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RECOMMENDATIONS FOR SHAPE OF EARTHQUAKE RESPONSE SPECTRA

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RECOMMENDATIONS FOR SHAPE OF EARTHQUAKE RESPONSE SPECTRA

prepared by

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RECOMMENDATIONS FOR SHAPE OF EARTHQUAKE RESPONSE SPECTRA

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I. SUMMARY OF MAJOR FINDINGS AND RECOMMENDATIONS

A. SCOPE

The major objectives of the studies described in this report were to analyse and evaluate a number of significant earthquake records and to utilize the results to develop "standardized" design spectrum shapes to be used in the seismic design of nuclear power plant facilities. Because earthquakes are complex phenomena, and since it is not possible to exactly predict the nature of seismic ground motions, statistical analyses of recorded ground motions must be used. The major findings and recommendations from the studies based on such statistical analyses, along with brief discussions of the data and the analytical approaches used, are discussed in this chapter.

B. DATA USED

Response spectrum shapes for thirty-three significant and different accelerograms generated by twelve major earthquakes were developed for damping ratios of 0.005, 0.01, 0.02, 0.05, 0.07, and 0.10. The California Institute of Technology prepared most of the accelerogram digitizations, which are consistent and reliable reproductions of the actual ground motions. The remaining digitizations were obtained from the State of California Office of Architecture and Construction, Los Angeles, and the Seismological Field Survey, NOAA, San Francisco. The thirty-three accelerograms for purposes of this study are termed the ensemble.

The response spectrum shapes were studied as an ensemble and as groups categorized according to peak ground accelerations, site soil characteristics, epicentral distances, and geographical locale of the recording stations. These studies were made to determine the influence of the various characteristics on the shape of the response spectra. Pertinent literature was searched to collect the most reliable available data concerning these earthquakes and their recording stations.

C. ANALYTICAL APPROACH

The following approach was used for the statistical analyses:

- Spectrum shape statistics, such as mean, median, and standard deviation were developed for the ensemble of all accelerograms and for each of the groups to provide indications of the central tendencies and uncertainties associated with the corresponding groups.

- A statistically acceptable probability model suitable for the complete ensemble of spectrum shapes was determined. Smooth "standardized" design spectrum shapes were derived on the basis of this probability model.

- Comparisons were made between the recommended spectrum shapes and the current Atomic Energy Commission (AEC) regulatory criteria, Newmark, Housner, and Blume F-factor spectrum shapes.

- Period-time amplitude plot studies of eight accelerograms generated by four important earthquakes were made to investigate the effects of earthquake duration.

The probabilistic approach was used because it was considered to be most rational, realistic, and appropriate for seismic design, especially of critical installations such as nuclear power plants. Previous studies and predictions of the frequency characteristics of seismic ground motions have usually been based on the analysis of only a few records. The results of the present studies are particularly significant for the following reasons:

- The studies are based on the analyses of thirty-three different accelerograms, a larger number than used in other studies.

- The accelerogram digitizations are the most reliable ones available.

- The studies are comprehensive because they include the effects of a number of parameters, detailed statistical analyses, and effects of earthquake duration.

D. MAJOR FINDINGS AND OBSERVATIONS

The following major findings resulted from the studies:

- Statistical predictions of spectral characteristics of future seismic ground motions are plausible and desirable.

- Smooth "standardized" design spectrum shapes can be used to represent probable severity of seismic motions. Recommended spectrum shapes developed from these studies are presented in Figures 4 through 6 for large, small, and negligible probabilities of being exceeded.

- The approach of using spectrum shapes derived from analyses of the ground motion with peak acceleration normalized to unity was validated because there was low correlation between the peak ground accelerations and the spectrum shape values. Separate treatment of these two as independent variables in these studies was therefore appropriate.

The following significant observations can be made from the results of group analyses:

- Various seismic parameters appear to influence response spectrum shape.

- Larger spectral amplifications can be expected to occur at a softer site. The predominance of long period motion for softer sites and of short period motion for firmer sites was not confirmed or rejected.

- Distance from epicenter did not appear to influence spectrum shape. Predominance of long period motion at longer epicentral distances did not seem conclusive. Neither, however, was there sufficient basis to reject this possibility.

- The studies by geographic grouping revealed minor variations in the central tendencies as indicated by the means and medians, although there were significant variations in the standard deviations or uncertainties. The ensemble represented a wide-range of frequency content much better than any other group and thus, it was adopted as the basis for the recommended spectrum shapes.

The following observations can be made from the comparisons between the recommended spectrum shapes and the AEC, Newmark, Housner, and Blume F-factor shapes for a 2% damping ratio:

- The current AEC design spectrum shape is below the small probability of exceedance shape for periods shorter than 0.5 sec, and those longer than 0.9 sec.

- The Newmark spectrum shape is consistently above the small probability of exceedance shape, except for a short interval in the vicinity of zero period.

- The Housner spectrum shape is below the large probability of exceedance shape for periods shorter than 0.4 sec, and it is above the latter for longer periods.

- The Blume F-factor spectrum shape for a standardized normal variable value of 1.0 is consistently higher than the small probability of exceedance shape.

From the period-amplitude-time studies, the following observations can be made:

- The earthquake duration effect on the response spectrum shape is small for periods shorter than 0.5 sec, the period range significant for the nuclear power plant structures. The dynamic amplification factor (DAF) at longer periods, however, would generally tend to be higher for long duration motions than for those of short duration.

E. RECOMMENDATIONS

Because risk minimization is the basic rationale for the seismic design of critical installations such as nuclear power plants, the seismic load criteria should consider risk variability with such factors as regional seismicity, geotectonics, etc. Thus, design spectrum shapes representing variable severity of seismic loadings should be specified to achieve appropriate minimization of the total risk.

The following recommendations pertinent to the design spectrum shapes are consistent with this seismic design objective. Other ground motion characteristics, such as peak ground acceleration and strong motion duration (in the case of time-history analyses) should be thoroughly considered to fully satisfy the seismic design objective. The curves in Figures 4 through 6 are spectrum shapes, not response spectra themselves. To derive pseudo absolute acceleration response spectra, it is necessary to evaluate the joint probabilities for peak ground accelerations and the spectrum shape values.

- The large probability of exceedance spectrum shapes shown in Figure 4 should be considered as lower bound spectrum shapes.

- For sites associated with relatively low risks, e.g., located in low seismicity areas, the design spectrum shapes for different damping ratios should not be lower than the small probability of exceedance spectrum shapes shown in Figure 5.

- For sites associated with relatively high risks, e.g., located in high seismicity areas, the design spectrum shapes for different damping ratios should not be lower than the negligible probability of exceedance spectrum shapes shown in Figure 6.

