39.3	80.4	IV		(3.8)		
1972	09	12	1715	39.7	79.9					

TABLE 6-2 (Cont)

Date Year	Month	Day	Origin Time	Latitude (°N)	Longitude (°W)	Intensity (MM)	Depth (km)	Magnitude	Felt Area ($x10^3$ mi^2)	Location
1974	10	10	2146	42.3	77.7			2.2		Hornell, NY
1974	10	20	1514	39.1	81.6	V		3.4		
1975	08	30	0614	42.7	78.1			2.1		S of Warsaw, NY
1978	10	26	2154	42.7	77.8		6	2.6		Mount Morris, NY

NOTES:

Table is condensed from the earthquake catalog provided in the BVPS-2 FSAR (SWEC, 1984a)

Data in parentheses taken from Nuttli (1981)

*Indicates shallow earthquakes per Nuttli (1981)

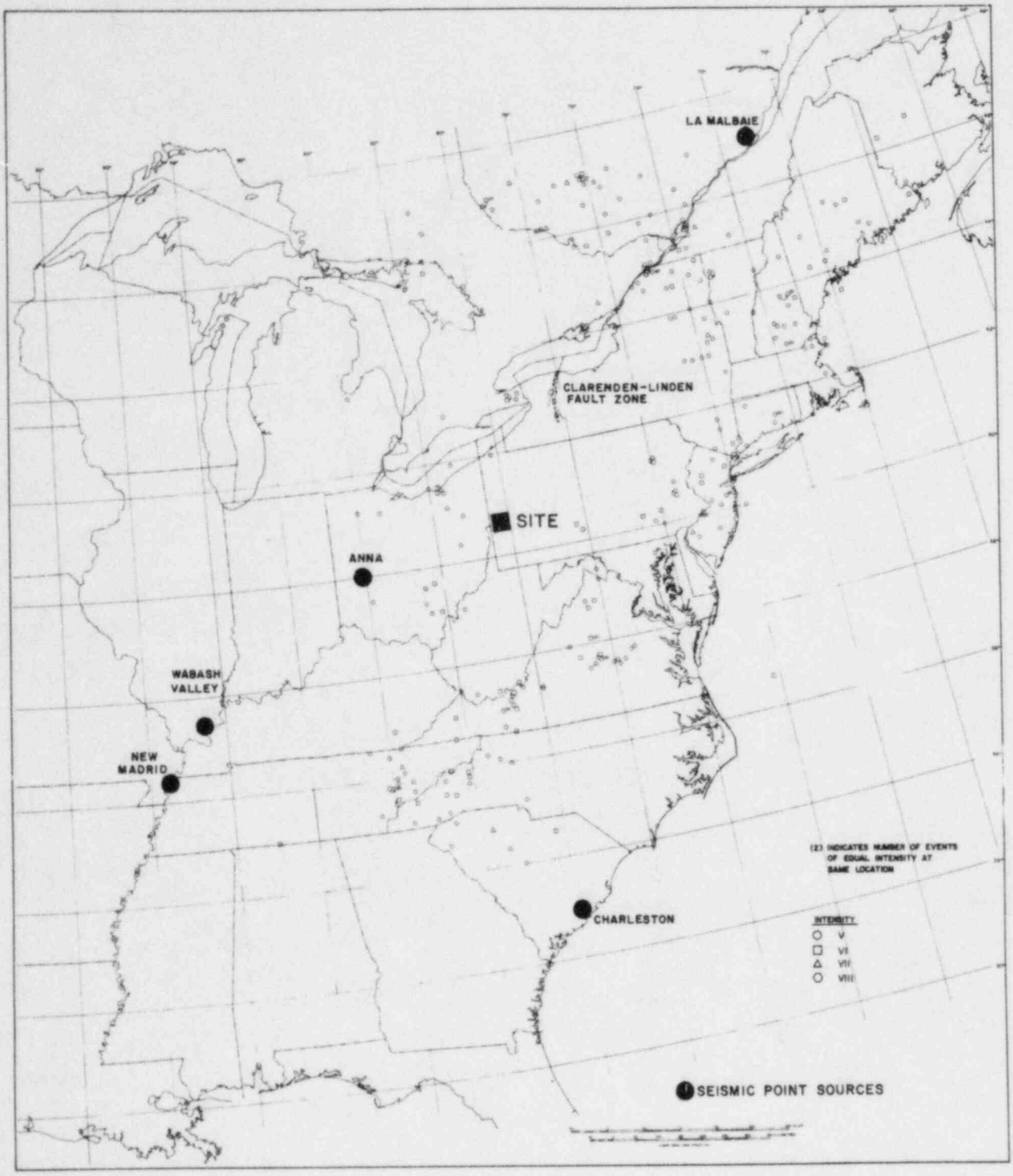


FIGURE 6-1
EPICENTERS WITH
INTENSITY ≥ V (MM)
(1871 - 1977)
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

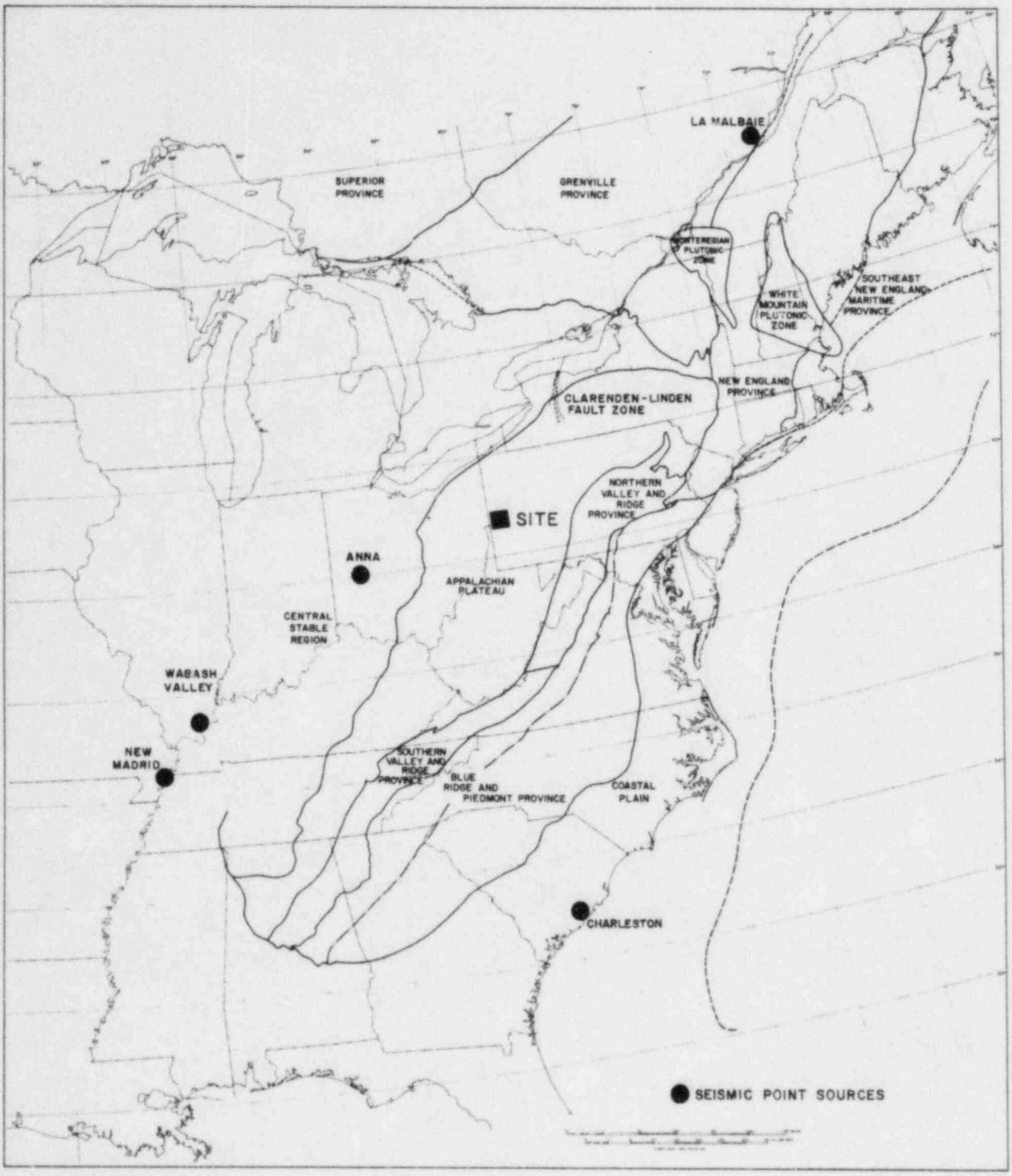


FIGURE 6-2
TECTONIC PROVINCES
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