  It must be noted, however, that the negligible exceedance probability spectrum shapes represent extreme ground motion amplification. An inappropriate use of these shapes could result in an extremely low probability seismic exposure and the corresponding design could be ultraconservative. For example, if a very high peak ground acceleration estimated deterministically on the basis of an extreme earthquake expected to occur at a very short distance (say, at a point on the nearby fault) from the site were to be combined with the negligible probability shape, an extremely low probability seismic exposure would result. The corresponding design would be ultraconservative because the risk considerations would then be unnecessarily duplicated by first assuming a highly improbable earthquake occurrence (because the probability of an extreme earthquake occurring at a given point is extremely small) and then, deterministically combining the estimated peak ground acceleration with the spectrum shape. Therefore, it is recommended that for the sites associated with relatively high risks, the above recommendation for the negligible probability shape be applied in conjunction with an appropriate procedure for probabilistically estimating the total seismic exposure.

- For sites judged to be significantly responsive to ground motion components with periods longer than 0.5 seconds, the above shapes should not be used without appropriate modifications for the particular site conditions.

II. INTRODUCTION

A. GENERAL

Earthquakes are complex phenomena that impose severe loadings on engineered structures. The earthquake phenomena primarily consist of large energy releases in limited volumes of the earth's crust and propagation of significant parts of these released energies as seismic body and surface waves. Engineered structures located in the propagation path of these waves respond with vibratory motions. These vibrations generate forces in the structures which have to be safely resisted. Instances of inadequate structural resistance to seismic loadings with disastrous consequences occur frequently. Some of the major earthquakes that caused considerable damage are: San Fernando (1971), Tokachi-Oki (1968), Lima (1966), Alaska (1964), Kern County (1952), El Centro (1940), Long Beach (1933), San Francisco (1906), Charleston (1885), and New Madrid (1811-12).

The severity of vibratory structural response to seismic motion largely depends on the seismic ground motion characteristics and the structure's dynamic characteristics. Some of the important ground motion characteristics are the peak motion parameters, such as acceleration, velocity, and displacement, and the frequency content of the ground motion. The ground motion frequency content can be generally described as a measure of relative predominance of different frequencies present in the ground motion. Spectrum shapes are one of the measures of the ground motion frequency content and are important in estimating seismic structural response.

Nuclear power plants are critically important structures, and as such must be designed for appropriate seismic conditions. Because earthquakes are complex phenomena and exact predictions of seismic ground motions are not possible, it is appropriate to base the seismic design criteria on statistical predictions of these motions. Various ground shaking intensity levels and the probabilities of their being exceeded should be established, and the seismic levels associated with appropriate probabilities of exceedance should be used in the design.

One approach to developing statistical predictions of seismic loadings is to determine probabilities of occurrence of ground motion frequency characteristics.

The study described herein analysed the frequency distribution of ground motions generated by a number of major earthquakes. The results were then used to develop "standardized" design spectrum shapes.

B. SCOPE

The studies in this report were oriented toward the delineation of appropriate shapes of earthquake response spectra to be recommended for seismic design purposes, based on the rationale described above. The project was authorized in the USAEC Division of Reactor Standards letter dated August 18, 1971. The major steps in the studies were as follows:

- Develop response spectrum shapes for the horizontal ground motion components of a number of selected major earthquakes.

- Study the effect of earthquake duration on spectrum shape by determining the relationship between the spectrum shape and number of cycles at predominant periods.

- Perform statistical studies of the spectrum shapes, including grouping of the spectra according to various earthquake and site characteristics.

- Recommend spectrum shapes appropriate for seismic design and evaluation of nuclear power plant facilities.

- Compare the results of the above analyses with the current AEC seismic design review procedures.

Studies of each of the above items and the results are discussed in the following text.

III. RESPONSE SPECTRUM SHAPES

A. INTRODUCTION

A number of important and reliable earthquake records of horizontal ground motion components were selected, response spectrum shapes developed, and statistical studies made of the ensemble of response spectrum shapes. A fairly large ensemble was used to derive significant results from the studies. The development of the spectra shapes and the statistical studies are discussed in this chapter. A number of important and reliable earthquake records of horizontal ground motion components were selected and response spectrum shape were developed. The ensemble of response spectrum shapes developed from the selected earthquake accelerograms and the corresponding statistical studies are presented in this chapter. To derive significant results from the statistical studies, a fairly large ensembie of important ground motions was analysed.

B. SELECTION OF HISTORIC EARTHQUAKES

A total of thirty-three accelerograms generated by twelve different major earthquakes with peak ground accelerations exceeding 0.ig were selected for the analysis (Table 1). Different magnitude ratings for an earthquake are sometimes reported in the literature because the values reported are usually averages of the values estimated at several recording stations. The magnitudes given in Table 1 were selected because they have been quoted most frequently. The rationale for selecting the earthquake records was as follows:

- The accelerograms were considered to be reliable records of the ground motions because most were recorded recently. Those not recorded recently, such as El Centro and Helena, have been extensively and reliably documented.
- The accelerograms were associated with fairly intense ground shaking.
- A wide-range of response spectra characteristics was represented by the selected accelerograms. The Lima and Hachinohe records were included because the Lima records contain a predominant high-frequency

content and the Hachinohe records a predominant low-frequency content. Inclusion of these records thus increased the range of different spectrum shape characteristics.

- The accelerograms included eight different and important records from the 1971 San Fernando earthquake.

- The accelerograms comprise a reasonably large ensemble, thus yielding a higher degree of confidence and reliability to the studies.

- The effects of geographical variations were included because the accelerograms were recorded at a number of different geographical locales.

C. ANALYTICAL ASPECTS OF A RESPONSE SPECTRUM

A response spectrum is defined as a plot of the maximum values of a response parameter of a family of linearly elastic single-degree-of-freedom systems with different frequency characteristics and with a given ratio of system damping to critical damping when subjected to a ground motion time-history versus the frequency characteristics (such as natural periods or frequencies) of the systems.

For the purposes of this report, the pseudo absolute acceleration response spectrum shapes for damping ratios of 0.005, 0.01, 0.02, 0.05, 0.07, and 0.10 were developed for the selected accelerograms.

Figure 1 shows a model of a single-degree-of-freedom system. The spring is linearly elastic with stiffness k and the dashpot indicates a viscous damper with a damping coefficient c.

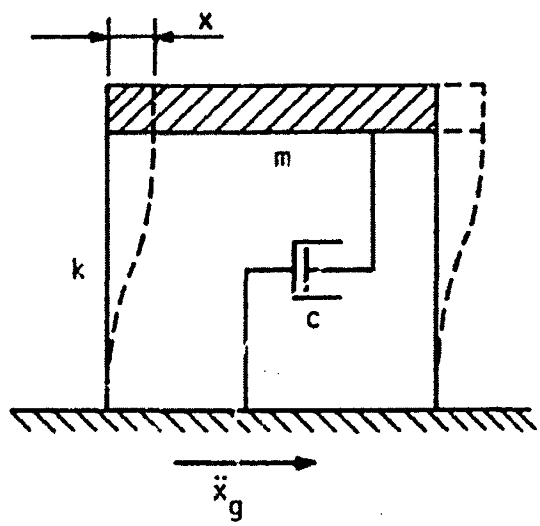

FIGURE 1. SINGLE-DEGREE-OF-FREEDOM SYSTEM

The equation of motion of this system is:

$$m\ddot{x} + c\dot{x} + kx = -m\ddot{x}_g \tag{1}$$

in which

m = mass [M]*

x = displacement relative to the ground [L]

$\dot{x} = \frac{dx}{dt}$ = velocity relative to the ground $[LT^{-1}]$

$\ddot{x} = \frac{d^2x}{dt^2}$ = acceleration relative to the ground $[LT^{-2}]$

c = damping constant $[MT^{-1}]$

k = spring constant $[MT^{-2}]$

$\ddot{x}_g$ = ground motion acceleration $[LT^{-2}]$

---

* [M] indicates the dimension of the quantity. The basic dimensions are mass, M; length, L; time, T.

Equation (1) can be rewritten as:

$$\ddot{x} + 2\zeta\omega\dot{x} + \omega^2 x = -\ddot{x}_g \tag{2}$$

in which

$$\omega = \sqrt{\frac{k}{m}} = \text{circular frequency } [T^{-1}]$$

$$\zeta = \frac{c}{2m\omega} = \text{damping ratio}$$

The solution of Equation (2) is given by

$$x(t) = -\int_0^t h(t-\tau)\, \ddot{x}_g(\tau)\, d\tau \tag{3}$$

in which

$$h(\tau) = \text{impulse response function } [T]$$

$$= \frac{1}{\bar{\omega}} \exp\left[-\zeta\omega\tau\right] \sin(\bar{\omega}\tau) \tag{4}$$

and

$$\bar{\omega} = \text{damped circular frequency } [T^{-1}]$$

$$= \omega\sqrt{1 - \zeta^2}$$

For a moderate amount of damping, $\bar{\omega}$ nearly equals ω. As example, for a relatively high damping value of 20%, $\bar{\omega}$ is equal to 0.98ω. Because the damping values for most of the dynamic analyses of nuclear power plant elements are considerably less than 20%, the difference between $\bar{\omega}$ and ω is negligible. Thus, ω will be used in place of $\bar{\omega}$. The system spring force, F, at an instant, t, is given by

$$F(t) = kx(t) = m\omega^2 x(t) \tag{5}$$

$$\text{Let } \ddot{z}_p(t) = \omega^2 x(t) \tag{6}$$

$$\text{Then } F(t) = m\,\ddot{z}_p(t) \tag{7}$$

$\ddot{z}_p$ has the dimensions of acceleration, $[LT^{-2}]$, and is termed pseudo absolute acceleration. Comparison of Equation (6) with Equation (2) indicates the reason for this quantity being termed "pseudo", namely, the magnitude of $\ddot{z}_p$ differs from that of the real absolute acceleration by a quantity, $2\zeta\omega\dot{x}$. The pseudo relative velocity, $\dot{x}_p$, is defined by

$$\dot{x}_p = \frac{\ddot{z}_p}{\omega} \quad [LT^{-1}] \tag{8}$$

Then, accepting $\Omega \approx \omega$,

$$\ddot{z}_p(t) = \omega\, \dot{x}_p(t) = \omega^2\, x(t) \tag{9}$$

In accordance with the definition of a response spectrum, the pseudo absolute acceleration response spectrum, S_a, is given by

$$S_a\,(T,\zeta,\ddot{x}_g) = \max \left| \ddot{z}_p\,(T,\zeta,\ddot{x}_g) \right| \tag{10}$$

in which

$$T = \text{natural period} \quad [T]$$

$$= \frac{2\pi}{\omega}$$

S_a depends on the system period, T, the system damping ratio, ζ, and the input ground motion, $\ddot{x}_g$. Equation (11) is derived from theoretical considerations and Equation (8)

$$S_a\,(0,\zeta,\ddot{x}_g) = \max \left| \ddot{x}_g \right| = a \tag{11}$$

Thus, for a rigid system ($\omega=\infty$, $T=0$), the pseudo absolute acceleration spectrum value equals the maximum ground acceleration, a. This is one reason why normalization of ground motion by peak ground acceleration is convenient. The spectrum value generated from the ground motion normalized by the peak acceleration is actually the dimensionless ratio of the pseudo absolute acceleration spectrum value to the peak ground acceleration and is termed dynamic amplification factor (DAF) for pseudo absolute acceleration.

Let $D(T,\zeta,\ddot{x}_g)$ = dynamic amplification factor (DAF) for pseudo absolute acceleration

$$\text{Then } D(T,\zeta,\ddot{x}_g) = \frac{S_a(T,\zeta,\ddot{x}_g)}{a} \tag{12}$$

$$\text{and } D(0,\zeta,\ddot{x}_g) = 1.0 \tag{13}$$

Thus, for zero period, D equals 1.0.

D. RESPONSE SPECTRUM SHAPES FROM HISTORIC EARTHQUAKES

The objective of the studies was to analyze the shapes of the response spectra, not the response spectra themselves. To facilitate the comparison of the spectrum shapes, the accelerograms were normalized to a peak ground acceleration of 1.0g. Thus, the spectral values obtained are dimensionless ratios of spectral acceleration to peak ground acceleration, or dynamic amplification factors (DAF). The response spectra generated from such normalized ground motions are termed response spectrum shapes, or DAF. The response spectrum shapes are useful for comparing the relative predominance of different frequencies in an individual accelerogram and for different accelerograms. Accelerograms can be normalized by several different methods. For the purposes of this study, normalization by peak ground acceleration was considered most useful and convenient, especially for the statistical predictions of response spectrum shapes.

A recursive algorithm[6] was used to compute the response spectrum shapes of the selected historic earthquakes for damping ratios of 0.005, 0.01, 0.02, 0.05, 0.07, and 0.10. Because the method of digitization of accelerograms significantly affects the response spectra,[7] the most recent and most reliable accelerogram digitizations were used in the analyses.

The spectrum shapes were computed for a period range of 0.04 sec to 2.5 sec, or a frequency range of 0.4 cps to 25 cps, which was considered sufficient to encompass the frequency characteristics of nuclear power plant components. This range of frequency characteristics was discretized by using 108 points to obtain good frequency resolution of the spectra.

The Fourier content of digitized accelerogram data may be accurate up to about 25 cps,[8] and thus the upper bound on the frequency range of the spectra was set at 25 cps. Most of the accelerogram data were as described in Reference 1 and hence the accelerogram corrections, such as smoothing of the fixed trace, smoothing of the timing marks, and the root-mean-square minimization of acceleration were applied to the data. Generally, the accelerograms are also corrected by shifting and/or rotating the base line or using a band-pass filter. Such corrections are necessary only for computing ground motion velocities and displacements. Because they do not significantly affect the computation of the pseudo absolute acceleration response,[8,9] these corrections were not considered necessary.