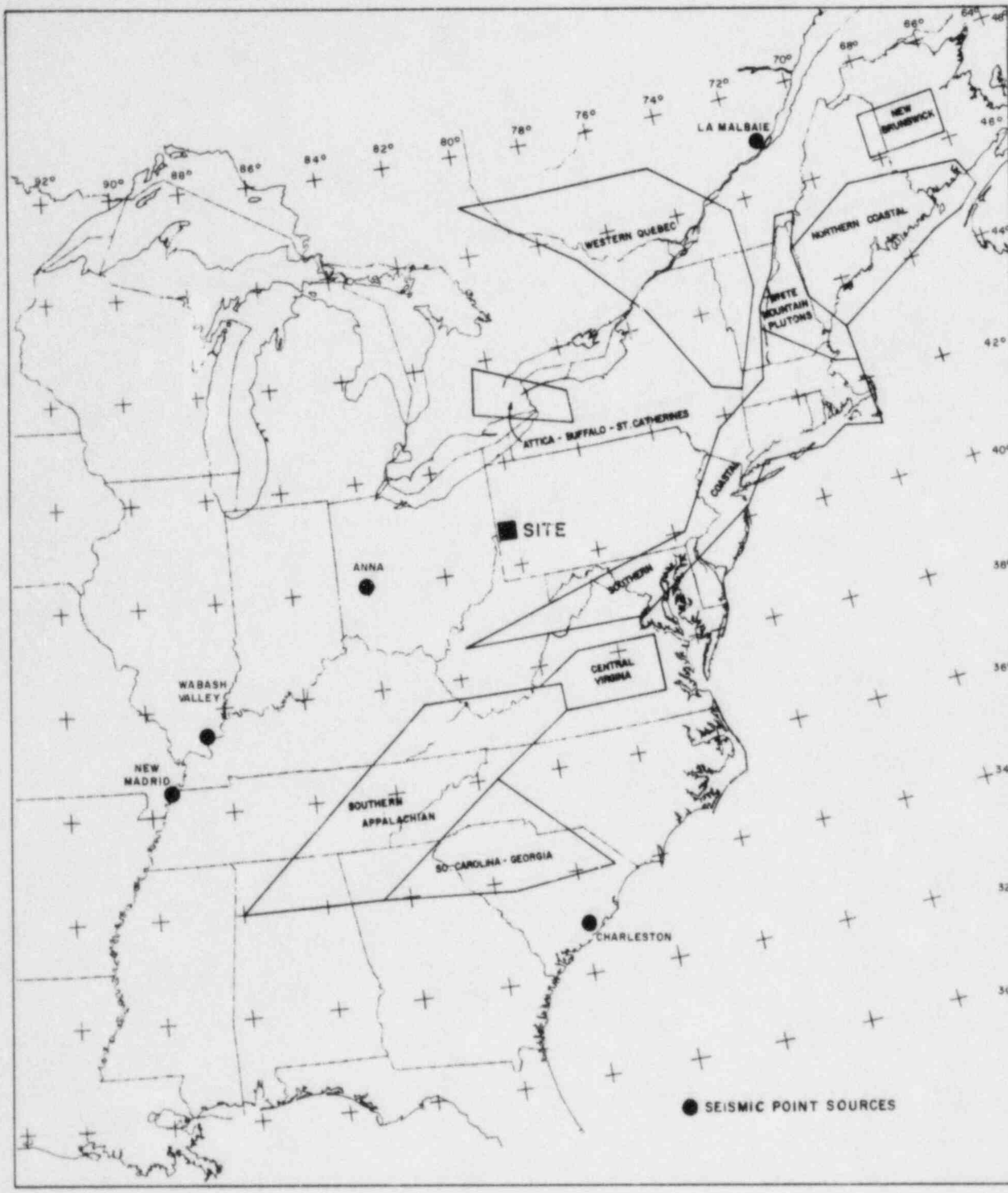


FIGURE 6-3
SEISMIC ZONES
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

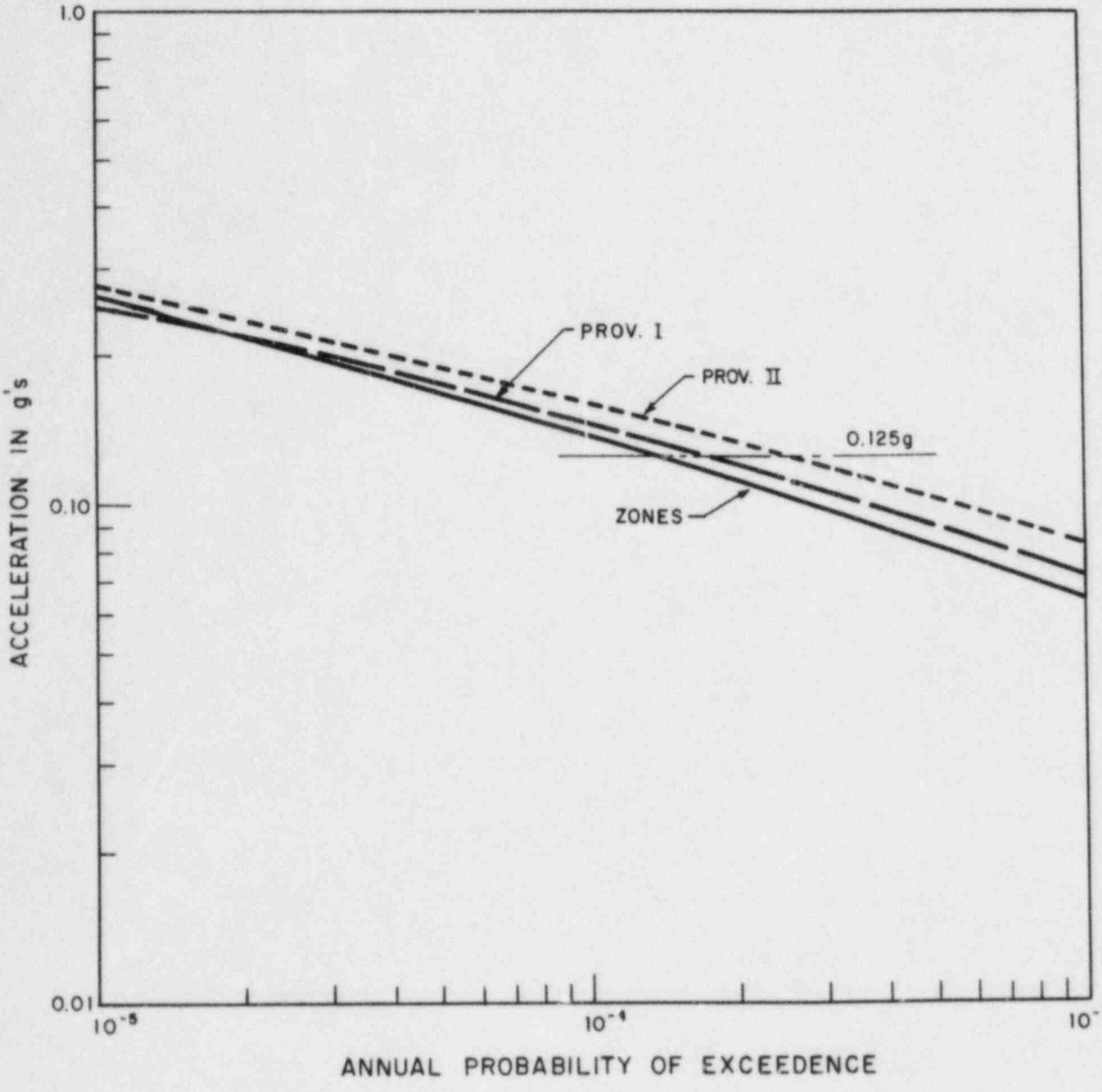


FIGURE 6-4
SEISMIC HAZARD
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

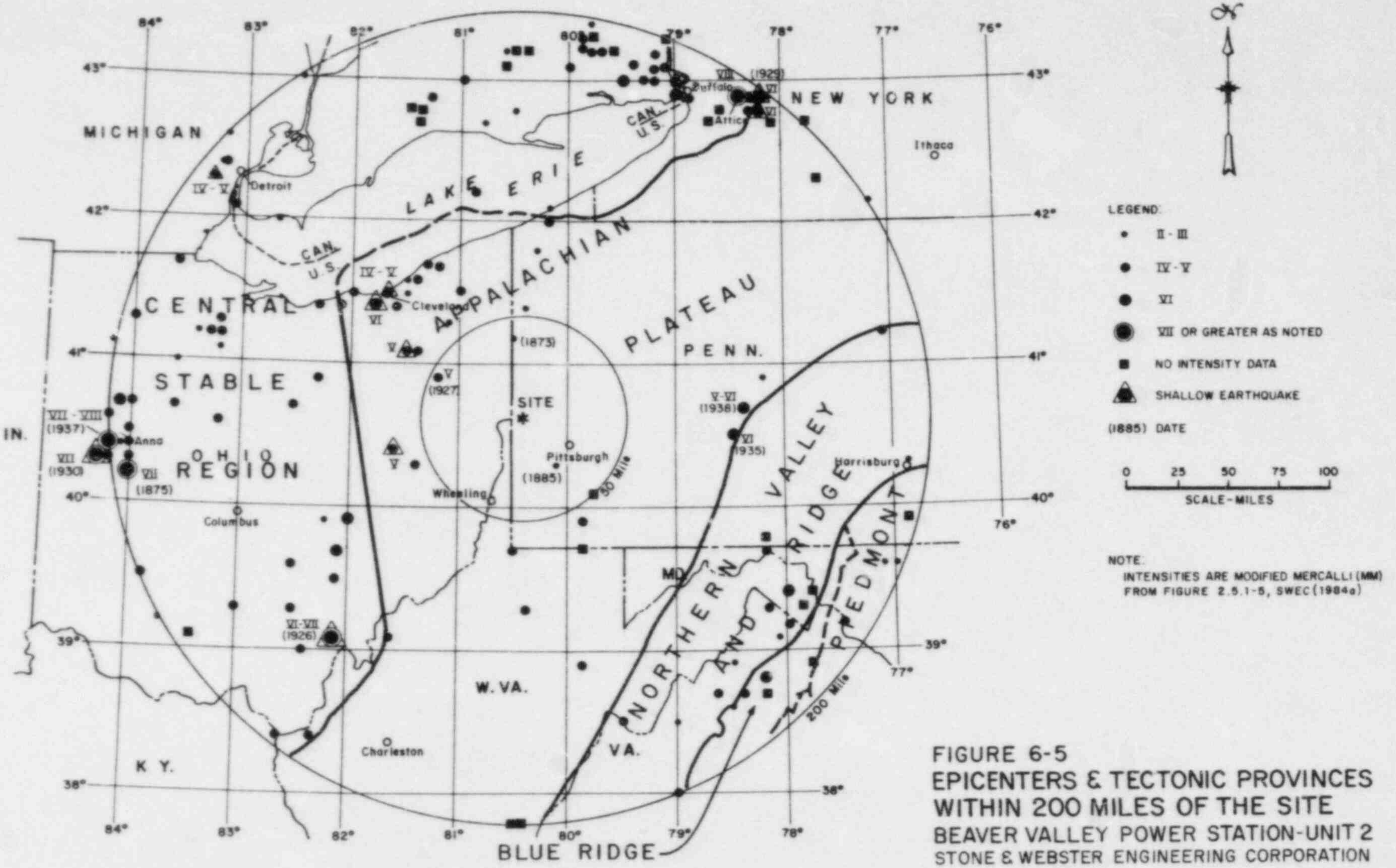
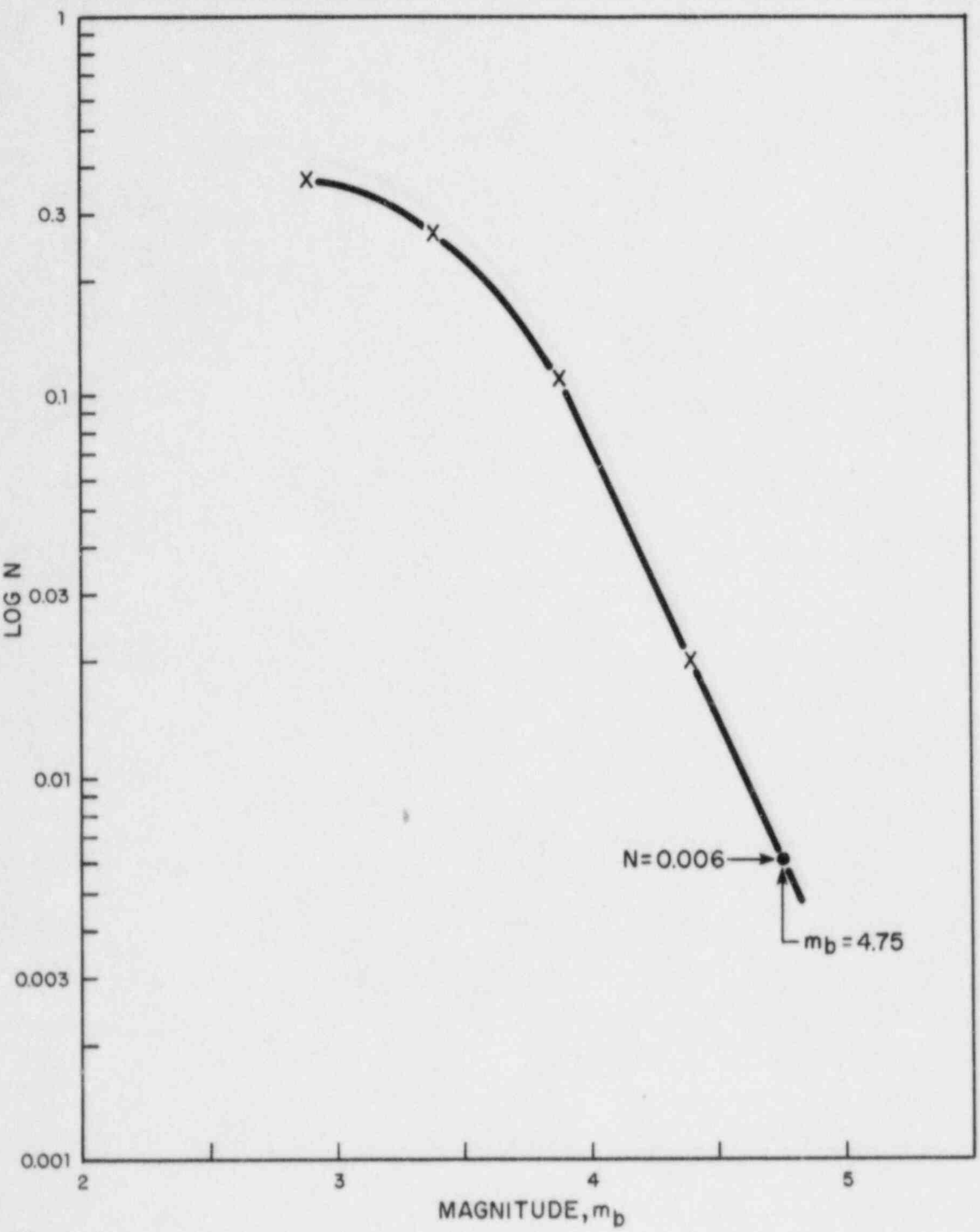


FIGURE 6-5
EPICENTERS & TECTONIC PROVINCES WITHIN 200 MILES OF THE SITE
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION



NOTE:

LOG N = $a - bm_b$

WHERE:

N = NUMBER OF EVENTS/YEAR WITH MAGNITUDE GREATER THAN OR EQUAL TO m_b.

a = CONSTANT

b = SLOPE OF RECURRENCE RELATION

m_b = BODY WAVE MAGNITUDE

FIGURE 6-6
RECURRENCE RELATIONSHIP
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

SECTION 7

CONCLUSIONS

The results of the analyses presented clearly demonstrate that the BVPS-2 horizontal and vertical design response spectra are appropriate.

SWEC (1984) presented data showing that the use of two-thirds as the ratio of vertical to horizontal response spectra is consistent with available earthquake data from the United States and Japan. This report shows that two-thirds is conservative at all frequencies.

The BVPS-2 horizontal design response spectrum for 5-percent structural damping compares favorably with site dependent response spectra computed from the combined results of two different state-of-the-art procedures. A probabilistic analysis also shows that the annual probability of exceeding the BVPS-2 design response spectrum is very low and that it has an acceptable degree of conservatism.

SECTION 8

REFERENCES

Acharya, H.K.; Lucks, A.S.; and Christian, J.T. Seismic Hazard in the Northeastern United States. Soil Dynamics and Earthquake Engineering, Vol. 3, No. 1, 1984.

Bollinger, G.A. Catalogue of Earthquake Activity in the Southeastern United States. Virginia Polytechnic Institute, 1975.

Brady, A.G.; Mork, P.N.; and Fletcher, J.P. Processed Accelerograms from Monticello Dam, Jenkinsville, South Carolina, 27 August 1978 and from Later Shocks. U.S. Geological Survey Open File Report 81-448, March, 1981.

Chang, F.K. Analysis of Strong Motion Data from the New Hampshire Earthquake of January 18, 1982. Prepared for the U.S. Nuclear Regulatory Commission. NUREG/CR-3327, 1983.

Chiburis, E.C. Earthquake Catalogue for the Northeastern U.S. and Southeastern Canada. Personal communication (unpublished), 1979.

Chung, D.H. and Bernreuter, D.L. Regional Relationships Among Earthquake Magnitude Scales. Lawrence Livermore Laboratory Report 52745. Prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-1457, 1980.

Cornell, C.A. Engineering Seismic Risk Analysis. Bulletin of the Seismological Society of America, Vol. 58, 1968.

Hermann, R.B. and Nuttli, O.W. Scaling and Attenuation Relations for Strong Ground Motion in Eastern North America. Proceedings of the 8th World Conference on Earthquake Engineering, San Francisco, July, 1984.

Idriss, I.M. Personal Communication with W. Savage of Woodward-Clyde Consultants. November, 1984.

McGuire, R. Fortran Computer Program for Seismic Risk Analysis. U.S. Geological Survey Open File Report 76-67, 1976.

McGuire, R. Testimony about V.C. Summer Nuclear Station. Atomic Safety and Licensing Board Hearings. Columbia, SC. Docket 50-3957, 1982.

Nuttli, O.W. Magnitude Recurrence Relations for Mississippi Valley Earthquakes. Bulletin of the Seismological Society of America, Vol. 64, No. 4, 1974.

Nuttli, O.W. Seismicity of the Central United States. In: Geology in the Siting of Nuclear Power Plants. Reviews in Engineering Geology, Vol. IV. Geological Society of America, 1979.

Nuttli, O.W. Instrumental Data. In: Nuttli, O.W.; Rodriquez, R. and Herrmann, R.B. Strong Ground Motion Studies for South Carolina Earthquakes. Prepared for U.S. Nuclear Regulatory Commission. NUREG/CR-3755, April, 1984.

Nuttli, O.W. Personal Communication with H. Acharya of SWEC. October 11, 1984a.

Nuttli, O.W., and Brill, K.G., Jr. Earthquake Source Zones in the Central United States Determined from Historical Seismicity. In: An Approach to Seismic Zonation for Siting Nuclear Electric Power Generating Facilities in the Eastern United States. U.S. Nuclear Regulatory Commission Report, NUREG/CR-1577, pp. 98-143, 1981.

Nuttli, O.W. and Herrmann, R.B. State-of-the-Art for Assessing Earthquake Hazards in the United States: Credible Earthquakes for the Central United States. Miscellaneous Paper S-73-1, Report No. 12. U.S. Army Engineers, Waterways Experiment Station, Vicksburg, MI., 1978.

Nuttli, O.W. and Hermann, R.B. Ground Motion of Mississippi Valley Earthquakes. Journal of Technical Topics in Civil Engineering, Vol. 110, No. 1. ASCE. May, 1984.

Schnabel, P.B.; Lysmer, J.; and Seed, H.B. SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites, Report EERC-72-12. University of California at Berkeley, 1972.

Seed, H.B. and Idriss, I.M. Soil Moduli and Damping Factors for Dynamic Response Analysis. Report EERC-70-10. College of Engineering, University of California at Berkeley, 1970.

Shannon and Wilson, Inc. and Agbabian Associates (SW-AA). Geotechnical Data from Accelerograph Stations Investigated During the Period 1975-1979, Summary Report. Prepared for U.S. Nuclear Regulatory Commission. NUREG/CR-1643, 1980.

Stone and Webster Engineering Corporation (SWEC). Report on the Soil Densification Program, Beaver Valley Power Station - Unit 2. Prepared for Duquesne Light Company, Pittsburgh, PA., 1976.

Stone and Webster Engineering Corporation (SWEC). Final Safety Analysis Report. Beaver Valley Power Station - Unit 2, 1983

Stone and Webster Engineering Corporation (SWEC). Seismic Design Response Spectra, Beaver Valley Power Station - Unit 2. Prepared for Duquesne Light Company, Pittsburgh, PA., June, 1984.

Trifunac, M.D. Stress estimates for the San Fernando, California Earthquake of February 9, 1971: Main Event and Thirteen Aftershocks. Bulletin of the Seismological Society of America, Vol. 62, No. 3, 1972.

APPENDIX 1

NUCLEAR REGULATORY COMMISSION

RESPONSE SPECTRA ACTION ITEMS

NUCLEAR REGULATORY COMMISSION RESPONSE SPECTRA ACTION ITEMS

The following action items were identified by the Nuclear Regulatory Commission (NRC) during its review of the Stone & Webster Engineering Corporation report discussing the reevaluation of the BVPS-2 horizontal and vertical design response spectra (SWEC, 1984).

From the August 16, 1984 notes of conference prepared by NRC:

1.0 Improve the site-specific rock spectrum by including additional strong motion rock records.

2.0 New attenuation laws are now available which differentiate between high magnitude and low magnitude earthquakes. This allows magnitude-specific amplification factors to be calculated. The applicant should compare these new data with those previously presented. (Reference: NUREG/CR-3755, "Strong Ground Motion Studies for South Carolina Earthquakes" by Nuttli, Rodriquez and Hermann, 1984).

3.0 Attempt to show that the soil records used are representative of the conditions at the BVPS-2 site by varying the rock properties while using a mean soil profile.

From the October 4, 1984 telephone conversation with the NRC:

4.0 Appalachian Plateau tectonic boundary and shallow earthquakes

4.1 The western boundary of the Appalachian Plateau tectonic province (as revised in the FSAR Amendment 4, Figure 2.5.1-5) was not defined well enough to exclude the November 1926 intensity VI - VII (MM) earthquake in southeastern Ohio from the Appalachian Plateau tectonic province.

4.2 Provide a more detailed discussion regarding the energy released by shallow earthquakes and the resulting damage effects on the BVPS-2 plant structures.

5.0 Vertical Response Spectra

Vertical response spectra should be computed from the suite of site matched ground surface records, and the mean vertical response spectrum should be compared with the mean horizontal spectrum. This is to justify the use of 2/3 as the ratio of the vertical to horizontal acceleration.

APPENDIX 2

SHALLOW EARTHQUAKES

SHALLOW EARTHQUAKES

Earthquakes with shallow focal depths, having lower magnitudes and smaller felt areas than other earthquakes with the same epicentral intensity, have occurred in the central United States. This type of earthquake has occurred within 200 miles of the BVPS-2 site and within the Appalachian Plateau tectonic province in which the site is located. Similar earthquakes could occur in the future in the vicinity of BVPS-2, but the occurrence of this type of earthquake is infrequent and the resulting ground motions are not expected to present a seismic hazard to the BVPS-2 plant structures.

The purpose of this appendix is to discuss the probable occurrence of shallow earthquakes near the BVPS-2 site, the energy release of these events and the resulting effects on plant structures.

Nuttli and Brill (1981) have identified a special class of earthquakes that occur in the central United States. These earthquakes have lower magnitudes and smaller felt areas than other earthquakes with the same epicentral intensity. An example of this type of event is the 1965 Illinois earthquake with an epicentral intensity of VII (MM), a radius of perceptibility of about 25 km and a computed magnitude of 3.8. By comparison, a more normal event such as the 1968 Illinois earthquake, which also had an epicentral intensity of VII (MM), had a radius of perceptibility of 500 km and a computed magnitude of 5.5. Theoretical studies by Herrman and Nuttli (1975) showed that the anomalous characteristics of this class of earthquakes are the result of shallow (<3 km) focal depths. Earthquakes with focal depths of less than 3 km strongly excite fundamental mode, high frequency surface waves that attenuate rapidly with distance, while these same waves are not excited by earthquakes with greater focal depths.

Nuttli and Brill (1981) thoroughly examined historical earthquakes in the central United States and identified 59 events as having shallow focal depths. Thirty-five of these events occurred in the principle earthquake zones previously identified by Nuttli (1979), and twenty-four did not. The distribution of shallow earthquakes in the central United States is, therefore, similar to the distribution of normal focal depth earthquakes, in that a significant fraction occur outside the principle seismic zones and might occur anywhere in the central United States.

The rate of occurrence of shallow earthquakes is extremely low (Nuttli, 1982). Out of about 1,200 earthquakes in the central United States with $m_b \geq 3.0$ (felt events), only 59 have been identified as shallow events. Similarly, the earthquake catalog for BVPS-2 (FSAR Table 2.5.2-2) lists about 230 events within 200 miles of the site, but only 10 of these are considered to have been shallow events (Table A2-1).