Linear plots of the spectrum shapes are presented with period as abscissa and alternatively with frequency as abscissa in Appendix A as Figures A1 through A66. These two ways of plotting complement each other, representing the spectrum details more fully. Frequency-plots were used in determining the spectral values for the high-frequency elements and period-plots were used for the long period elements.

TABLE 1

SALIENT CHARACTERISTICS OF SELECTED ACCELEROGRAMS

Earthquake	Year	Recording Station	Magnitude	Component	Peak Ground Acceleration, g Units
El Centro	1940	El Centro, California	7.0	NS EW	0.33 0.22
El Centro	1934	El Centro, California	6.5	NS EW	0.26 0.18
Kern County	1952	Taft, California	7.7	N21°E S69°E	0.18 0.16
Olympia	1949	Olympia, Washington	7.1	N4°W S86°W	0.19 0.31
Helena	1935	Helena, Montana	6.0	NS EW	0.13 0.16
San Francisco	1957	Golden Gate Park, California	5.3	N10°E N80°W	0.11 0.13
Parkfield	1966	Cholame-Shandon # 2, California	5.6	N65°E S25°W	0.51 Not Recorded
Parkfield	1966	Cholame-Shandon # 5, California	5.6	N5°W N85°E	0.40 0.47
Tokachi-Oki	1968	Hachinohe, Japan	7.8	NS EW	0.19 0.23
Lima	1966	Lima, Peru	7.5	N8°E N82°W	0.42 0.27
San Fernando	1971	Castaic, ORR, California	6.6	N21°E S69°E	0.34 0.29
San Fernando	1971	Bank of Calif., California	6.6	N11°E N79°W	0.23 0.14
San Fernando	1971	Universal-Sheraton, Calif.	6.6	NS EW	0.18 0.13
San Fernando	1971	V.N. Holiday Inn, California	6.6	NS EW	0.28 0.15
Eureka	1954	Eureka, California	6.6	N79°E N11°W	0.26 0.18
Olympia	1965	Olympia, Washington	6.5	S4°E S86°W	0.20 0.16
Parkfield	1966	Temblor, California	5.6	N65°W N25°E	0.28 0.33

NOTE: Information presented in the above table is compiled from References 1, 2, 3, 4, and 5.

IV. STATISTICAL ANALYSES OF SPECTRUM SHAPES

A. INTRODUCTION

The analyses in this chapter were oriented toward statistical predictions of the characteristics of future ground motions. Spectrum shape statistics such as mean, median, and standard deviation were computed for the complete ensemble of spectrum shapes discussed in Chapter III. These statistics were also computed for the accelerograms grouped in four different ways:

- maximum ground acceleration,
- soil characteristics at the recording site,
- epicentral distance, and
- geographical locale of the recording stations.

The median and mean values indicate the central tendency of a sample. The standard deviation measures uncertainty associated with the sample. In most of the cases, the combination of either the mean or median and the standard deviation suffices for statistical predictions.

B. STATISTICAL ANALYSIS TECHNIQUES

In an ensemble of n response spectrum shapes, shown in Figure 2, let $D_i(T_j,\xi)$ denote the spectral ordinate of the ith spectrum shape for the period, T_j, and the damping ratio, ξ. Then, the mean, $m_D(T_j,\xi)$, and standard deviation, $s_D(T_j,\xi)$, are computed by the following equations:

$$m_D(T_j,\xi) = \frac{1}{n} \sum_{i=1}^{n} D_i(T_j,\xi) \tag{14}$$

$$s_D(T_j,\xi) = \left\{ \frac{1}{n-1} \sum_{i=1}^{n} \left[D_i(T_j,\xi) - m_D(T_j,\xi) \right]^2 \right\}^{\frac{1}{2}} \tag{15}$$

The median of the ensemble, $\breve{m}_D(T_j,\zeta)$, is determined as follows: First, the spectral values, $D_i(T_j,\zeta)$, $i = 1, 2, \ldots, n$, are rearranged in a descending order. Then, if n is an even number,

$$\breve{m}_D(T_j,\zeta) = \tfrac{1}{2}\left[D_{\frac{n}{2}}(T_j,\zeta) + D_{\frac{n}{2}+1}(T_j,\zeta)\right] \tag{16a}$$

If n is an odd number,

$$\breve{m}_D(T_j,\zeta) = D_{\frac{n+1}{2}}(T_j,\zeta) \tag{16b}$$

The mean spectrum shape, $m_D(\zeta)$, the median spectrum shape, $\breve{m}_D(\zeta)$, and the standard deviation spectrum shape, $s_D(\zeta)$, are constructed by computing means, medians, and standard deviations for 108 periods in the period range under consideration. The mean and median spectrum shape values for zero period equal unity and the standard deviation spectrum value for zero period equals zero because the DAF value for zero period is constant and equals unity. From Equations (14) and (16), the actual values of the mean and median shapes will not be equal, if there is a skew in the data.

C. STATISTICS OF SPECTRUM SHAPE ENSEMBLE

The mean, median, and standard deviation response spectrum shapes for the complete ensemble of the selected accelerograms and for all damping ratios were computed as described above and are presented in Appendix B as Figures B1 through B18. The following observations regarding these spectrum shapes are pertinent:

- The mean and median spectrum shapes, indicators of the central tendency of the ensemble, are similar for each damping ratio. The small quantitative difference between these two statistics indicates that the DAF data has some skewness. See Chapter VI for a detailed discussion of the DAF distributions.

- The mean and median spectrum shapes are smooth. As expected, the smoothness increases with the damping ratios.

- As the period approaches zero the mean and median shape values approach unity and the standard deviation approaches zero, as expected. The standard deviation decreases as the period increases. This decrease, however, is much smaller than the corresponding decrease in the mean and median shapes. Thus, the relative uncertainty in the DAF increases with the period, especially for periods longer than 0.25 sec. For periods longer than 0.5 sec, the relative uncertainty is substantially larger than for the shorter periods, and its fairly rapid upward trend continues to 2.5 sec period.

  The main reason for the increase in uncertainty with period is that the ensemble contains several accelerograms with either short or long strong ground motion duration. As will be demonstrated in Chapter V, the short duration accelerograms show a predominance of short periods only, whereas those with long duration show the predominance of both short and long periods. Thus, the central tendency of the ensemble is accentuated in the short period range and considerably subdued in the long period range. Due to relatively large deviations of DAF's in the long period range, however, the relative uncertainty for this range is greater than for the short period range.

- The mean and median spectrum shapes decrease and become flatter with increasing damping ratios, which indicates relatively greater decrease for the short periods than for the long periods. The standard deviation spectrum shapes also decrease and becomes flatter with increasing damping ratio. This decrease is smaller, however, than in the mean and median and is especially true for the long periods which results in greater flatness. Thus, the relative uncertainty in DAF values remains practically indifferent to the changes in damping ratio. Increased damping tends to attenuate response more for short periods than for long periods.

D. STATISTICS OF GROUPED SPECTRUM SHAPES

1. General

The rationale of the grouping approach will be briefly discussed first so that the group statistics may be appropriately interpreted.

A number of earthquake characteristics could influence response spectrum shapes.[10] Grouping of the records by a selected characteristic helps to investigate and estimate the influence of such characteristics on response spectrum shapes. Such an investigation has maximum significance if performed under the ideal condition that only the characteristic under consideration is varied while others are kept constant. It is apparent from the sparsity of the available ground motion data, however, that this is not feasible. It is helpful, nevertheless, to understand what information could be obtained from the grouping approach under ideal conditions.

Assume that a seismic characteristic, s, in the range, $s_1 < s < s_2$, favors a frequency range, $f_1 < f < f_2$, over other frequencies. Then, the mean, median, and standard deviation spectrum shapes for the accelerograms in the group, $s_1 < s < s_2$, would be expected to display the following characteristics:

- In the frequency range, $f_1 < f < f_2$, the mean and median spectrum values for this group will be generally higher than those for the other groups, indicating the preference of this group. The same behavior will be expected when the ensemble mean and median are compared with the group mean and median.

- In the frequency range, $f_1 < f < f_2$, the standard deviation spectrum shapes will be generally lower than those for the other groups, indicating a smaller degree of uncertainty associated with the spectrum values for the preferred frequencies. The same behavior will be expected when the standard deviation shapes of the ensemble are compared with those of the group.

Higher spectrum shape values for the preferred frequency range will be more probable than for the other frequencies. The reliability of such an interpretation depends on two factors, namely, the number of accelerogram samples in the group, and the range of seismic parameter values defining the group. The reliability will increase with an increase in the number of samples, and decrease with an increase in the range of seismic parameter values.

Statistics of the spectrum shapes grouped in four different ways were computed to investigate the influence of different earthquake characteristics on the response spectra. The accelerograms were grouped according to:

- the maximum recorded ground acceleration (Table 2),
- the soil characteristics at the recording station (Table 3),
- the epicentral distance of the recording station (Table 4), and
- the geographical locale of the recording stations (Tables 5, 6, 7, and 8).

The specific details of the groups and the analytical results are significant. Different values for a characteristic of an earthquake are sometimes reported in the literature. In such cases, an apparently reasonable value of the characteristic was adopted in the analyses without further investigating the authenticity of the value. It would be worthwhile, however, to conduct such an investigation to improve the reliability of the available information.

2. Maximum Ground Acceleration

Table 2 lists a grouping of accelerograms according to maximum ground accelerations. This grouping of accelerograms described below achieves a reasonable balance between group size and range of accelerations.

Group	Maximum Ground Acceleration, a	Number of Accelerograms
A1	$a \geq 0.3g$	8
A2	$0.2g \leq a < 0.3g$	10
A3	$a < 0.2g$	15

The mean, median, and standard deviation spectrum shapes for the three groups of accelerograms for a 0.02 damping ratio are presented in Appendix C as Figures C1 through C9. The following are pertinent observations regarding these spectrum shapes:

- The Group A1 mean and median shapes are generally somewhat lower than the mean and median shapes of the Groups A2 and A3 (Figures C1, C2, C4, C5, C7, and C8). The Group A1 standard deviation spectrum shape for periods longer than 1.0 second is considerably lower than the ones of the other groups for the same period range (Figures C3, C6, and C8). This means that higher DAF values for Group A1 are less probable than they would be for Groups A2 and A3. This is particularly true for periods longer than 1.0 second; in other words, higher DAF values occur for accelerograms with $a < 0.3g$.

- No clear trends are apparent for the Groups A2 and A3.

In spite of the first observation above, the maximum ground accelerations of the accelerograms generally have low correlation with the corresponding DAF values. Thus, probabilities for the DAF values, as discussed in Chapter VI, may be considered independent of those for the maximum ground accelerations. This conclusion leads to this important result:

From Equation (12),

$$S_a(T_j,\zeta,\ddot{x}_g) = a \cdot D(T_j,\zeta,\ddot{x}_g) \tag{17}$$

Thus, the probabilities of exceedance for the spectral ordinate, S_a, used for computing response of structures, can be derived by a rather simple combination of the probabilities for the peak ground acceleration, a, and the DAF for pseudo absolute acceleration, D. This method of combination of probabilities is discussed further in Chapter VI.

3. <u>Soil Characteristics</u>

The following site characteristics could influence the response spectrum shape:

- Soil density
- Soil layering
- Layer thicknesses
- Depth to firm rock
- Water table elevation at the site
- Soil moisture content
- Shear and compressional wave velocities in the soil
- Nature of soil behavior -- linear or nonlinear

It is apparent from the above list that the influence of the soil characteristics on the response spectrum shape is a complex phenomenon. Investigation of this phenomenon is and has been treated as an independent field.[11] Thus, the subject can be treated only in an approximate way in the present analysis.

It was shown [11,12] that the soil impedance, I, is determined by Equation (18) is one of the factors of considerable importance in this kind of analysis.

$$I = \rho V_s \tag{18}$$

in which

ρ = specific soil density

V_s = velocity of shear wave in soil

In the present analysis, soil impedances of the top layrrs at the recording stations were used as the basis for grouping of the accelerograms. In the case of a site with a number of shallow soil layers, an overall average value of impedance was used. For the selected accelerograms, information on the soil characteristics at various recording sites is sparse and contains a high degree of uncertainty. More detailed soil, geological and geophysical investigations of various recording station sites are needed to form a firm basis for the kind of analysis described in Subsection 1 of this chapter.

The grouping of accelerograms according to their site impedance in Table 3 can be condensed as follows:

Group	Impedance, I, (ft/sec)x10^3	Number of Accelerograms
B1	$4.0 < I < 5.5$	13
B2	$I \leq 3.9$	16

The accelerograms recorded at Helena and Temblor are not included in these groups because the estimated impedance values for these sites, based on the available data, are considerably higher than those of the other sites and could result in an anomalous influence on the analysis. The mean, median, and standard deviation spectrum shapes for the accelerograms in these two groups for 0.02 damping ratio value are presented in Appendix C as Figures C10 through C15.

The following are pertinent observations regarding these spectrum shapes:

- The mean and median shapes for each group are generally similar to each other.
- The mean shape of the Group B1 is generally lower than that of the Group B2.
- No clear trend is seen in the standard deviation shapes.

It has been found[12] that the accelerograms recorded at firmer sites generally show lower DAFs than those for the accelerograms recorded at softer sites. This is indicated by the second observation above. It would seem reasonable that ground motions recorded at soft sites would show a predominance of lower frequencies and those recorded at firm sites would have higher predominant frequencies. Such a trend was not strongly indicated by the results of this analysis because of the uncertainty associated with the soil characteristics data, however, these results should not be considered as a negation of this belief.