BVPS-2 is located in the Appalachian Plateau tectonic province, an area of low seismicity, with very few normal focal depth earthquakes reported in the vicinity of the site (Figure 2-1). The number of shallow earthquakes presumed to have occurred within the Appalachian Plateau tectonic province is extremely low (Figure A2-1). Shallow earthquakes occurring in other tectonic provinces near the site would not be felt at the site because of the very small felt areas for these events.

Historical seismicity suggests an average rate of approximately one shallow earthquake every forty years in the Appalachian Plateau tectonic province. Nuttli and Brill (1981) showed that shallow earthquakes in the central United States are not felt beyond 20 to 25 km from the epicenter, so although a shallow earthquake could occur within the Appalachian Plateau tectonic province, the likelihood of it being felt at the BVPS-2 site is extremely low.

The highest intensity shallow earthquake that occurred in the Appalachian Plateau tectonic province was an intensity VI (MM) event, occurring in 1900, with a body-wave magnitude of 3.8. An intensity VI-VII (MM) shallow earthquake occurred in southeastern Ohio in 1926. This earthquake had a body-wave magnitude of 3.4 and a felt-area of only 350 sq mi, which suggests that is was not felt beyond about 10 miles from the epicenter. This earthquake occurred within the Central Stable Region tectonic province, but close to the common boundary with the Appalachian Plateau tectonic province. To be conservative, the effect on an intensity VI-VII (MM) earthquake, with a magnitude of 3.8, occurring near the BVPS-2 site has been evaluated.

The entire data base for the eastern United States that might be used for the prediction of ground motion from shallow earthquakes is the strong motion records for four earthquakes near Monticello reservoir in South Carolina. The first of these earthquakes occurred in August 1978. This earthquake had a body-wave magnitude of 2.8 and was assigned an epicentral intensity of V (MM). The accelerograph recorded a peak ground acceleration of 0.25 g and a duration of one-half second of strong ground shaking. This was the highest value of peak ground acceleration recorded in the eastern United States up to that time. The earthquake of October 1979 in this vicinity however produced records with peak ground acceleration of 0.35 g and a duration of one second. The magnitude of this earthquake was also 2.8.

Analysis of these strong motion records indicated that the peak accelerations occurred as high frequency spikes of short duration and therefore did not represent a significant energy input to typical power plant structures (McGuire, 1982). Brady et al (1981) found the records had frequencies as high as 25 and 30 Hz. One component of the record for the August, 1978 earthquake had the peak acceleration at a frequency of 33 Hz, and an aftershock of this earthquake recorded the peak acceleration at 40 Hz. Furthermore, these strong motion records may be inappropriate to characterize ground motion from shallow earthquakes for design purposes because soil amplification studies showed that the sapprolite underlying the accelerograph amplified the ground motion at certain frequencies (McGuire, 1982). Also, field evidence suggests that the interaction of soil and the concrete accelerograph foundation produced significant amplification of high frequencies.

The Fairfield Pumped Storage Facility is located within 1 to 2 km of the earthquake epicenters, and is closer to the epicenters than the strong motion instrument, but it was not damaged by either the 1978 or 1979 earthquake. The lack of damage to this facility is particularly significant because it was not designed or constructed to the same high seismic design standards used for nuclear power plants (McGuire, 1982). The V.C. Summer Nuclear Station, which is approximately 8 km from the epicenters of these events was not damaged either.

The lack of correlation between the high peak accelerations recorded for these shallow events and damage to any facility within one or two kilometers of the epicenter shows that high accelerations by themselves are not an indication of damage potential. The high frequency spikes do not contain sufficient energy to overcome the inertia of large structures, and thus do not affect structural response. Damage to structures comes predominantly from long duration shaking and not from one or two high frequency, high acceleration, short duration pulses which represent only small impulsive excitations (Trifunac, 1972).

Murphy and O'Brien (1977) developed an empirical relationship between intensity and acceleration on the basis of data from earthquakes in the western United States and southern Europe. Nuttli (1979) observed that ground motion attenuation for shallow earthquakes in the eastern United States is as rapid as attenuation for western United States earthquakes. Therefore, the Murphy and O'Brien (1977) empirical intensity-acceleration relationship might be applicable to shallow eastern United States events. Their relationship predicts a peak acceleration of 0.08g for the epicentral intensity VI-VII shallow earthquake being evaluated.

Nuttli and Herrmann (1984) used a semi-theoretical approach to compute ground accelerations for a shallow earthquake which occurred in Illinois in 1965. This earthquake had an body-wave magnitude of of 3.8, a focal depth of 1.5 km, an epicentral intensity of VII (MM) and an intensity of III (MM) at an epicentral distance of 15 km. They used the relationship:

$$\log a_h = 0.57 + 0.50\, m_b - 0.83 \log (R^2 + h^2)^{1/2} - 0.00069R \qquad \text{(EQ A2-1)}$$

where: a_h is the peak horizontal acceleration in cm/sec^2
m_b is the body wave magnitude
R is the epicentral distance in km
h is the focal depth in km

The computed values of acceleration as a function of epicentral distance for this event are shown in Figure A2-2, and can be compared to the peak acceleration values determined from the observed intensities according to the Murphy and O'Brien (1977) relationship. Nuttli and Herrmann (1984) used the relationship given by Equation A2-1 even though they indicate it is only valid for $m_b \geq 4.5$. Nuttli (1984) suggested that the following relationship be used for earthquakes with $m_b < 4.5$.

$$\log a_h = 0.57 + 0.25\, m_b - 0.83 \log (R^2 + h^2)^{1/2} - 0.00069R \qquad \text{(EQ A2-2)}$$

where the variables are as defined for Equation A2-1.

Computed acceleration values from Equation A2-2 are also shown in Figure A2-2. The three relationships shown in Figure A2-2 indicate a wide variation in computed peak accelerations for the same shallow earthquake, demonstrating the difficulty in predicting peak ground motion for shallow earthquakes. In fact, the data base used to develop Equations A2-1 and A2-2 was limited to the normal focal depth earthquakes and their application to shallow earthquakes may not be valid.

As discussed previously, the largest magnitude shallow earthquake to have occurred in the Appalachian Plateau tectonic province had a body-wave magnitude of 3.8. If a similar event should occur at the BVPS-2 site, with a median focal depth of 1.5 km (midway between 0 and 3 km), the predicted peak accelerations from Equations A2-1 and A2-2 are 0.214g and 0.024g, respectively.

Appsel et al (1983) attempted to estimate theoretically the ground motion from earthquakes with focal depths between 0 and 16 km using a sophisticated three-dimensional modeling procedure. However, their study is not directly applicable for estimating strong ground motion for shallow earthquakes at the BVPS-2 site, since the smallest event they considered had a magnitude of 4.5. This is significantly higher than the magnitude 3.8 shallow focus event being evaluated for BVPS-2. Also, Appsel et al (1983) computed response spectra for shallow earthquakes for epicentral distances of up to 35 km for stiff soil sites. Comprehensive investigation by Nuttli and Brill (1981) show that shallow earthquakes in the eastern United States are not felt beyond 20-25 km from the epicenter.

Shallow earthquakes can occur in the vicinity of the BVPS-2 site, although the likelihood of such an occurrence is extremely low. However, if a shallow earthquake with a magnitude of 3.8 or an intensity of VI-VII (MM) occurred at the BVPS-2 site, predicted peak accelerations range from 0.024g to 0.214g, depending on which earthquake-acceleration relationship is used. Experience with eastern United States shallow earthquakes has shown, however, that these high peak accelerations are associated with high frequency, short duration ground motions which do not damage large seismically designed structures. The BVPS-2 design acceleration of 0.125g is based on a normal focal depth earthquake, and consequently plant design is conservative for the effects of shallow earthquakes.

APPENDIX 2

REFERENCES

Appsel, R.J.; Hadley, D.M.; and Hart, R.S. Effects of Earthquake Rupture Shallowness and Local Soil Conditions on Simulated Ground Motions. Report prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-3102, 1983.

Brady, A.G.; Mork, P.N.; and Fletcher, J.P. Processed Accelerograms from Monticello Dam, Jenkinsville, South Carolina, August 27, 1975 and Later Shocks. USGS Open File Report 81-448. March 1981.

Fletcher, J.B. A Comparison Between the Tectonic Stress Measured In Situ and Stress Parameters from Induced Seismicity at Monticello Reservoir, South Carolina. Journal of Geophysical Research, Vol. 87, No. B8, pp. 6931-6944, 1982.

Herrmann, R.B., and Nuttli, O.W. Ground-Motion Modelling at Regional Distances for Earthquakes in a Continental Interior, II. Effect of Focal Depth, Azimuth, and Attenuation. International Journal of Earthquake Engineering and Structural Dynamics, Vol. 4, pp. 59-72, 1975.

McGuire, R. Testimony about V.C. Summer Nuclear Station. Atomic Safety and Licensing Board Hearings, Columbia, SC. Docket 50-395T, 1982.

Murphy, J.R., and O'Brien, L.J. The Correlation of Peak Ground Acceleration Amplitude with Seismic Intensity and Other Physical Parameters. Bulletin of the Seismological Society of America, Vol. 67, No. 3, pp. 877-915, 1977.

Nuttli, O.W. Instrumental Data. Contained in Nuttli, O.W.; Rodriguez, R.; and Herrmann, R.B. Strong Ground Motion Studies for South Carolina Earthquakes. Nuclear Regulatory Commission, NUREG/CR-3755. April 1984.

Nuttli, O.W., and Brill, K.G., Jr. Earthquake Source Zones in the Central United States Determined from Historical Seismicity in An Approach to Seismic Zonation for Siting Nuclear Electric Power Generating Facilities in the Eastern United States. U.S. Nuclear Regulatory Commission Report NUREG/CR-1577, pp. 98-143, 1981.

Nuttli, O.W., and Herrmann, R.B. Strong Ground Motion Relations for Mississippi Valley Earthquakes. Paper presented at ASCE Meeting held in St. Louis, Missouri, October, 1981.

Nuttli, O.W., and Herrmann, R.B. Ground Motion of Mississippi Valley Earthquakes. Journal of Technical Topics in Civil Engineering, Vol. 110, No. 1, pp. 54-69, 1984.

Trifunac, M.D. Stress Estimates for the San Fernando, California Earthquake of February 9, 1971: Main Event and Thirteen Aftershocks, Bulletin of the Seismological Society of America, Vol. 62, No. 3, pp. 721-750, 1972.

TABLE A2-1
VERY SHALLOW EARTHQUAKES
WITHIN 200 MILES OF
BEAVER VALLEY POWER STATION

Date	Time	Latitude °N	Longitude °W	I_o (MM)	m_b	Source
08/17/1877	16:50	42.3	83.3	IV-V	3.2	CSR
04/09/1900	14:00	41.4	81.8	VI	3.8	APP
06/27/1906	12:10	40.4	81.6	V	3.4	APP
11/05/1926	15:53	39.1	82.1	VI-VII	3.4	CSR
09/30/1930	20:40	40.3	84.3	VII	4.2	Anna, Ohio
01/22/1932		41.1	81.5	V	3.6	APP
05/26/1955	18:09	41.5	81.7	IV-V	3.6	APP
06/29/1955	01:16	41.5	81.7	IV	3.6	APP
01/01/1966	13:23	42.8	78.2	VI	4.6	Clarendon Linden
06/13/1967	19:08	42.9	78.2	VI	4.4	Clarendon Linden

CSR - Central Stable Region
APP - Appalachian Plateau Province

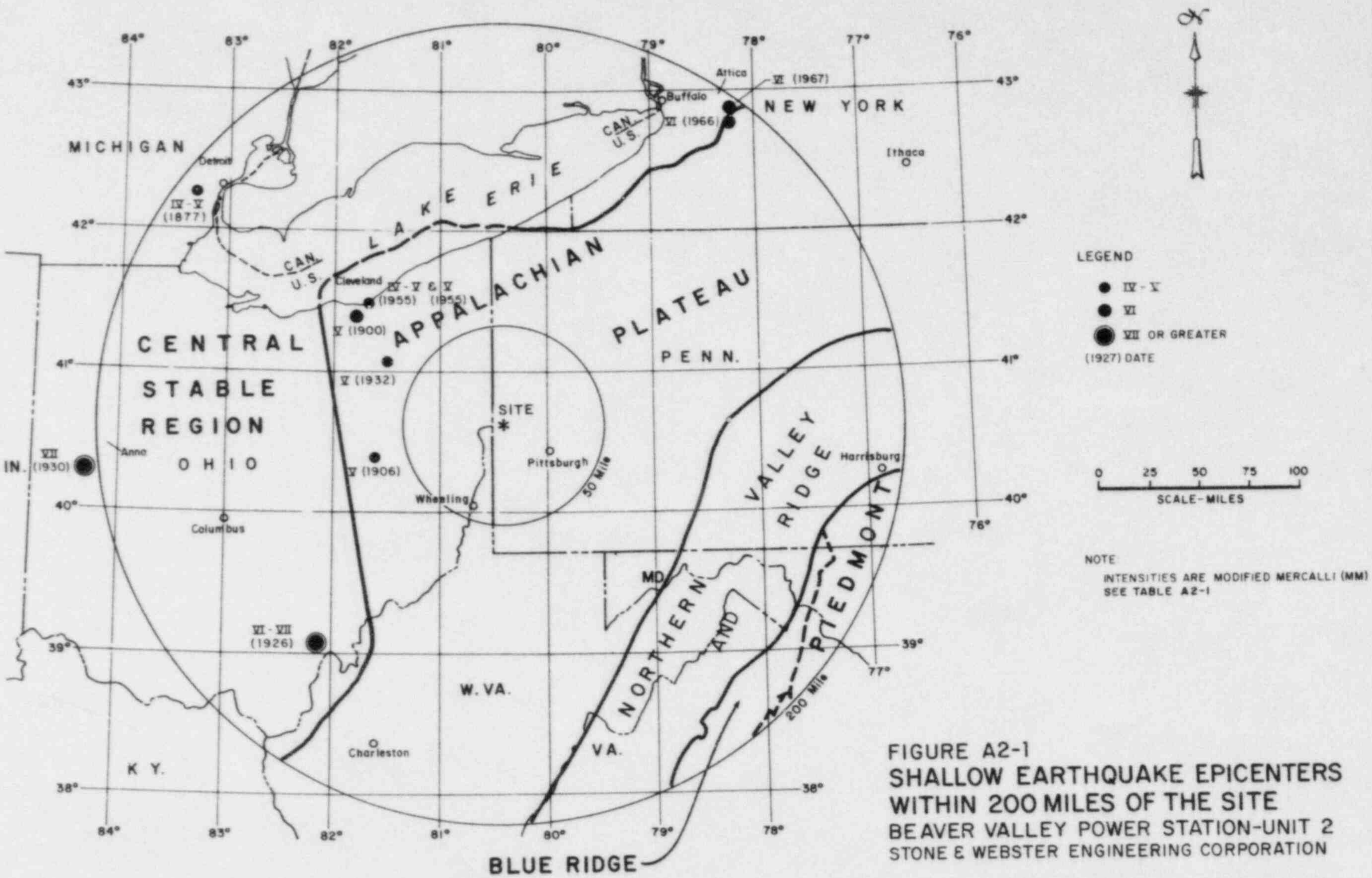
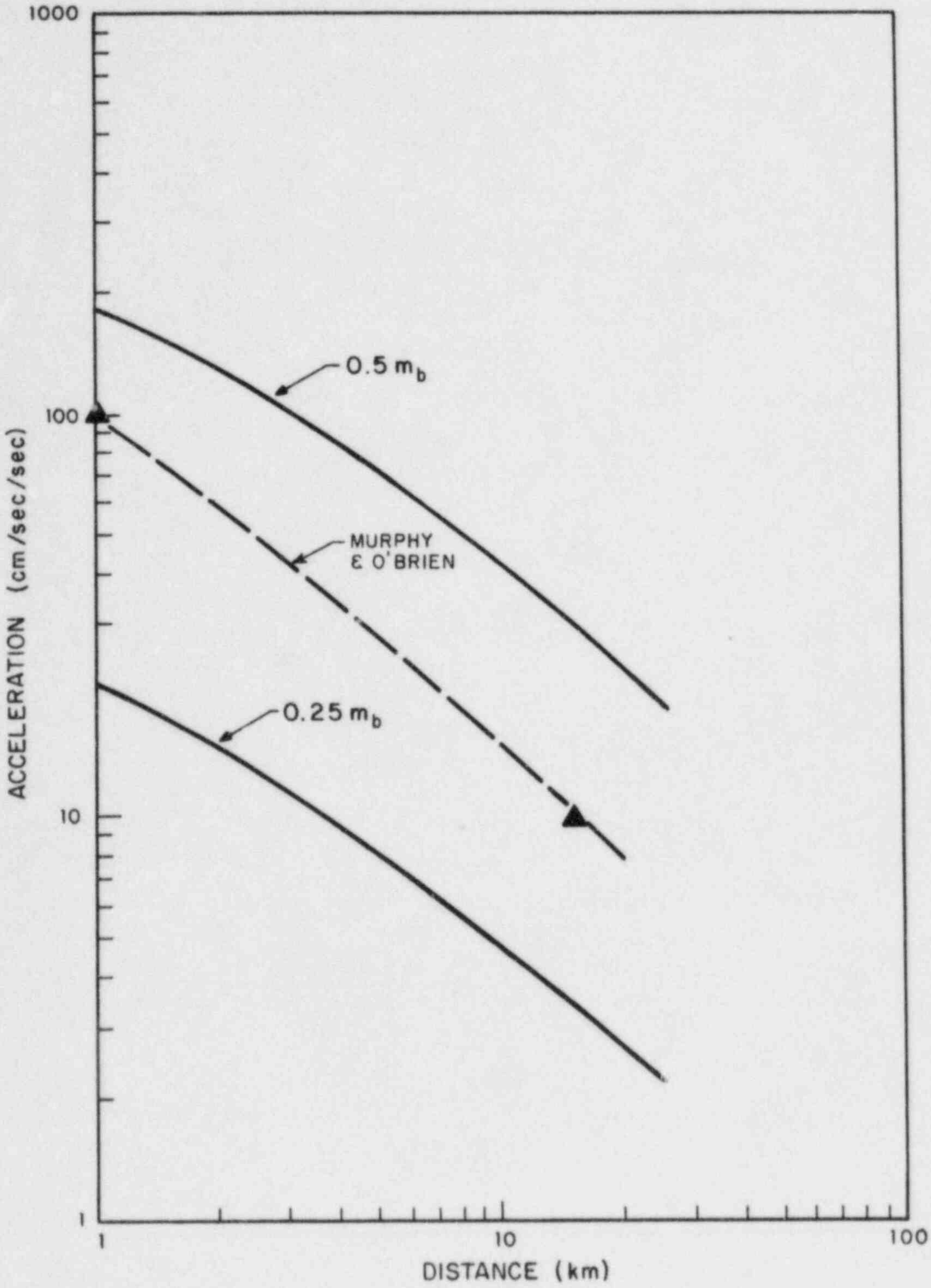