4. <u>Epicentral Distances of Recording Stations</u>

The accelerograms were arranged according to the epicentral distances of the recording stations as follows (Table 4):

Group	Epicentral Distance, D Miles	Number of Accelerograms
C1	$15 < D \leq 45$	14
C2	$D \leq 15$	15

The accelerograms recorded at Hachinohe and Lima were not included in the analysis because the reported epicentral distances for these recording stations are much longer than those for the other stations and hence could have an anomalous influence on the analysis.

The mean, median, and standard deviation spectrum shapes for the accelerograms in the Groups C1 and C2 for a 0.02 damping ratio are in Appendix C as Figures C16 through C21. The following are pertinent observations regarding these spectrum shapes:

- The mean and median shapes for each group are similar to each other.
- The mean shapes for both the groups are approximately equal.
- The standard deviation shape for the Group C1 is considerably lower than for the Group C2 for periods longer than 0.5 second.

Although the comparisons of the median spectrum shapes do not clearly indicate predominance of lower frequencies for accelerograms recorded at longer epicentral distances or predominance of higher frequencies in records with shorter epicentral distances, the third observation above would tend to confirm these effects. As other parameters, such as soil characteristics, would also influence the response spectrum shapes, the absence of clear trends in this grouping are not unexpected. In addition, epicentral distance per se may not be a significant factor with respect to the response spectrum shapes. This may be particularly true for earthquakes associated with fairly long fault breaks. In such cases, the distance between the station and the nearest point of surface rupture might be more appropriate. Also, the reported epicentral distances may not be the actual ones because epicenters cannot be located exactly.

E. GEOGRAPHIC GROUPING OF SPECTRUM SHAPES

The selected accelerograms were recorded at a number of different geographical locales in seismically active areas of the world. The accelerograms were generated by earthquakes that originated in different geological settings and perhaps by different earthquake source mechanisms.

In all, spectrum shapes for five different geographic groups of accelerograms, including the ensemble, were statistically analyzed as follows:

Group	Geographical Locale	Number of Accelerograms
I	San Fernando Valley earthquake	8
II	Southern California	19
III	California	23
IV	Western U.S.A.	29
V	Worldwide	33

The salient characteristics of the thirty-three accelerogram ensemble are listed in Table I (Chapter III); those for the remainder of the above groups are reproduced in Tables 5 through 8.

Mean, median, and standard deviation spectrum shapes for Groups I through IV for 0.02 damping ratio are presented in Appendix C as Figures C22 through C33. Ensemble spectrum shape statistics for 0.02 damping ratio (Group V) are in Appendix B as Figures B7 through B9.

A number of pertinent observations regarding comparisons of the spectrum shape statistics for a geographical grouping can be made:

- The mean and median shapes for each group are similar to each other. The mean shapes are generally smoother than the median shapes.

- The Group I mean spectrum shape is generally higher than those for the other groups, especially for the period ranges of 0.2 - 0.4 sec and 0.7 - 2.5 sec. In the latter period range, this shape is substantially higher than those for the other groups which indicates a strong predominance of long period motion. In the short period range, 0.04 - 0.02 sec, the Group I shape is slightly lower than the Group V mean shape.

- The Group II mean spectrum shape is somewhat higher than those for Groups III, IV, and V. This tendency is more pronounced for the longer period range (greater than 0.5 sec). This shape is slightly lower than the Group IV and V shapes in the short period range, 0.04 - 0.2 sec.

- The mean spectrum shapes for Groups III, IV, and V are close to each other.

- The standard deviation spectrum shapes show more variations than the mean shapes.

- The Group I standard deviation spectrum shape is higher than those for the other groups in the period ranges of 0.2 - 0.4 sec and 1.0 - 2.5 sec, with the exception that the Group V shape is substantially higher in the range of 1.0 - 1.25 sec but lower than the others in the remaining period ranges.

- The Group II and III standard deviations are similar. Both are substantially lower than those for Group IV and V in the short period range, 0.04 - 0.1 sec.

- The Group IV standard deviation shape is similar to that for Group V except it is lower than the latter in the period ranges of 0.04 - 0.1 sec and 0.8 - 1.2 sec.

- The ground motions recorded in California are predominant in the period ranges of 0.2 to 2.5 sec. This is particularly true for the accelerograms generated by the San Fernando earthquake. Incorporation of the spectrum shapes from the other parts of the western U.S.A. and worldwide results in predominant dynamic amplification in the short period range, 0.04 - 0.2 sec.

It appears appropriate to develop standardized design spectrum shapes on the basis of the ensemble spectrum statistics for the following reasons:

- The ensemble mean and standard deviation spectrum shapes appear to encompass broader ranges of frequency content than those of any other group. Thus, the predictions based on the ensemble statistics would better represent the conditions not yet recorded in local areas in addition to those recorded.

- The reliability of the statistical measures and the predictions based on them increases with the sample size. The ensemble consists of more earthquake records than any other group. Therefore, the ensemble statistics and predictions based on them would be more reliable than those for any other group.

F. SUMMARY OF FINDINGS

Statistical analyses of the ensemble of response spectrum shapes and the grouped spectrum shapes were presented in this chapter. The spectrum shapes were grouped in four ways; by maximum ground acceleration, by epicentral distance, by soil characteristics, and by geographical locales. The major findings were:

- The mean and median spectrum shapes for the groups are smooth in comparison with the shapes for individual accelerograms, and they are similar to each other. The median shape is less smooth than the mean and shows small quantitative variations from the mean, indicating some skewness in spectrum shape data.

- The mean and median shape values decrease for longer periods and higher damping. The rate of decrease with longer periods, however, decreases with higher damping, resulting in flatter shapes for higher damping.

- The standard deviation spectrum shapes show greater variations than the mean and median, indicating greater variability of uncertainty.

- The standard deviation shapes also generally decrease with longer period and higher damping. However, the rates of decrease are relatively smaller than those for the means and medians, indicating increased relative uncertainty for longer periods and an indifference of relative uncertainty with respect to damping.

- The influences of various seismic parameters on response spectrum shape were indicated from the grouping approach. The significance of the results of this part of the study, however, would be enhanced if the following conditions could be met:

  1. The uncertainties associated with some of the available data are investigated and minimized.

  2. A large number of reliable accelerograms are available so as to allow variation of only one parameter while the others are kept constant.

Because reliable ground motion data are sparse, it is difficult to satisfy the second condition. The following significant observations, however, can be made from the results of group analyses:

- The approach of using spectrum shape derived from the ground motion analysis by normalizing the peak ground motion to unity was confirmed because the peak ground accelerations and the spectrum shape values had low correlation. Separate treatment of these two as independent variables was therefore appropriate.

- Spectral amplification at a soft site can be expected to be larger than at a firm site. The expected long period predominance for soft sites and short period predominance for firm sites were not confirmed or rejected.