FIGURE A2-1
SHALLOW EARTHQUAKE EPICENTERS WITHIN 200 MILES OF THE SITE
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION



LEGEND:

▲ ACCELERATIONS DETERMINED FROM OBSERVED INTENSITIES AND MURPHY & O'BRIEN (1977) RELATIONSHIP

NOTE:

DATA FROM NUTTLI & HERRMANN (1984)

FIGURE A2-2

ACCELERATION VS DISTANCE FOR 1965 ILLINOIS EARTHQUAKE

BEAVER VALLEY POWER STATION-UNIT 2

STONE & WEBSTER ENGINEERING CORPORATION

APPENDIX 3

SHEAR WAVE VELOCITY CONTRAST
SITE MATCHED RECORDING STATIONS

SHEAR WAVE VELOCITY CONTRAST
SITE MATCHED RECORDING STATIONS

General

This appendix provides a summary of the evaluation of velocity contrast ratios at the recording stations selected as site matched to BVPS-2 and used in the site matched response spectra analyses presented in Section 3.

The velocity contrast ratio is defined as the shear wave velocity of the rock or of a rock-like base layer divided by the shear wave velocity of the immediately overlying soil layer. Table A3-1 is a summary of the velocity contrast ratios determined for each of the site matched recording stations. Available soil profile and shear wave velocity data at each of the stations are shown in Figures A3-1 through A3-6.

Alexander Building, San Francisco, California

The bedrock underlying the station is the Franciscan Assemblage. From measurements made at Golden Gate Park in San Francisco, its shear wave velocity is estimated to be 3000 ft/sec (Appendix 3, SWEC, 1984). The shear wave velocity of the soil directly overlying the rock is about 1600 ft/sec, which gives a velocity contrast ratio of 1.9.

State Building, San Francisco, California

The bedrock underlying the station is the Franciscan Assemblage with a shear wave velocity of 3000 ft/sec. Shear wave velocity measurements extend to a depth of about 100 ft, but the top of the rock is at a depth of 211 ft. Assuming that the shear wave velocity at the 100 ft depth of 1600 ft/sec remains relatively constant for the rest of the soil profile gives a velocity contrast ratio of 1.9.

City Hall, Oakland, California

The shear wave velocity profile for the first 91 ft matches BVPS-2 very well; no data are provided below 91 ft. Seed and Idriss (1969) developed a soil profile model at this station showing a very dense, hard clay below 91 ft that extends to a depth of 1000 ft. The shear modulus of the soil layer above the clay was estimated to be 4.75×10^6 psf and the shear modulus of the clay was estimated to be 36×10^6 psf. Clearly, there is a significant velocity contrast at a depth of 91 ft. The ratio of the shear wave velocities of the layers are approximately equal to the ratio of the square root of the shear moduli, which gives a velocity contrast ratio of 2.8.

Old Ridge Route, Castaic, California

The shear wave velocity profile at the station indicates a very weathered sandstone to a depth of about 70 ft, at which the shear wave velocity abruptly increases, indicating a more competent, rock like, material. The velocity contrast at this depth is about 2.0.

6074 Park Drive, Wrightwood, California

The soil at the station is described as a silty, sandy gravel and is classified as Quarternary Alluvium. Shear wave velocity data at the station are not available, but from measurements made at other recording stations in the Los Angeles area, the average shear wave velocity of the Quarternary Alluvium is about 1200 ft/sec (SW-AA, 1980). Assuming that the shear wave velocity of the rock is 3000 ft/sec gives an estimated velocity contrast ratio at this station of 2.5.

Federal Building, Eureka, California

The soil profile at the station consists of about 350 ft of Quarternary and Pleistocene sediments. According to SW-AA (1979), the Hookton formation is estimated to have a maximum thickness of 400 ft in the Eureka area, so it is likely that the boring was terminated at the top of rock. The bedrock in the Eureka area is of the Franciscan Assemblage (SW-AA, 1979).

At a depth of between 120 ft and 140 ft there is an increase in shear wave velocity from about 1250 ft/sec to 2000 ft/sec. Experience has shown that for a soil profile such as this, only the upper 100-150 ft of soil is a significant contributor to the amplified response at the ground surface. Therefore, it may be appropriate to consider that the soil profile is truncated at the level of the first velocity contrast. At this depth, the velocity contrast ratio is 1.6.

At the 350 ft depth, the shear wave velocity of the soil is 2000 ft/sec. Assuming that the shear wave velocity of the Franciscan Assemblage rock is 3000 ft/sec gives a velocity contrast ratio at the top of rock of 1.5.

APPENDIX 3

REFERENCES

Seed, H.B. and Idriss, I.M. Influence of Soil Conditions on Ground Motions During Earthquakes. Journal of the Soil Mechanics and Foundations Division, ASCE. Vol 95, No. SM1, January, 1969.

Shannon and Wilson and Agbabian Associates (SW-AA). Geotechnical Data from Accelerograph Stations Investigated During the Period 1975-1979, Summary Report. Prepared for the U.S. Nuclear Regulatory Commission. NUREG/CR-1643, 1980.

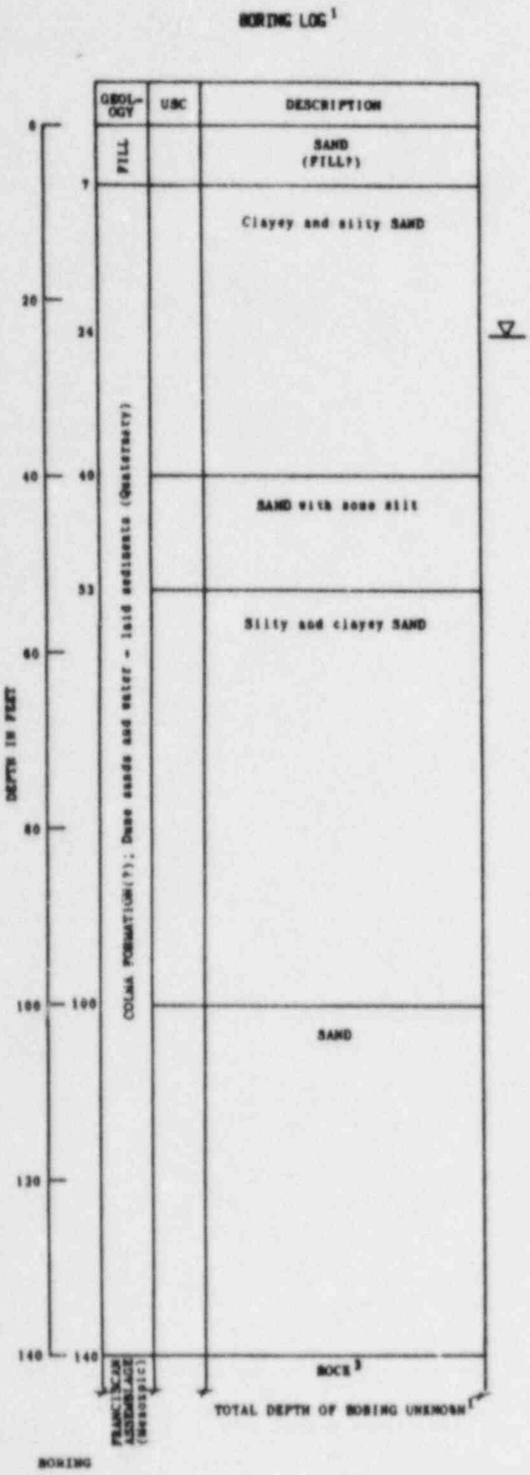
Stone & Webster Engineering Corporation (SWEC). Seismic Design Response Spectra, Beaver Valley Power Station - Unit 2. Prepared for Duquesne Light Company, Pittsburgh, PA., June, 1984.

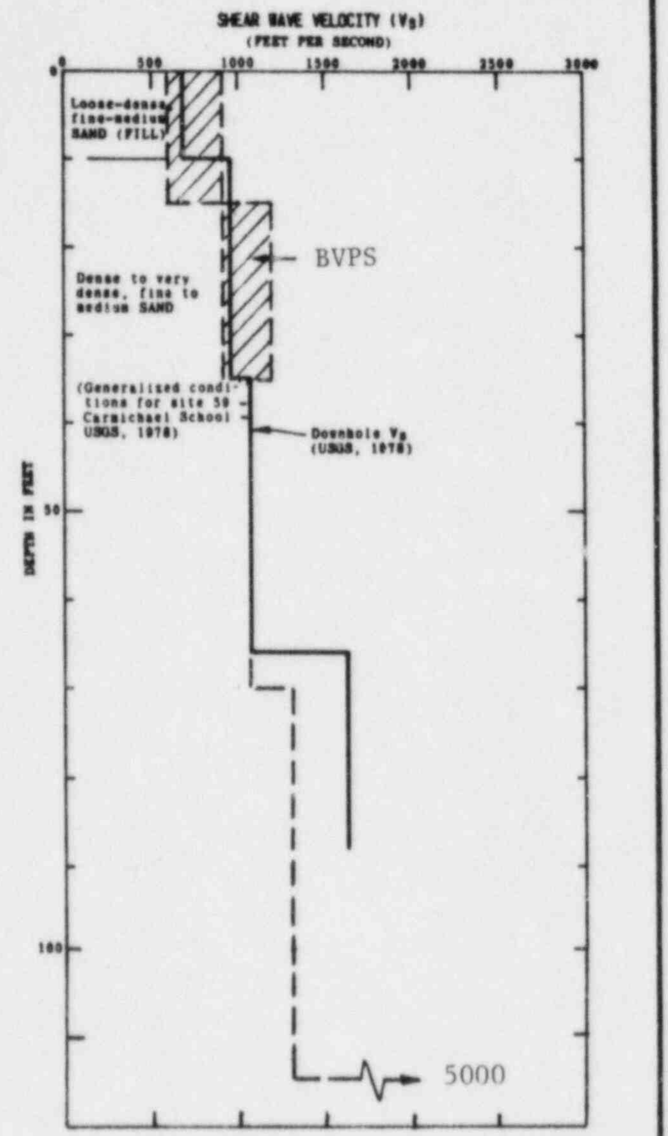
TABLE A3-1

VELOCITY CONTRAST RATIOS

SITE MATCHED RECORDING STATIONS

Station Name	Velocity Contrast Ratio
Alexander Building San Francisco, CA	1.9
State Building San Francisco, CA	1.9
City Hall Oakland, CA	2.8
Old Ridge Route Castaic, CA	2.0
6074 Park Drive Wrightwood, CA	2.5
Federal Building Eureka, CA	1.5-1.6





NOTES:
1) Source of boring information not identified in Seed and Idriss (1969)
2) About 10 feet of fill underlies the site (USGS, unpub.).
3) Bedrock is at Elevation -100 ft. (depth of 135 ft.) based on Schlocker (1974). Depth to bedrock is quite variable in the site area.

BORING

Elevation:	Approximately 35 feet MSL (USGS Topographic Quad.)
Data Source:	Seed and Idriss (1969)[1]

VELOCITIES

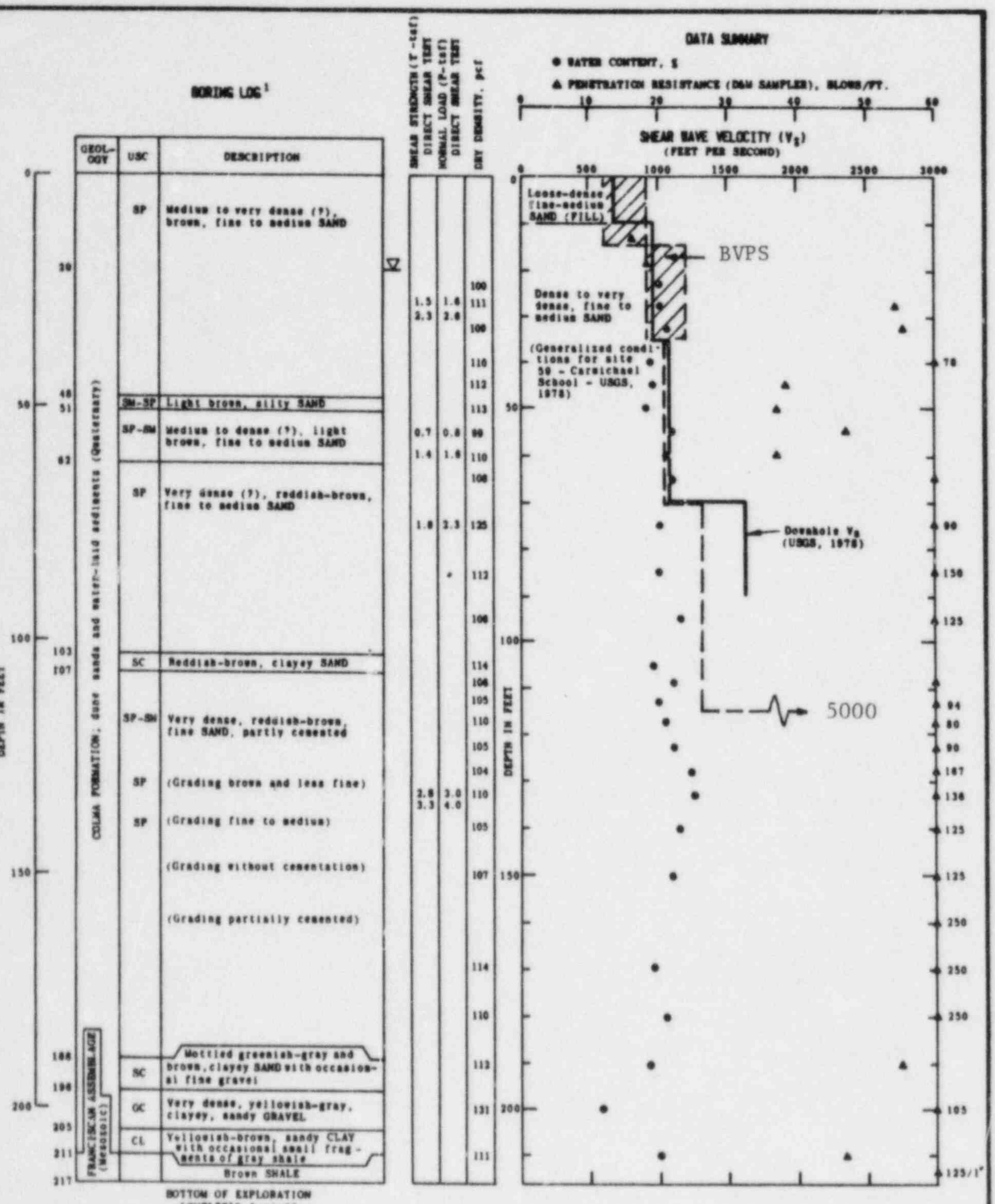
Source:	USGS (1977, 1978)
Location:	Site 59, Carmichael School (CAR) 5300 feet south-southwest of Alexander Building.
Date:	May 6, 1976

REPORT: SW-AA (1977b)

BUILDING: The Alexander Building (155 Montgomery) is a 16-story high-rise with a basement. The lowest level accelerograph is in the basement, about 10 feet below grade.

SUMMARY LOG
ALEXANDER BUILDING
SAN FRANCISCO, CALIFORNIA

FIGURE A3-1



BOTTOM OF EXPLORATION
COMPLETED 8/11/58

BORING

Elevation: 67.6 feet

Location: East side of Polk Street, between Turk Street and Golden Gate Avenue. Approximately 300 feet North of State Building.

Data Source: Dames & Moore, 1958 Foundation Investigation for Federal Building Boring No. 4 in report (reprinted in Woodward - Lundgren & Assoc., 1973).

VELOCITIES

Source: USGS (1977 and 1978)

Location: Site 59, Carmichael School (CAR) 4000 feet southeast of State Building.

Date: May 6, 1976

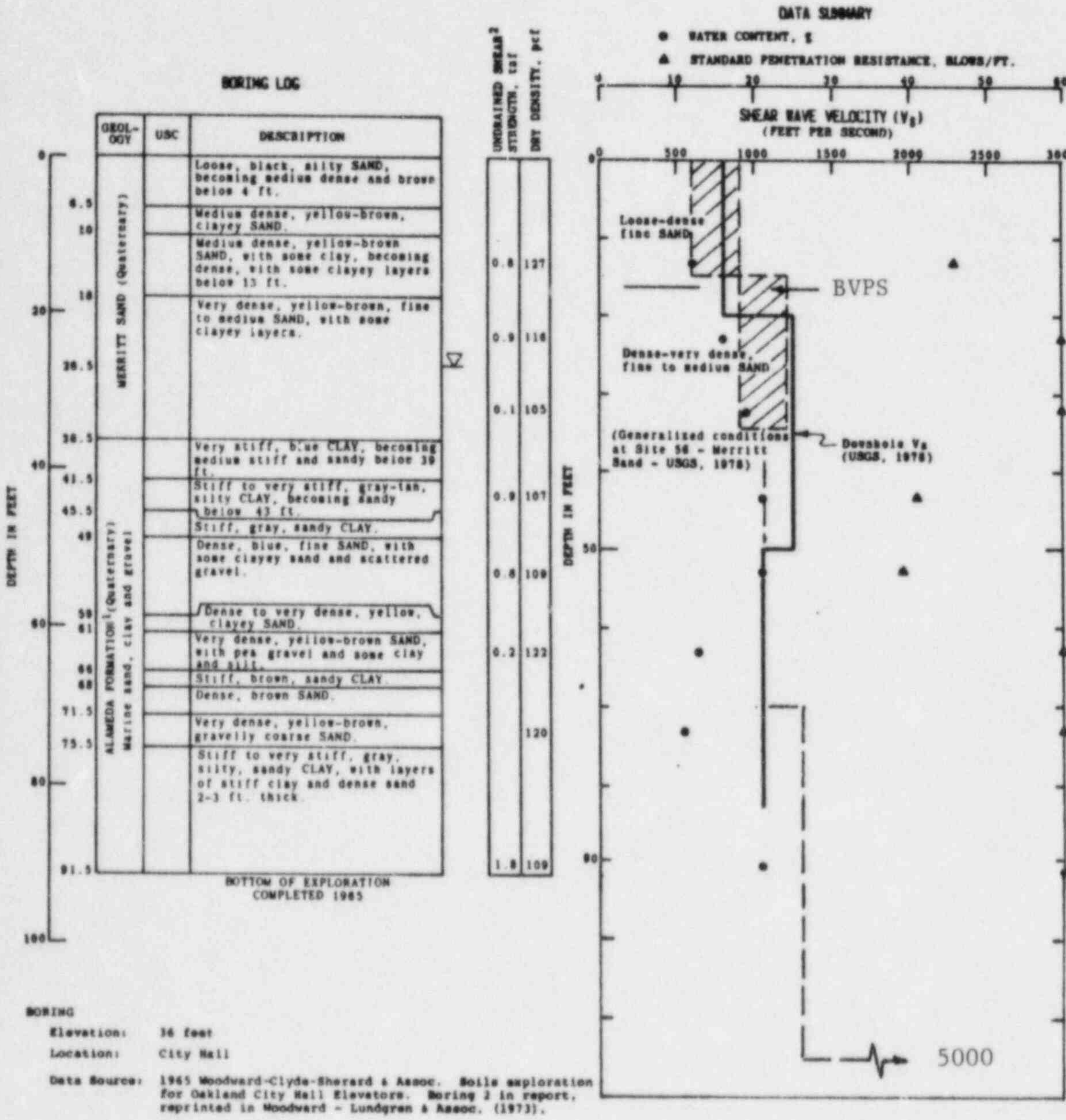
REPORT SW-AA (1977b)

BUILDING The State Bldg. (350 McAllister) is a 7-story structure with a basement (extends about 10 feet below grade) where the accelerograph was located.

NOTE: 1) Depth to bedrock in the vicinity of the State Bldg. is quite variable (Schlocker, 1974).

SUMMARY LOG
STATE BUILDING
SAN FRANCISCO, CALIFORNIA

FIGURE A3-2



BORING

Elevation: 36 feet

Location: City Hall

Data Source: 1965 Woodward-Clyde-Sherard & Assoc. Soils exploration for Oakland City Hall Elevators. Boring 2 in report, reprinted in Woodward - Lundgren & Assoc. (1973).

VELOCITIES

Source: USGS (1977, 1978)

Location: Site 56, Merritt Sand (MER, MS) 2500 feet northwest of Oakland City Hall.

Date: May 3, 1976

REPORT SW-AA (1977b)

BUILDING The Oakland City Hall (1421 Washington Street) is a 15-story structure with a basement. The lowest level accelerograph is in the basement, about 10 feet below grade.

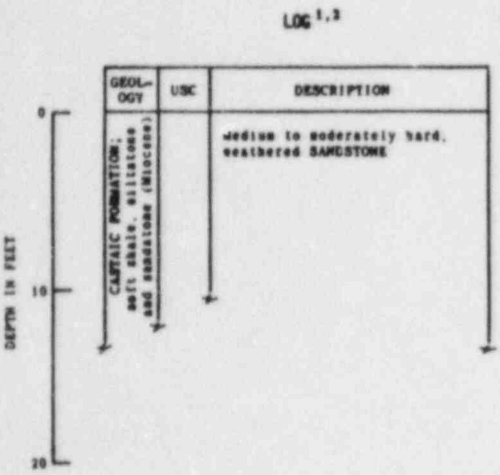
NOTES:

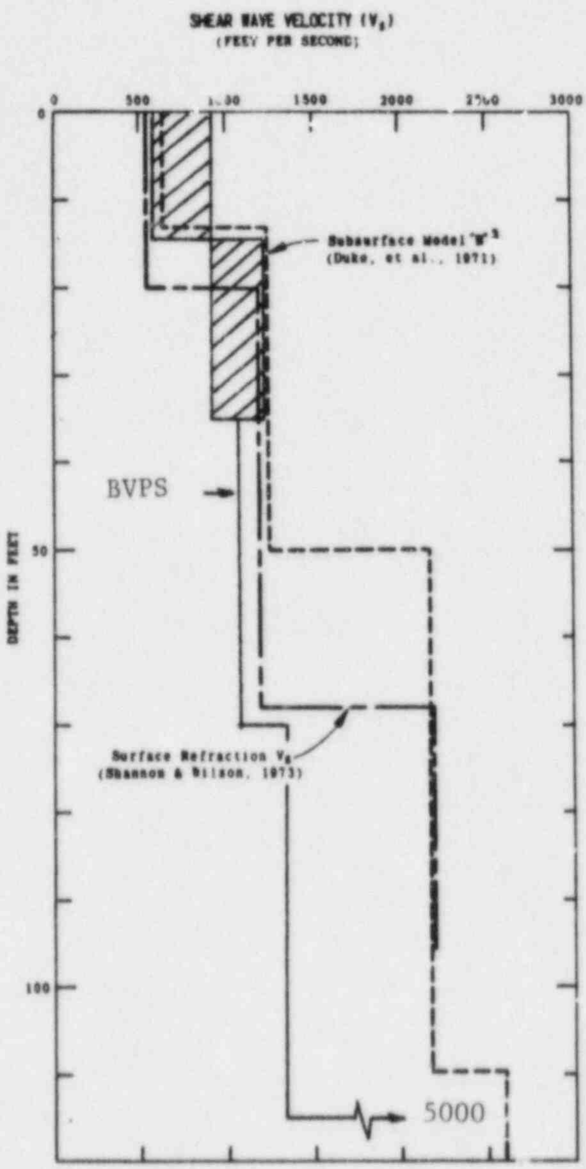
1) The upper section of the Alameda Formation consists of sandy, silty clay. The lower part consists of continental and marine sand, clay and gravel. Maximum known thickness, 1,050 feet. (Woodward-Lundgren and Associates, 1973).

2) Shear strengths are assumed to correspond to U-U tests run at overburden pressure.

SUMMARY LOG
CITY HALL
OAKLAND, CALIFORNIA

FIGURE A3-3





VELOCITIES

Data Source: Shannon & Wilson, Inc. (1973)

Location: Two perpendicular lines intersecting at Southeast Corner of Accelerograph Station[2]

Date: September 1973

Results: Indicated V_s values are the averages from the two lines

- Duke, et al. (1971); Site No. 27, subsurface model "B"
- 700 feet Northwest of Accelerograph Station (line elevation 2475 feet, MSL)
- October 4, 1971

REPORT SW-AA (1977b)

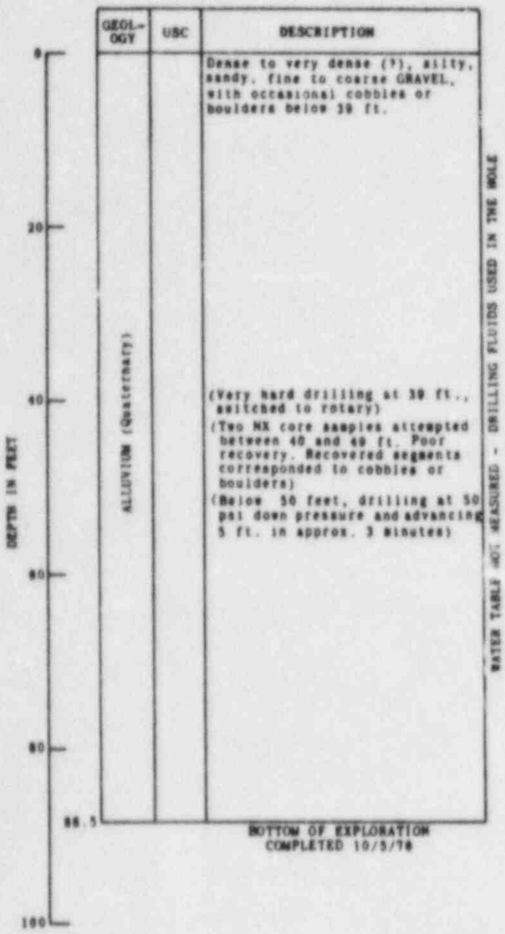
BUILDING The accelerograph, originally located in a small instrument shelter founded at grade, has been relocated to Castaic Dam.

NOTES:
1) No borings were made at the site. Material denoted on log corresponds to that observed during our site reconnaissance (SW-AA, 1977b).
2) Surface elevation approximately 2560 feet, MSL (USGS topographic quad.).
3) Velocities based on refraction measurements to 50 feet. Below 50 feet, velocities were estimated based on site geology.

SUMMARY LOG
OLD RIDGE ROUTE
CASTAIC, CALIFORNIA

FIGURE A3-4

BORING LOG[1]



BORING

Elevation:	Approximately 5910 feet, MSL (USGS topographic quad.)
Location:	15 feet from accelerograph station
Data Source:	SW-AA (1977b)
Equipment:	Mobile B-61 hollow stem auger Augered 0-39 feet sampling only cutting returns. Switched to rotary below 39 feet and sampled cutting returns and attempted 2-NX cores between 40 and 49 feet.

VELOCITIES: Not Available

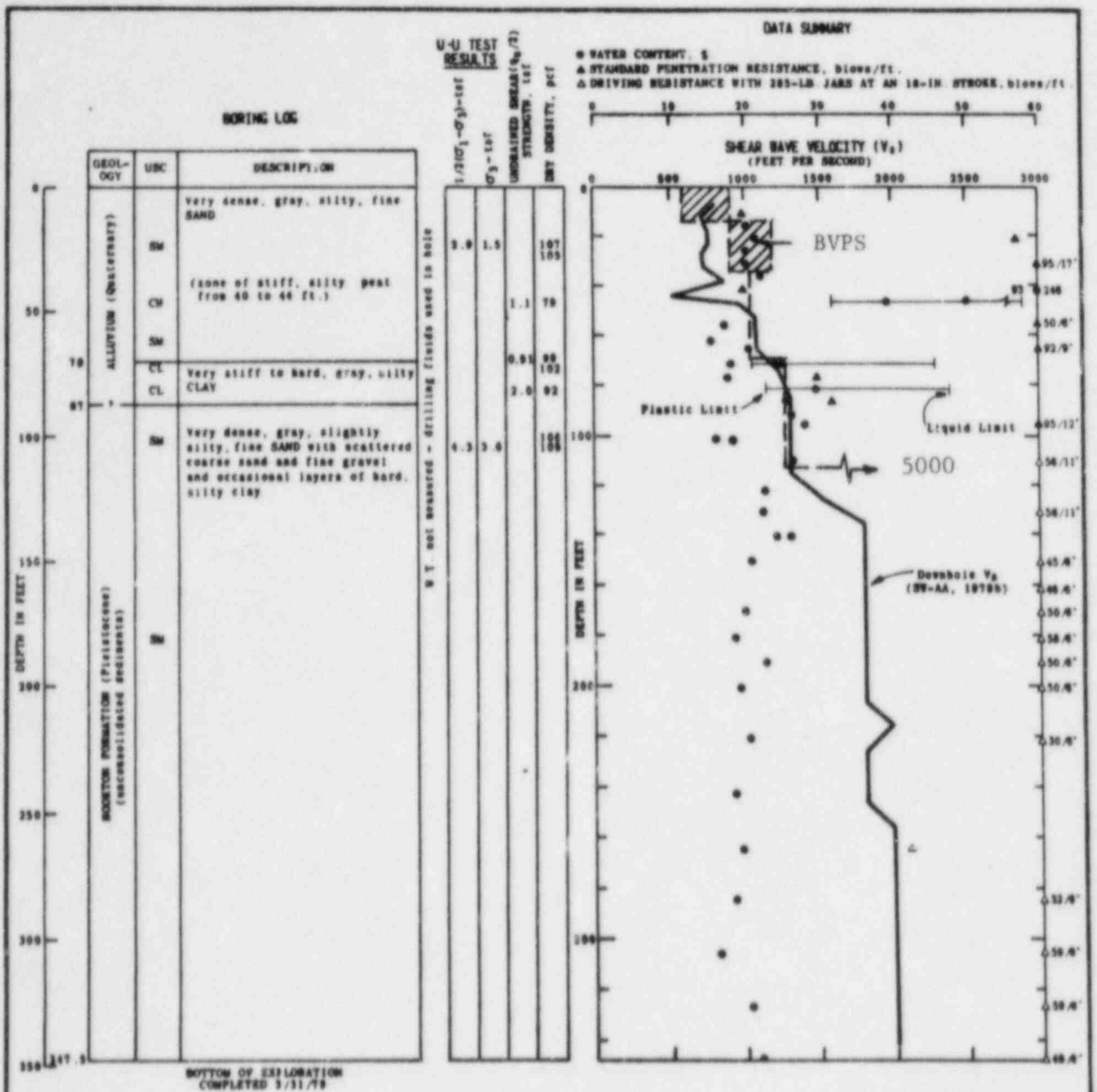
REPORT: SW-AA (1977b)

BUILDING: Although the station has been discontinued, the accelerograph at the United California Bank Building (6074 Park Drive) was located in the daylight basement (grade level) of a one story structure.

NOTE: 1) Bedrock was not encountered within the depth of the boring.

SUMMARY LOG
6074 PARK DRIVE
WRIGHTWOOD, CALIFORNIA

FIGURE A3-5



BORING

Elevation:	40 feet, MSL (interpolated from USGS topo quad)
Location:	12 feet south of the Federal Building
Data Source:	BW-AA (1979b)
Equipment:	Failing 1500 rotary drill; sampling with a 2" O.D. split spoon drive barrel and a Pitcher barrel.

VELOCITIES

Source:	BW-AA (1979b)
Location:	Downhole testing performed in above boring
Date:	May 31, 1979

REPORT BW-AA (1977b, 1979b)

BUILDING The Federal Building (500 "B" St.) is a three-story structure with one basement. The accelerograph is located in the basement, about 10 feet below grade.

SUMMARY LOG
FEDERAL BUILDING
EUREKA, CALIFORNIA

FIGURE A3-6

APPENDIX 4

EARTHQUAKE, RECORDING STATION, AND CORRECTED ACCELEROGRAM DATA

EARTHQUAKE, RECORDING STATION AND CORRECTED ACCELEROGRAM DATA

General

This appendix provides the information and data, with references, for the earthquakes and recording stations which are summarized in Table 4.3. It also provides data on the corrected accelerograms which were utilized in the soil response analysis discussed in Section 4, and shown on Tables 4.4 and 4.5.