- The influence of epicentral distance on spectrum shape diminishes with the increasing epicentral distances. The expected long period predominance at longer epicentral distances was not indicated; neither was the rejection of this belief indicated.

- The results of the geographic grouping revealed that the central tendencies of the groups, indicated by means and medians, do not vary significantly with different geographical locales. Although the uncertainties or standard deviations did show significant variations, the ensemble represented a wide-range of frequency content much better than any other group. Thus, the ensemble was adopted as the basis for the recommended spectrum shapes.

TABLE 2

GROUPING OF ACCELEROGRAMS ACCORDING TO MAXIMUM GROUND ACCELERATIONS

Number	Accelerogram	Component	Maximum Ground Acceleration, g Units	
1	Parkfield #2	N65°E	0.51	Group A_1
2	Parkfield #5	N85°E	0.47	
3	Lima	N8°E	0.42	
4	Parkfield #5	N5°W	0.40	
5	Castaic ORR	N21°E	0.34	
6	El Centro, 1940	NS	0.33	
7	Temblor	N25°E	0.33	
8	Olympia, 1949	S86°W	0.31	
9	Castaic ORR	S69°E	0.29	Group A_2
10	V.N. Holiday Inn	NS	0.28	
11	Temblor	N65°W	0.28	
12	Lima	N82°W	0.27	
13	El Centro, 1934	NS	0.26	
14	Eureka	N79°E	0.26	
15	Hachinohe	EW	0.23	
16	Bank of California	N11°E	0.23	
17	El Centro, 1940	EW	0.22	
18	Olympia, 1965	S4°E	0.20	
19	Olympia, 1949	N4°W	0.19	Group A_3
20	Hachinohe	NS	0.19	
21	El Centro, 1934	EW	0.18	
22	Taft	N21°E	0.18	
23	Universal-Sheraton	NS	0.18	
24	Eureka	N11°W	0.18	
25	Taft	S69°E	0.16	
26	Helena	EW	0.16	
27	Olympia, 1965	S86°W	0.16	
28	V.N. Holiday Inn	EW	0.15	
29	Bank of California	N79°W	0.14	
30	Helena	NS	0.13	
31	Golden Gate Park	N80°W	0.13	
32	Universal-Sheraton	EW	0.13	
33	Golden Gate Park	N10°E	0.11	

TABLE 3

GROUPING OF ACCELEROGRAMS ACCORDING TO THE SOIL IMPEDANCE AT THE RECORDING STATIONS

Number	Recording Station	Impedance, I $\frac{ft}{sec} \times 10^3$	
1	Helena	19.1	
2	Temblor	10.3	
3	Golden Gate Park	5.4	Group B1
4	Cholame-Shandon #2	4.3	Group B1
5	Cholame-Shandon #5	4.3	Group B1
6	Hachinohe	4.3	Group B1
7	Castaic, ORR	4.3	Group B1
8	Eureka	4.3	Group B1
9	Lima	4.2	Group B1
10	Van Nuys Holiday Inn	3.0	Group B2
11	Olympia	2.1	Group B2
12	Bank of California	1.6	Group B2
13	Universal-Sheraton	1.6	Group B2
14	Taft	1.3	Group B2
15	El Centro	1.1	Group B2

Note: Information presented in the above table is deduced and/or compiled from References 5, 11, 13, 14, 15, 16, 17, 18 and 19.

TABLE 4

GROUPING OF ACCELEROGRAMS ACCORDING TO EPICENTRAL DISTANCE OF THE RECORDING STATIONS

Number	Recording Station	Epicentral Distance, Miles	
1	Hachinohe	100	
2	Lima	100	
3	Taft	44	Group C1
4	Olympia, 1965	35	Group C1
5	Olympia, 1949	31	Group C1
6	El Centro, 1934	20	Group C1
7	Castaic ORR	18	Group C1
8	Bank of California	18	Group C1
9	Universal-Sheraton	18	Group C1
10	Eureka	15	Group C2
11	El Centro, 1940	13	Group C2
12	Van Nuys Holiday Inn	13	Group C2
13	Golden Gate Park, S.F.	8	Group C2
14	Helena	4	Group C2
15	Temblor	4	Group C2
16	Cholame-Shandon #5	3.3*	Group C2
17	Cholame-Shandon #2	0.05*	Group C2

* Shortest distance from the San Andreas fault

Note: Information presented in the above table is compiled from References 2, 3, 4, 5, 13, and 14.

TABLE 5
GEOGRAPHIC GROUP I:
SAN FERNANDO VALLEY EARTHQUAKE

Earthquake	Year	Recording Station	Magnitude	Component	Peak Ground Acceleration, g Units
San Fernando	1971	Castaic, ORR, California	6.6	N21°E S69°E	0.34 0.29
San Fernando	1971	Bank of California, California	6.6	N11°E N79°W	0.23 0.14
San Fernando	1971	Universal-Sheraton, Calif.	6.6	NS EW	0.18 0.13
San Fernando	1971	V.N. Holiday, Inn, California	6.6	NS EW	0.28 0.15

TABLE 6
GEOGRAPHIC GROUP II:
SOUTHERN CALIFORNIA

Earthquake	Year	Recording Station	Magnitude	Component	Peak Ground Acceleration, g Units
El Centro	1940	El Centro, California	7.0	NS EW	0.33 0.22
El Centro	1934	El Centro, California	6.5	NS EW	0.26 0.18
Kern County	1952	Taft, California	7.7	N21°E S69°E	0.18 0.16
Parkfield	1966	Cholame-Shandon #2 California	5.6	N65°E Not Recorded	0.51
Parkfield	1966	Cholame-Shandon #5 California	5.6	N5°W N85°E	0.40 0.47
San Fernando	1971	Castaic, ORR California	6.6	N21°E S69°E	0.34 0.29
San Fernando	1971	Bank of California, California	6.6	N11°E N70°W	0.23 0.14
San Fernando	1971	Universal-Sheraton, Calif.	6.6	NS EW	0.18 0.14
San Fernando	1971	V.N. Holiday, Inn, California	6.6	NS EW	0.28 0.15
Parkfield	1966	Temblor, California	5.6	N65°W N25°E	0.28 0.33

TABLE 7
GEOGRAPHIC GROUP III:
CALIFORNIA

Earthquake	Year	Recording Station	Magnitude	Component	Peak Ground Acceleration, g Units
El Centro	1940	El Centro, California	7.0	NS EW	0.33 0.22
El Centro	1934	El Centro California	6.5	NS EW	0.26 0.18
Kern County	1952	Taft, California	7.7	N21°E S69°E	0.18 0.16
San Francisco	1957	Golden Gate Park, California	5.3	N10°E N90°W	0.11 0.13
Parkfield	1966	Cholame-Shandon #2, California	5.6	N65°E Not Recorded	0.51
Parkfield	1966	Cholame-Shandon #5, California	5.6	N5°W N85°E	0.40 0.47
San Fernando	1971	Castaic, ORR, California	6.6	N21°E S69°E	0.34 0.29
San Fernando	1971	Bank of California, California	6.6	N11°E N79°W	0.23 0.14
San Fernando	1971	Universal-Sheraton, Calif.	6.6	NS EW	0.18 0.14
San Fernando	1971	V.N. Holiday, Inn, California	6.6	NS EW	0.28 0.15
Eureka	1954	Eureka, California	6.6	N79°E N11°W	0.26 0.18
Parkfield	1966	Temblor, California	5.6	N65°W N25°E	0.28 0.33

TABLE 8
GEOGRAPHIC GROUP IV:
WESTERN U.S.A.