Earthquake and Recording Station Data

The data and information for the earthquakes and recording stations summarized in Table 4.3 are provided in numerical order, with the numbers corresponding to the reference numbers of Table 4.3.

No. 1 Helena, Montana

The October 31, 1935, Helena, Montana earthquake occurred at 11:38 Mountain Standard Time. It had a Richter magnitude of 6.0 and an epicentral location of 46.62° north latitude and 112.0° west longitude (SW-AA, 1980a). This event was recorded at the Federal Building accelerograph station, located at 46°35'23" north latitude and 112°02'25" west longitude, at an epicentral distance of 4 mi (6.4 km) (SW-AA, 1980a). Kanamori and Jennings (1978) have calculated a local magnitude of 5.30 and 5.70 for the north-south and east-west components of this event, respectively, and an epicentral distance of 5.0 km. The subsurface conditions at this station consist of weathered Precambrian limestone (SW-AA, 1980a). It should be noted that this earthquake record is attributed to the Carroll College seismograph station by Trifunac et al, (1975); however, the Carroll College Station was not established until June 1940, when the accelerograph was removed from the Federal Building and installed on the Carroll College campus (SW-AA, 1980a).

No. 2 Helena, Montana

The October 31, 1935, Helena, Montana earthquake occurred at 12:18 Mountain Standard Time. It had an epicentral location of 46.62° north latitude and 112.0° west longitude and no reported magnitude (SW-AA, 1980a). This event was recorded at the Federal Building accelerograph station, located at 46°35'23" north latitude and 112°02'25" west longitude, at an implied epicentral distance of 4 mi (6.4 km) (SW-AA, 1980a). Kanamori and Jennings (1978) have calculated a local magnitude of 4.05 and 3.90 for the north-south and east-west components of this event, respectively, and an epicentral distance of 5.0 km. The subsurface conditions for this station consist of weathered Precambrian limestone (SW-AA, 1980a).

No. 3 Helena, Montana

The November 21, 1935, Helena, Montana earthquake occurred at 20:58 Mountain Standard Time. It had an epicentral location of 46.62° north latitude and 112.0° west longitude and no reported magnitude (SW-AA, 1980a). This event was recorded at the Federal Building accelerograph station, located at 46°35'23" north latitude and 112°02'25" west longitude, at an implied epicentral distance of 4 mi (6.4 km) (SW-AA, 1980a). Kanamori and Jennings (1978) have calculated a local magnitude of 3.70 and 3.95 for the north-south and east-west components of this event, respectively, and an epicentral distance of 5.0 km. The subsurface conditions for this station consist of weathered Precambrian limestone (SW-AA, 1980a).

No. 4 Helena, Montana

The November 28, 1935, Helena, Montana earthquake occurred at 07:42 Mountain Standard Time. It had an epicentral location of 46.62° north latitude and 112.0° west longitude and no reported magnitude (SW-AA, 1980a). This event was recorded at the Federal Building accelerograph station, located at 46°35'23" north latitude and 112°02'25" west longitude, at an implied epicentral distance of 4 mi (6.4 km) (SW-AA, 1980a). Kanamori and Jennings (1978) have calculated a local magnitude of 5.0 for the north-south and east-west components of this event, and an epicentral distance of 5.0 km. The subsurface conditions for this station consist of weathered Precambrian limestone (SW-AA, 1980a).

No. 5 San Francisco, California

The March 22, 1957, San Francisco, California earthquake occurred at 11:44 Pacific Standard Time. It had a Richter magnitude of 5.3 and an epicentral location of 37°40' north latitude and 122°29' west longitude (SW-AA, 1980c). This event was recorded at the Golden Gate Park accelerograph station, located at 37°46'19" north latitude and 122°28'37" west longitude (SW-AA, 1980b). This station has an epicentral distance of 7 mi (11.3 km) (SW-AA, 1980c). The subsurface conditions at this station consist of thin alternating beds of radiolarian chert and shale. Below a few feet of weathered rock, the chert is hard and brittle and the shale is moderately hard and brittle. This bedrock is part of the Franciscan basement complex (SW-AA, 1980b).

No. 6 Parkfield, California

The June 28, 1966, Parkfield, California earthquake occurred at 04:26:12.4 Greenwich Mean Time. It had a Richter magnitude of 5.6 and an epicentral location of 35°54' north latitude and 120°54' west longitude (SW-AA, 1980c). This event was recorded at the Temblor accelerograph station of the Cholame-Shandon Array located located at 35°42'36" north latitude and 120°10'12" west longitude (SW-AA, 1980b), at an epicentral distance of 24 mi (38.6 km) (SW-AA, 1980c). The subsurface conditions at this station consist of serpentinite and serpentinized peridotite that are moderately weathered at the surface and highly sheared and brecciated throughout. The rock varies from moderately hard to hard below a thin zone of weathering (SW-AA, 1980b).

No. 7 Lycle Creek, California

The Lytle Creek, California earthquake of September 12, 1970, occurred at 06:30 Pacific Standard Time. It had a Richter magnitude of 5.4 and an epicentral location of 34°16' north latitude and 117°32' west longitude (SW-AA, 1980c). This event was recorded at the Cedar Springs Allen Ranch accelerograph station located at 34°16'38" north latitude and 117°20'04" west longitude (SW-AA, 1980b), at an epicentral distance of 12 mi (19.3 km) (SW-AA, 1980c). The subsurface conditions at this station consist of granitic basement rock that is hard and fresh near the surface (SW-AA, 1980b).

No. 8 San Fernando, California

The February 9, 1971, San Fernando, California earthquake occurred at 06:00 Pacific Standard Time. It had a Richter magnitude of 6.4 and an epicentral location of 34°24.7' north latitude and 118°24.0' west longitude (SW-AA, 1978). This event was recorded at the Lake Hughes Array No. 4 accelerograph station located at 34°38'53" north latitude and 118°28'56" west longitude (SW-AA, 1980b), at an epicentral distance of 18 mi (29.0 km) (SW-AA, 1980c). The subsurface conditions at this station consist of moderately weathered granitic bedrock that is moderately to strongly decomposed to depths of about 15 ft, with fresher rock below (SW-AA, 1980b).

No. 9 San Fernando, California

The February 9, 1971, San Fernando, California earthquake occurred at 06:00 Pacific Standard Time. It had a Richter magnitude of 6.4 and an epicentral location of 34°24.7' north latitude and 118°24.0' west longitude (SW-AA, 1978). This event was recorded at the Lake Hughes Array No. 9 accelerograph station located at 34°36'28" north latitude and 118°33'40" west longitude (SW-AA, 1980b), at an epicentral distance of 17.9 mi (28.8 km). The subsurface conditions at this station consist of 9 ft of silty and gravelly sand overlying granitic gneiss (SW-AA, 1978).

No. 10 San Fernando, California

The February 9, 1971, San Fernando, California earthquake occurred at 06:00 Pacific Standard Time. It had a Richter magnitude of 6.4 and an epicentral location of 34°24.7' north latitude and 118°24.0' west longitude (SW-AA, 1978). This event was recorded at the Lake Hughes Array No. 12 accelerograph station located at 34°34'17" north latitude and 118°33'35" west longitude (SW-AA, 1980b), at an epicentral distance of 15 mi (24.1 km) (SW-AA, 1980c). The subsurface conditions at this station consist of 5 to 10 ft of landslide debris overlying moderatey hard sandstone conglomerate and shale (SW-AA, 1980b).

No. 11 Cape Mendocino, California

The January 12, 1975, Cape Mendocino, California earthquake occurred at 01:37:17.2 Universal Time. It had a Berkeley magnitude of 4.4 and an epicentral location of 40.22° north latitude and 124.26° west longitude (Coffman and Stover, 1977). This event was recorded at the Petrolia Cape Mendocino accelerograph station (USGS #1249, CDMG #5) located at 40.35° north latitude and 124.35° west longitude (Coffman and Stover, 1977). The epicentral distance was calculated to be 16.5 km. The subsurface conditions at this station consist of Cretaceous Franciscan volcanic sandstone (graywacke), with intercalated shales, disturbed by Quarternary landslides (Sherburne, 1984).

No. 12 Cape Mendocino, California

The June 7, 1975 Cape Mendocino, California earthquake occurred at 08:46:22.4 Universal Time. It had a Berkeley magnitude of 5.2 and an epicentral location of 40.57° north latitude and 124.14° west longitude (Coffman and Stover, 1977). This event was recorded at the Petrolia Cape Mendocino accelerograph station (USGS #1249, CDMG #5) located at 40.35° north latitude and 124.35° west longitude (Coffman and Stover, 1977). The epicentral distance was calculated to be 30.2 km. The subsurface conditions at this station consist of Cretaceous Franciscan volcanic sandstone (graywacke), with intercalated shales, disturbed by Quarternary landslides (Sherburne, 1984).

No. 13 Oroville, California

The August 1, 1975, Oroville, California earthquake occurred at 12:20 Pacific Standard Time. It had a Berkeley local magnitude of 5.7 and an epicentral location of 39.44° north latitude and 121.53° west longitude (Maley et al, 1975). This event was recorded at the Oroville Dam Crest, at an epicentral distance of 11 km. The subsurface conditions at this station are described as an earthfill dam (Maley et al, 1975).

No. 14 Oroville, California

The August 1, 1975, Oroville, California earthquake occurred at 12:20 Pacific Standard Time. It had a Berkeley local magnitude of 5.7 and an epicentral location of 39.44° north latitude and 121.53° west longitude (Maley et al, 1975). This event was recorded at the Oroville Dam Seismograph Station, at an epicentral distance of 12 km. The subsurface conditions at this station are described as meta-volcanic rock (Maley et al, 1975).

No. 15 Oroville, California Aftershock

The August 6, 1975, Oroville, California aftershock occurred at 03:50:29.7 Universal Time. It had a Berkeley local magnitude of 4.7 at a focal depth of 10.4 km. The location of the epicenter was at 39°29.95' north latitude and 121°31.53' west longitude (Toppozada et al, 1975). This event was recorded at the Don Johnson Ranch (DJR) with an hypocentral distance of 13.3 km. The epicentral distance was calculated to be 8.3 km. The DJR accelerograph is located at 39°25.47' north latitude and 121°31.26' west longitude. The site geology is described as greenstone-sediment contact, with the greenstone 10 meters below the surface (Toppozada et al, 1975). Weston (1981) reports that there are 10 meters of Pleistocene gravels and alluvium overlying bedrock at the Don Johnson Ranch and that the measured shear wave velocity of the overburden is 1,100 ft/sec and is 5,000 ft/sec for the bedrock.

No. 16 Oroville, California Aftershock

The August 8, 1975, Oroville, California aftershock occurred at 07:00:50.6 Universal Time. It had a Berkeley local magnitude of 4.9 at a focal depth of 6.8 km. The location of the epicenter was at 39°29.92' north latitude and 121°30.10' west longitude (Toppozada et al, 1975). This event was recorded at the Don Johnson Ranch (DJR) with an hypocentral distance of 10.8 km. The epicentral distance was calculated to be 8.4 km. The DJR accelerograph is located at 39°25.47' north latitude and 121°31.26' west longitude. The site geology is described as greenstone-sediment contact, with the greenstone 10 meters below the surface (Toppozada et al, 1975). Weston (1981) reports that there are 10 meters of Pleistocene gravels and alluvium overlying bedrock at the Don Johnson Ranch and that the measured shear wave velocity of the overburden is 1,100 ft/sec and is 5,000 ft/sec for the bedrock.

No. 17 Oroville, California Aftershock

The August 8, 1975, Oroville, California aftershock occurred at 07:00:50.6 Universal Time. It had a Berkeley local magnitude of 4.9 at a focal depth of 6.8 km. The location of the epicenter was at 39°29.92' north latitude and 121°30.10' west longitude (Toppozada et al, 1975). This event was recorded at the California Division of Mines and Geology Station No. 6, referred to as Oroville No. 6, located at 39°26.93' north latitude and 121°29.38' west longitude. The epicentral distance was calculated to be 5.6 km. The Oroville No. 6 site geology is described as Mesozoic greenstone (Toppozada et al, 1975).

No. 18 Oroville, California Aftershock

The September 27, 1975, Oroville, California aftershock occurred at 22:34 Universal Time. It had a Berkeley local magnitude of 4.6 at a focal depth of 12.0 km. The location of the epicenter was at 39°31.34' north latitude and 121°31.74' west longitude (Seekins and

Hanks,1978). This event was recorded at the Don Johnson Ranch (DJR) accelerograph station located at 39°25.47' north latitude and 121°31.26' west longitude. The epicentral distance was calculated to be 10.9 km. The DJR site geology is described as greenstone-sediment contact, with the greenstone 10 meters below the surface (Toppozada et al, 1975). Weston (1981) reports that there are 10 meters of Pleistocene gravels and alluvium overlying bedrock at the Don Johnson Ranch and that the measured shear wave velocity of the overburden is 1,100 ft/sec and is 5,000 ft/sec for the bedrock.

No. 19 Oroville, California Aftershock

The September 27, 1975, Oroville, California aftershock occurred at 22:34 Universal Time. It had a Berkeley local magnitude of 4.6 at a focal depth of 12.0 km. The location of the epicenter was at 39°31.34' north latitude and 121°31.74' west longitude (Seekins and Hanks, 1978). This event was recorded at the California Division of Mines and Geology Station No. 8, referred to as Oroville No. 8, located at 39°26.35' north latitude and 121°28.03' west longitude. The epicentral distance was calculated to be 11.0 km. The Oroville No. 8 site geology is described as Mesozoic greenstone (Toppozada et al, 1975).

No. 20 Friuli, Italy Aftershock

The September 11, 1976, Friuli, Italy aftershock occurred at 16:35:00 Greenwich Mean Time. It had a local magnitude of 5.9, a focal depth of 6 km, and an epicentral location of 46°19' north latitude and 13°10' east longitude (Basili et al, 1978). This event was recorded at the Somplago (D) accelerograph station, at an epicentral distance of 6.0 km. The Somplago (D) accelerograph is located at 46°20'33" north latitude and 13°03'58" east longitude, inside the underground powerhouse of a hydroelectric station approximately 260 meters below the surface (Basili et al, 1978). Basili et al (1978) report the materials upon which the instrument rests to be a fractured complex of Triassic limestone and dolomite. Muzzi and Vallini (1978) report that the compression wave velocity of the rock below the accelerograph was measured to be about 4.3 km/sec (14,100 ft/sec) by a geophysical seismic survey.

No. 21 Friuli, Italy Aftershock

The September 11, 1976, Friuli, Italy aftershock occurred at 16:35:00 Greenwich Mean Time. It had a local magnitude of 5.9, a focal depth of 6 km, and an epicentral location of 46°19' north latitude and 13°10' east longitude (Basili et al, 1978). This event was recorded at the San Rocco accelerograph station, at an epicentral distance of 14.5 km. The San Rocco accelerograph is located at 46°13'35" north latitude and 12°59'59" east longitude (Basili et al, 1978). Muzzi and Vallini (1978) state that the San Rocco Station site is at an outcropping of hard limestone. A more detailed description of this material reports it to be stratified and fissured Cretaceous limestone, a few tens of meters thick, overthrust on Miocene sandstone and marl (CNEN-ENEL, 1976).

No. 22 Friuli, Italy Aftershock

The September 11, 1976, Friuli, Italy aftershock occurred at 16:31:12 Greenwich Mean Time. It had a local magnitude of 5.5, a focal depth of 9 km, and an epicentral location of 46°17' north latitude and 13°10' east longitude (Basili et al, 1978). This event was recorded at the San Rocco accelerograph station, at an epicentral distance of 15.5 km. The San Rocco accelerograph is located at 46°13'25" north latitude and 12°59'59" east longitude (Basili et al, 1978). Muzzi and Vallini (1978) state that the San Rocco Station site is at an outcropping of hard limestone. A more detailed description of this material reports it to be stratified and fissured Cretaceous limestone, a few tens of meters thick, overthrust on Miocene sandstone and marl (CNEN-ENEL, 1976).

No. 23 Friuli, Italy Aftershock

The September 11, 1976, Friuli, Italy aftershock occurred at 16:31:12 Greenwich Mean Time. It had a local magnitude of 5.5, a focal depth of 9 km, and an epicentral location of 46°17' north latitude and 13°10' east longitude (Basili et al, 1978). This event was recorded at the Somplago (D) accelerograph station, at an epicentral distance of 10.0 km. The Somplago (D) accelerograph is located at 46°20'33" north latitude and 13°03'58" east longitude, inside the underground powerhouse of a hydroelectric station approximately 260 meters below the surface (Basili et al, 1978). Basili et al (1978) report the materials upon which the instrument rests to be a fractured complex of Triassic limestone and dolomite. Muzzi and Vallini (1978) report that the compression wave velocity of the rock below the accelerograph was measured to be about 4.3 km/sec (14,100 ft/sec) by a geophysical seismic survey.

No. 24 Friuli, Italy Aftershock

The September 15, 1976, Friuli, Italy aftershock occurred at 04:38:53 Greenwich Mean Time. It had a local magnitude of 5.0, a focal depth of 21.5 km, and an epicentral location of 46°16' north latitude and 13°10' east longitude (Basili et al, 1978). This event was recorded at the Somplago (D) accelerograph station, at an epicentral distance of 11.3 km. The Somplago (D) accelerograph is located at 46°20'33" north latitude and 13°03'58" east longitude, inside the underground powerhouse of a hydroelectric station approximately 260 meters below the surface (Basili et al, 1978). Basili et al (1978) report the materials upon which the instrument rests to be a fractured complex of Triassic limestone and dolomite. Muzzi and Vallini (1978) report that the compression wave velocity of the rock below the accelerograph was measured to be about 4.3 km/sec (14,100 ft/sec) by a geophysical seismic survey.

No. 25 Friuli, Italy Aftershock

The September 15, 1976, Friuli, Italy aftershock occurred at 09:21:28 Greenwich Mean Time. It had a local magnitude of 6.0, a focal depth of 12 km, and an epicentral location of 46°20' north latitude and 13°10' east longitude (Basili et al, 1978). This event was recorded at the San Rocco accelerograph station, at an epicentral distance of 19.0 km. The San Rocco accelerograph is located at 46°13'35" north latitude and 12°59'59" east longitude, (Basili et al, 1978). Muzzi and Vallini (1978) state that the San Rocco Station site is at an outcropping of hard limestone. A more detailed description of this material reports it to be stratified and fissured Cretaceous limestone, a few tens of meters thick, overthrust on Miocene sandstone and marl (CNEN-ENEL, 1976).

No. 26 Santa Barbara, California

The August 13, 1978, Santa Barbara, California Earthquake occurred at 22:54:52.4. It had a local magnitude of 5.1, a focal depth of 12.5 km, and an epicentral location of 34°22.2' north latitude and 119°43.0' west longitude (Porter, 1978). This event was recorded at the North Hall accelerograph station located on the University of California Santa Barbara campus in Goleta, California. This station is located at 34.415° north latitude and 119.846° west longitude and had an epicentral distance of 12.75 km (Porter, 1978). The accelerograph is attached to the topside of a 4 inch thick reinforced concrete floor slab supported by tie beams between caissons (Porter, 1978). Weston (1981) reports that the North Hall foundation consists of a concrete slab at grade resting on bell-shaped caissons which extend through 13 ft of alluvial material and are bottomed in siltstone of the Sisquoc Formation. The shear wave velocity of the siltstone is 2,000 to 2,500 ft/sec, based on field observation.

No. 27 Coyote Lake, California

The August 6, 1979, Coyote Lake, California earthquake occurred at 17:05:22.71 Universal Time. It has a local magnitude of 5.9, a focal depth of 6.3 km, and an epicentral location of 37°6.12' north latitude and 121°30.20' west longitude (Uhrhammer, 1980). This event was recorded at the San Martin, California, Coyote Creek accelerograph station at an epicentral distance of 2 km. The accelerograph is located at 37.118° north latitude and 121.550° west longitude. The site geology is described as conglomerate (Procella et al, 1979). Brady et al (1981) describe the station location as a rock site consisting of Cretaceous age Berryessa Formation, which consists of Oakland conglomerate, sandstone, and shale.

No. 28 Coyote Lake, California

The August 6, 1979 Coyote Lake, California earthquake occurred at 17:05:22.71 Universal Time. It had a local magnitude of 5.9, a focal depth of 6.3 km, and an epicentral location of 37°6.12' north latitude and 121°30.20' west longitude (Uhrhammer, 1980). This event was recorded at the Gilroy No. 1 accelerograph station at an epicentral distance of 16 km. This station is located at the Gavilan College water tower at 36.973° north latitude and 121.572° west longitude. The site geology is described as Franciscan sandstone (Porcella et al, 1979). Brady et al (1981) describe the station location as a rock site, consisting of Cretaceous-Jurassic age Franciscan Formation, which consists of sandstone, shale, and chert. The compression wave and shear wave velocities of the Franciscan rock were measured in a 20-meter deep boring at the station site, and were found to be 3.1 km/sec (10,200 ft/sec) and 2.0 km/sec (6,600 ft/sec), respectively (Joyner et al, 1981).

No. 29 Coyote Lake, California

The August 6, 1979, Coyote Lake , California earthquake occurred at 17:05:22.71 Universal Time. It had a local magnitude of 5.9, a focal depth of 6.3 km, and an epicentral location of 37°6.12' north latitude and 121°30.20' west longitude (Uhrhammer, 1980). This event was recorded at the Gilroy No. 6, San Ysidro accelerograph station at an epicentral distance of 10 km. This station is located at 37.026° north latitude and 121.484° west longitude. The site geology is described as Berryessa congolomerate (Porcella et al, 1979). Brady et al (1981) describe the station location as a rock site, consisting of Cretaceous age Berryessa Formation, which consists of Oakland conglomerate, sandstone, and shale.

No. 30 Livermore, California

The January 26, 1980, Livermore, California earthquake occurred at 06:33:35.96 Pacific Standard Time. The University of California, Berkeley Seismograph Station reported a local magnitude of 5.8, an epicentral location of 37.74° north latitude and 121.74° west longitude, and a focal depth of 14.5 km. The United States Geological Survey at Menlo Park reported a local magnitude of 5.2, an epicentral location of 37.76° north latitude and 121.70° west longitude, and a focal depth of 7.3 km (McJunkin and Ragsdale, 1980). This event was recorded at the Livermore-Morgan Territory Park accelerograph station, located at 37.819° north latitude and 121.795° west longitude, at an epicentral distance of 11.0 km. This station is underlain by Upper Cretaceous undifferentiated Great Valley sandstone and shale (McJunkin and Ragsdale, 1980).

No. 31 New Hampshire

The January 18, 1982, New Hampshire earthquake occurred at 19:14:42 Eastern Standard Time. It had a Richter magnitude of 4.7, a body-wave magnitude of 4.4, a focal depth between 4.5 and 8.0 km, and an epicentral location of 43.5° north latitude and 71.6° west longitude (Chang, 1983). This event was recorded at the Franklin Falls Dam right abutment accelerograph station, located at 43.447° north latitude and 71.660° west longitude, at an epicentral distance of 8 km.

This accelerograph station is reported to be a rock site by Chang (1983). SWEC reviewed available data from U.S. Army Corps of Engineers borings made prior to construction of the dam and visited the dam site to confirm the foundation conditions for the right abutment accelerograph station. It is located on the west side of the river valley in an area excavated to form the spillway for the dam. The accelerograph station shelter is founded on what appears to be a rock outcrop, on the top of the lowest of three terraces on the east side of the spillway. It is close to the top of the slope which is fairly steep at about 1V:2H.

No. 32 New Brunswick Aftershock

The March 31, 1982, New Brunswick aftershock occurred at 21:02:20 Universal Time. It has a Nuttli magnitude of 4.8, an epicentral location of 47.00° north latitude, and 66.57° west longitude with a focal depth of 4 km (Weichert et al, 1982). The body-wave magnitude was reported to be 5.0 by Wetmiller et al (1984). This event was recorded at the Mitchell Lake Road accelerograph station, located at 47°02.15' north latitude and 66°36.62' west longitude at an epicentral distance of 4.2 km. The foundation for this station is reported as bedrock (Weichert et al, 1982).

Corrected Accelergram Data

The corrected earthquake time histories used in the previous submittal (SWEC, 1984) were obtained from the Califronia Institute of Technology (CIT), Earthquake Engineering Laboratory Data Tape (Volume II), Corrected Accelerograms. CIT stopped the data processing project in May, 1973, after completing work on the 1971 San Fernando earthquake. Thus, accelerograms corrected by CIT are not available for earthquakes occurring after 1971. Earthquake record correction was taken over by the Seismic Engineering Branch of the U.S. Geological Survey at Menlo Park, California, with distribution of corrected records handled by the National Geophysical Data Center (NGDC) of the National Oceanic and Atmospheric Administration (NOAA). Strong-motion records for some California earthquakes are also corrected and distributed by the California Division of Mines and Geology (CDMG). Unfortunately, corrected records are not available from NGDC or CDMG for all the earthquakes and recording stations listed in Table 4-4. Stone & Webster obtained uncorrected strong-motion records for those events where corrected records are not available (the Oroville aftershocks and the Friuli aftershocks) and processed them utilizing the computer program SIVA to obtain corrected records. Details of the SIVA processing procedures are contained in Sunder and Connor (1982). Table A4-1 lists all the earthquake records of Table 4-4, with the source of the earthquake record (corrected and/or uncorrected), information on filter limits used in correcting the strong-motion record, and a comparison of the uncorrected and corrected maximum acceleration values.

APPENDIX 4

REFERENCES

Basili, M., S. Polinari, G. Tinelli, R. Berardi, A. Berenzi, and L. Zonetti. Strong-Motion Records of Friuli Earthquake, in Comitato Nazionale Energia Nucleare (CNEN) - Proceedings of Specialist Meeting on The 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations, Rome, Italy, 11-13 October, 1977, Vol. II, pp 375-386. May, 1978.

Brady, A.G., P.N. Mork, V. Perez, and L.D. Porter. Processed Data from the Gilroy Array and Coyote Creek Records, Coyote Lake Earthquake, 6 August 1979, U.S. Geological Survey, Open-File Report 81-42, pp 171. 1981.

Chang, F.K. Analysis of Strong-Motion Data from the New Hampshire Earthquake of 18 January 1982, NUREG/CR-3327, Report to U.S. Nuclear Regulatory Commission. September, 1983.

Comitato Nazionale Energia Nucleare - Ente Nazionale Energia Elettrica (CNEN-ENEL) Commission on Seismic Problems Associated with the Installation of Nuclear Plants. Contribution to the Study of Friuli Earthquake of May 1976, Appendix B, CNEN's Geophysical Instrumentation, pp 127-135. November, 1976.

Coffman, J.L. and C.W. Stover, Editors. United States Earthquakes, 1975, U.S. Department of Commerce, National Oceanic and Atmospheric Administration and U.S. Department of the Interior, Geological Survey, Boulder, Colorado. 1977.

Joyner, W.B., R.E. Warrick, and T.E. Fumal. The Effect of Quaternary Alluvium on Strong Ground Motion in the Coyote Lake, California, Earthquake of 1979, Bulletin of the Seismiological Society of America, Vol. 71, No. 4, pp 1333-1349. August, 1981.

Kanamori, H., and P.C. Jennings. Determination of Local Magnitude, from Strong-Motion Accelerograms, Bulletin of the Seismological Society of America, Vol. 68, No. 2, pp 471-485. April, 1978.

Maley, R.P., V. Perez, and B.J. Morrill. Strong-Motion Seismograph Results from the Oroville Earthquake of 1 August 1975, in Oroville, California, Earthquake 1 August 1975, California Division of Mines and Geology Special Report 124, pp 115-122. 1975.

McJunkin, R.D., and J.T. Ragsdale. Strong-Motion Records from the Livermore Earthquake of 24 and 26 January 1980, California Division of Mines and Geology Preliminary Report 28, pp 91. 1980.

Muzzi, F. and S. Vallini. The Friuli 1976 Earthquake Considered as a "Near Source Earthquake," Presentation and Discussion of the Surface Recordings, in Comitato Nazionale Energia Nucleare (CNEN) - Proceedings of Specialist Meeting on The 1976 Friuli Earthquake and the Antiseismic Design of Nuclear Installations, Rome, Italy, 11-13 October, 1977, Vol. II, pp 460-526. May, 1978.

Porcella, R.L., R.B. Matthiesen, R.D. McJunkin, and J.T. Ragsdale. Compilation of Strong-Motion Records from the August 6, 1979, Coyote Lake Earthquake, U.S. Geological Survey, Open-File Report 79-385, 1979.

Porter, L.D., Compilation of Strong-Motion Records Recovered from the Santa Barbara Earthquake of 13 August 1978, California Division of Mines and Geology Preliminary Report 22. October, 1978.

Seekins, L.C. and T.C. Hanks. Strong-Motion Accelerograms of the Oroville Aftershocks and Peak Acceleration Data, Bulletin of the Seismological Society of America, Vol. 68, No. 3, pp 677-689. June, 1978.

Shannon and Wilson, Inc. and Agbabian Associates (SW-AA). Verification of Subsurface Conditions at Selected "Rock" Accelerograph Stations in California, Vol. 1, NUREG/CR-0055, Report Prepared for U.S. Nuclear Regulatory Commission. 1978.

Shannon and Wilson, Inc. and Agbabian Associates (SW-AA), Geotechnical and Strong-Motion Earthquake Data from U.S. Accelerograph Stations, NUREG/CR-0985, Vol. 3, Report to U.S. Nuclear Regulatory Commission. 1980a.

Shannon and Wilson, Inc. and Agbabian Associates (SW-AA). Verification of Subsurface Conditions at Selected "Rock" Accelerograph Stations in California, Vol. 2, NUREG/CR-0055, Report to U.S. Nuclear Regulatory Commission. 1980b.

Shannon and Wilson, Inc. and Agbabian Associates (SW-AA). Verification of Subsurface Conditions at Selected "Rock" Accelerograph Stations in California, Vol. 2, Appendix, Earthquake Records, NUREG/CR-0055, Report to U.S. Nuclear Regulatory Commission. 1980c.

Sherburne, R.. Personal Communication from California Division of Mines and Geology to R. Borjeson of Stone & Webster Engineering Corporation, October 29, 1984.

Stone & Webster Engineering Corporation (SWEC), Seismic Design Response Spectra, Beaver Valley Power Station - Unit 2. Prepared for Duquesne Light company, Pittsburgh, Pennsylvania. June, 1984.

Sunder, S.S. and J.J. Connor. A New Procedure for Processing Strong-Motion Earthquake Signals. Bulletin of the Seismological Society of America, Vol. No.2, pp 643-661. April, 1982.

Toppozada, T.R., W.M. Wells, J.H. Power, and T.C. Hanks. Strong-Motion Accelerograms of the Aftershocks, in Oroville, California, Earthquake, 1 August 1975, California Division of Mines and Geology Special Report 124, pp 101-107. 1975.

Trifunac, M.D., A.G. Brady, and D.E. Hudson. Strong-Motion Earthquake Accelerograms - Digtized and Plotted Data. Vol. II - Corrected Accelerograms and Integrated Ground Velocity and Displacement Curves: Part B - Accelerograms IIB021 to IIB040. Report EERL-7 California Insititute of Technology, Earthquake Engineering Research Laboratory. February, 1973.

Uhrhammer, R.A., Observations of the Coyote Lake, California Earthquake Sequence of August 6, 1979. Bulletin of the Seismological Society of America, Vol. 70, No. 2, pp 559-570. April, 1980.

Weichert, D.H., P.W. Pomeroy, P.S. Munro, and P.N. Mork. Strong-Motion Records from Miramichi, New Brunswick, 1982 Aftershocks, Earth Physics Branch Open-File Report 82-31, Ottawa, Canada, pp 94. 1982.

Weston Geogphysical Corporation (WGC). Site-Specific Response Spectra, Midland Plant - Units 1 and 2, Addendum to Part 1, Response Spectra - Original Ground Surface, Prepared for Consumers Power Company. June, 1981.

Wetmiller, R.J., J. Adams, F.M. Anglin, H.S. Hasegawa, and A.E. Stevens. Aftershock Sequences of the 1982 Miramichi, New Brunswick, Earthquake. Bulletin of the Seismological Society of America, Vol. 74, No. 2, pp 621-653. April, 1982.

APPENDIX 4

TABLE A4-1
CORRECTED ACCELEROGRAM DATA

Ref No. [1]	Earthquake Date Year Mo Day	Recording Station	Earthquake Record Source [2]	Component	High Pass Filter: Termination (Hz)	High Pass Filter: Cut Off (Hz)	Low Pass Filter: Cut Off (Hz)	Low Pass Filter: Termination (Hz)	Peak Acceleration (CM/SEC^2): Uncorrected	Peak Acceleration (CM/SEC^2): Corrected	Ratio [3]
1	1935 10 31	Carrol College, Helena, MT	CIT	EW	0.050	0.070	25.0	27.0	-153.11	142.50	-1.07
				NS	0.050	0.070	25.0	27.0	138.38	143.50	0.96
6	1966 06 28	Cholame-Shandon Array, Temblor	CIT	N65W	0.050	0.070	25.0	27.0	-276.77	-264.31	1.05
				S25W	0.050	0.070	25.0	27.0	-403.38	-340.80	1.18
7	1970 09 12	Allen Ranch, Cedar Springs, CA	CIT	S05W	0.050	0.070	25.0	27.0	-55.94	54.90	-1.02
				S85E	0.050	0.070	25.0	27.0	84.40	-69.90	-1.20
8	1971 02 09	Array No. 4, Lake Hughes CA	CIT	S69E	0.100	0.125	25.0	27.0	196.29	168.20	1.16
				S21W	0.100	0.125	25.0	27.0	156.05	-143.50	-1.09
14	1975 08 01	Oroville Dam Seismograph Station	NOAA	N53W	0.160	0.590	23.0	25.0	101.38	-82.53	-1.23
				N37E	0.160	0.590	23.0	25.0	-106.19	90.60	-1.17
17	1975 08 08	Oroville, CA CDMG No. 6	NOAA [4]	S55E	0.886	1.250	35.0	45.4	74.19	75.59	-0.98
				N35E	1.139	1.600	35.0	45.2	105.21	97.96	1.07
19	1975 09 27	Oroville, CA CDMG No. 8	NOAA [4]	N90W	0.886	1.250	35.0	45.4	-150.59	-156.56	0.96
				S00E	0.814	1.150	35.0	45.4	-71.90	-72.36	0.99
21	1976 09 11	San Rocco	NOAA [4]	NS	0.245	0.350	25.0	30.5	-89.68	-85.03	1.05
				EW	0.245	0.350	25.0	30.5	-89.93	87.47	-1.03
22	1976 09 11	San Rocco	NOAA [4]	NS	0.210	0.300	25.0	30.5	-40.11	-38.58	1.04
				EW	0.245	0.350	25.0	30.5	68.55	68.20	1.01
25	1976 09 15	San Rocco	NOAA [4]	NS	0.175	0.250	25.0	30.6	-138.86	-144.91	0.96
				EW	0.154	0.220	25.0	30.6	-229.69	-227.89	1.01
27	1979 08 06	Coyote Creek, San Martin, CA	NOAA	250	0.050	0.250	23.0	25.0	245.26	244.63	1.00
				160	0.050	0.250	23.0	25.0	138.58	137.72	1.01
28		Gilroy No. 1, Gavilan College Water Tower	NOAA	320	0.050	0.250	23.0	25.0	-115.91	-111.09	1.04
				230	0.050	0.250	23.0	25.0	-93.53	-83.73	1.12
29		Gilroy No. 6, San Ysidro, CA	NOAA	320	0.050	0.250	23.0	25.0	-313.48	-314.57	1.00
				230	0.050	0.250	23.0	25.0	-414.08	-408.79	1.01
31	1982 01 18	Franklin Falls Dam Right Abutment	WES	45		0.330	50.0	100.0	282.52	287.70	0.98
				315		0.330	50.0	100.0	565.05	-539.96	-1.05

APPENDIX 4

TABLE A4-1
CORRECTED ACCELEROGRAM DATA

Ref No. [1]	Earthquake Date Year Mo Day	Recording Station	Earthquake Record Source [2]	Component	High Pass Filter: Termination (Hz)	High Pass Filter: Cut Off (Hz)	Low Pass Filter: Cut Off (Hz)	Low Pass Filter: Termination (Hz)	Peak Acceleration (CM/SEC²): Uncorrected	Peak Acceleration (CM/SEC²): Corrected	Ratio [3]
32	1982 03 31	Mitchell Lake Road	EPB	118		1.000	50.0	100.0	131.64	-148.77	-0.90
				28		1.000	50.0	100.0	-200.66	-231.46	0.87

NOTES:

[1] • Refer to Table 4-3

[2] • NOAA - United States Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, National Geophysical Data Center.

• WES - Department of the Army, Waterways Experiment Station, Corps of Engineers, Geotechnical Laboratory, Earthquake Engineering and Geophysics Division.

• EPB - Energy Mines and Resources Canada, Earth Sciences, Earth Physics Branch, Division of Seismology and Geomagnetism.

• CIT - California Institute of Technology, Earthquake Engineering Research Laboratory.

[3] Ratio of uncorrected to corrected acceleration

[4] Uncorrected records were obtained from source noted. Records were corrected by SWEC.

APPENDIX 5

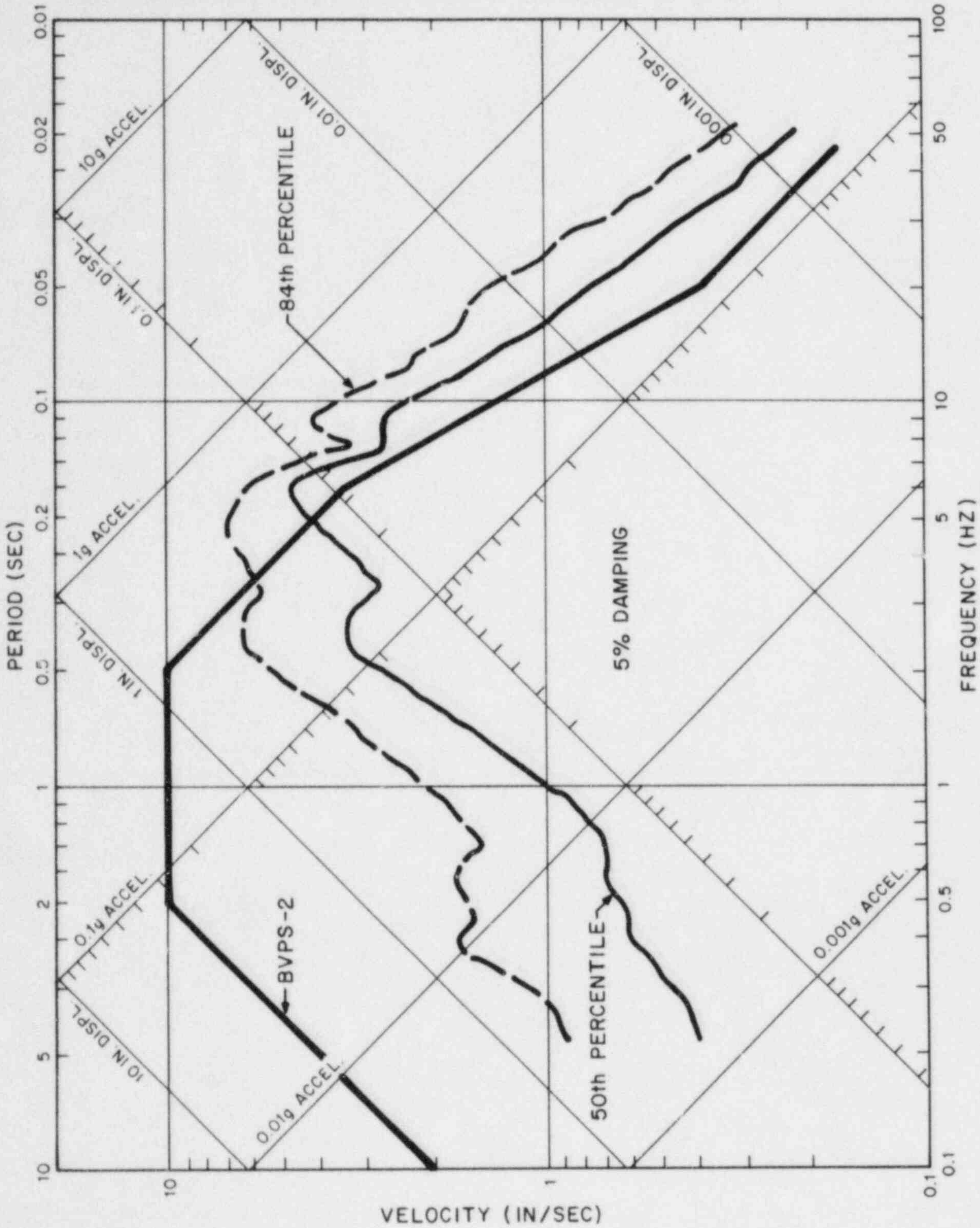
SOIL RESPONSE ANALYSIS: UNSCALED

SOIL RESPONSE ANALYSIS: UNSCALED

The rock outcrop records which met the criteria for use without scaling in the soil response analysis were identified in Table 4-5. The 10 component recordings of the five earthquakes listed are too small a data set to be used for a statistical estimate of population parameters, namely the 50th and 84th percentile response spectra. The size of the data set allows unusual or outlier records to bias the results of the analysis more than would be possible in a larger data set, such as that of the scaled earthquake records (Table 4-4). Furthermore, four out of the five earthquakes listed in Table 4-5 had magnitudes higher than the BVPS-2 SSE, which results in a higher response than is appropriate.

In general, response spectra determined from a set of unscaled records for earthquakes having magnitudes within ± 0.5 magnitude units of a target magnitude are considered less normative than those determined from scaled records. A range of ± 0.5 magnitude units represents a difference in earthquake energy release between the highest and lowest magnitude event of about 30 times. This large difference of energy release is reduced by the scaling process.

In spite of the reasons presented demonstrating that an unscaled soil response analysis is inappropriate, the analysis was performed using the records listed in Table 4-5. The resulting 50th percentile and the 84th percentile response spectra are shown in Figure A5-1.



NOTE:

RESPONSE SPECTRA COMPUTED
FROM RECORDS LISTED IN TABLE 4-5

FIGURE A5-1
HORIZONTAL RESPONSE SPECTRA
FROM SOIL RESPONSE
ANALYSIS: UNSCALED
BEAVER VALLEY POWER STATION-UNIT 2
STONE & WEBSTER ENGINEERING CORPORATION

APPENDIX 6

SITE DEPENDENT RESPONSE SPECTRA

STATISTICAL ANALYSIS PROCEDURE

SITE DEPENDENT RESPONSE SPECTRA
STATISTICAL ANALYSIS PROCEDURE

The site matched and soil response analyses provide two separate statistical estimates of the site dependent response spectra. Advantages and limitations can be ascribed to each method, and it cannot be stated with certainty which one provides the best estimate of the true site dependent spectra. The two approaches are intended to augment each other, and therefore, their results are combined in a way that provides the best estimate of the 50th and 84th percentile site dependent response spectra. This appendix describes the statistical procedure and derives the expressions used to combine the site matched and soil response analyses results.

A6.1 Definition of Symbols

Symbol	Definition
χ^2	Chi-square statistic
E(x)	Expected value of the random variable x
f	Number of degrees of freedom for chi-square distribution
MEDV	Median site dependent pseudo-velocity, in/sec
MSDV	84th percentile site dependent pseudo-velocity, in/sec
MSDLOGV	Mean plus one standard deviation (84th percentile) $\log_{10}$ pseudo-velocity
n	Number of observations (earthquake records)
s^2	Variance of the sample $\log_{10}$ pseudo-velocities
$s_{\bar{v}}^2$	Variance of the sample mean $\log_{10}$ pseudo-velocities
sm,sr	Subscripts for site matched analysis and soil response analysis, respectiviely
σ^2	Variance of the population of $\log_{10}$ pseudo-velocities
μ	Mean of the population of $\log_{10}$ pseudo-velocities
v	Log_{10} pseudo-velocity
$\bar{v}$	Sample mean $\log_{10}$ pseudo-velocity
W_{sm}, W_{sr}	Weighting factors for the mean $\log_{10}$ pseudo-velocities from the site matched and soil response analyses, respectively

A6.2 ESTIMATION OF THE MEAN

The response spectrum psuedo-velocities are log-normally distributed and therefore, standard statistical methods are applied to the base 10 logarithms of the pseudo-velocities.

An estimate of the population mean $\log_{10}$ pseudo-velocity is provided by the linear combination of the mean $\log_{10}$ pseudo-velocities from the site matched and soil response analyses as:

$$\bar{v} = W_{sm} \cdot \bar{v}_{sm} + W_{sr} \cdot \bar{v}_{sr} \qquad \text{(Eq A6-1)}$$

The weighting factors, W_{sm} and W_{sr}, are derived, described below, so that the variance of the estimate of the mean is a minimum.

The expected value of $\bar{v}$ is:

$$E(\bar{v}) = W_{sm}\, E(\bar{v}_{sm}) + W_{sr}\, E(\bar{v}_{sr}) \qquad \text{(Eq A6-2)}$$

and, if both sets of data are drawn from the same population, then:

$$E(\bar{v}_{sm}) = E(\bar{v}_{sr}) = \mu \qquad \text{(Eq A6-3)}$$

It then follows that:

$$E(\bar{v}) = \mu\, (W_{sm} + W_{sr}) \qquad \text{(Eq A6-4)}$$

and if $\bar{v}$ is an unbiased estimate of the underlying population mean, μ, the sum of the weighting factors is unity; i.e.:

$$W_{sm} + W_{sr} = 1 \qquad \text{(Eq A6-5)}$$

The variance of the estimate of the mean $\log_{10}$ pseudo-velocity is given by the expression:

$$s^2_{\bar{v}} = W^2_{sm}\, s^2_{\bar{v}_{sm}} + W^2_{sr}\, s^2_{\bar{v}_{sr}} \qquad \text{(Eq A6-6)}$$

Since the variance of the mean for each analysis can be described in terms of the variance of the sample observations as s^2/n, Equation A6-6 can be rewritten as:

$$s^2_{\bar{v}} = W^2_{sm}\, (s^2_{sm}/n_{sm}) + W^2_{sr}\, (s^2_{sr}/n_{sr}) \qquad \text{(Eq A6-7)}$$

and since $W_{sr} = 1 - W_{sm}$,

$$s^2_{\bar{v}} = W^2_{sm}\, (s^2_{sm}/n_{sm}) + (1-W_{sm})^2\, (s^2_{sr}/n_{sr}) \qquad \text{(Eq A6-8)}$$

The weighting factors are found by taking the partial derivative of $s^2_{\bar{v}}$ with respect to W_{sm} and setting the result equal to zero for the minimum variance. The resulting expressions for W_{sm} and W_{sr} are given by:

$$W_{sm} = \frac{n_{sm}/s^2_{sm}}{n^2_{sm}/s^2_{sm} + n_{sr}/s^2_{sr}} \qquad \text{(Eq A6-9a)}$$

$$W_{sr} = \frac{n_{sr}/s^2_{sr}}{n_{sm}/s^2_{sm} + n_{sr}/s^2_{sr}} \qquad \text{(Eq A6-9b)}$$

Equations A6-9a and A6-9b can be simplified by substituting the following:

$$R = n_{sm}/s^2_{sm} + n_{sr}/s^2_{sr} \qquad \text{(Eq A6-10a)}$$

which gives:

$$W_{sm} = \frac{1}{R} \cdot \frac{n_{sm}}{s^2_{sm}} \qquad \text{(Eq A6-10b)}$$

$$W_{sr} = \frac{1}{R} \cdot \frac{n_{sr}}{s^2_{sr}} \qquad \text{(Eq A6-10c)}$$

The calculations described by equations A6-1 and A6-10 are carried out at each frequency at which the two sets of spectra are evaluated. All calculations are performed using the $\log_{10}$ pseudo-velocities; the conversion to velocity is:

$$MEDV = 10^{\bar{v}} \quad \text{(in/sec)} \qquad \text{(Eq A6-11)}$$

A6.3 ESTIMATION OF THE VARIANCE

It can be shown that if s^2 is the variance of a random sample of size n from the normal population $N(v, \mu, \sigma^2)$, then $(n-1)s^2/\sigma^2$ has a chi-square distribution with (n-1) degrees of freedom. Therefore:

$$s^2 = \frac{\sigma^2}{n-1} \chi^2 \qquad \text{(Eq A6-12)}$$

It can also be demonstrated that if the results of repeated independent samplings from the same population have chi-square values of $\chi_1^2, \chi_2^2, \chi_3^2 \ldots$ with $f_1, f_2, f_3, \ldots$ degrees of freedom, respectively, then the individual results are equivalent to a chi-square value given by $\chi_1^2 + \chi_2^2 + \chi_3^2 + \ldots$ with $f_1 + f_2 + f_3 + \ldots$ degrees of freedom. Accordingly, the sum of the chi-square values from the site matched and soil response analyses is:

$$\chi^2 = \chi^2_{sm} + \chi^2_{sr}$$

$$\chi^2 = \frac{(n_{sm}-1)\, s^2_{sm}}{\sigma^2} + \frac{(n_{sr}-1)\, s^2_{sr}}{\sigma^2} \qquad \text{(Eq A6-13a)}$$

with degrees of freedom given by:

$$f = (n_{sm}-1) + (n_{sr}-1) = (n_t-2) \qquad \text{(Eq A6-13b)}$$

where:

$$n_t = n_{sm} + n_{sr}$$

Multiplying both sides of Equation A6-13a by $\sigma^2/(n_t-2)$ gives:

$$\frac{\sigma^2 \chi^2}{(n_t-2)} = \frac{(n_{sr}-1)\, s^2_{sr}}{(n_t-2)} + \frac{(n_{sm}-1)\, s^2_{sm}}{(n_t-2)} \qquad \text{(Eq A6-14a)}$$

And since $n_{sr} = 28$ and $n_{sm} = 18$:

$$s^2 = 0.6136\, s^2_{sr} + 0.3864\, s^2_{sm} \qquad \text{(Eg A6-14b)}$$

Equation A6-14b provides the best estimate of the variance of the site dependent response spectra as a combination of the site matched and soil response analyses results weighted in terms of the number of observations (earthquake records).

It then follows that the 84th percentile value of the $\log_{10}$ pseudo-velocities is calculated as:

$$MSDLOGV = \bar{v} + (s^2)^{\frac{1}{2}} \qquad \text{(Eq A6-15)}$$

and the conversion to velocity is:

$$MSDV = 10^{MSDLOGV} \quad \text{(in/sec)} \qquad \text{(Eq A6-16)}$$