Earthquake	Year	Recording Station	Magnitude	Component	Peak Ground Acceleration, g Units
El Centro	1940	El Centro, California	7.0	NS EW	0.33 0.22
El Centro	1934	El Centro, California	6.5	NS EW	0.26 0.18
Kern County	1952	Taft, California	7.7	N21°E S69°E	0.18 0.16
Olympia	1949	Olympia, Washington	7.1	N4°W S86°W	0.19 0.31
Helena	1935	Helena, Montana	6.0	NS EW	0.13 0.16
San Francisco	1957	Golden Gate Park, California	5.3	N10°E N80°W	0.11 0.13
Parkfield	1966	Cholame-Shandon #2, California	5.6	N65°E Not Recorded	0.51
Parkfield	1966	Cholame-Shandon #5, California	5.6	N5°W N85°E	0.40 0.47
San Fernando	1971	Castaic, ORR, California	6.6	N21°E S69°E	0.34 0.29
San Fernando	1971	Bank of California, California	6.6	N11°E N79°W	0.23 0.14
San Fernando	1971	Universal- Sheraton, Calif.	6.6	NS EW	0.18 0.13
San Fernando	1971	V.N. Holiday, Inn, California	6.6	NW EW	0.28 0.15
Eureka	1954	Eureka, California	6.6	N79°E N11°W	0.26 0.18
Olympia	1965	Olympia, Washington	6.5	S4°E S86°W	0.20 0.16
Parkfield	1966	Temblor, California	5.6	N65°W N25°E	0.28 0.33

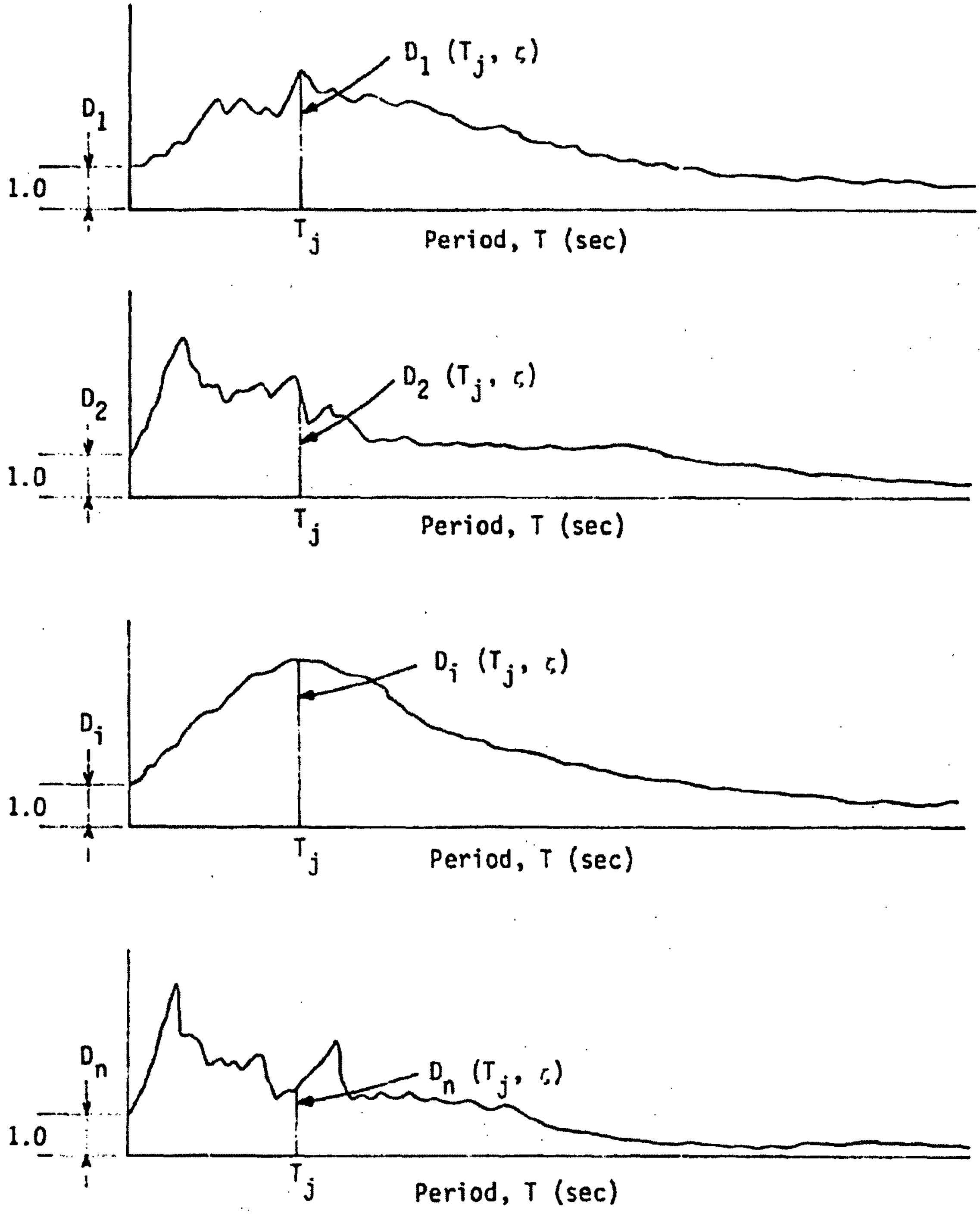

FIGURE 2. ENSEMBLE OF n RESPONSE SPECTRUM SHAPES

V. EFFECTS OF EARTHQUAKE DURATION

A. GENERAL

It is generally thought that long duration shaking is more damaging to buildings than short duration shaking, even though the amplitues may be equal. Although the duration of strong shaking may not directly affect the onset of damage, damage could be increased by continued strong motion. Thus, it seems reasonable to postulate that damage potential of an earthquake is directly dependent on the response levels induced and their duration. For this reason the effects of duration of strong seismic motion were included in this study.

The response spectrum, which is normally used to define seismic input motion, is a plot of the maximum values of a specified response parameter. The response spectrum permits ready evaluation of the frequency content of the seismic input motion. However, the duration of the maximum responses and their frequency of occurrence are not discernible from the spectrum curve. It is therefore possible that response levels smaller than the maximums may exist, which might induce greater structure damage. The study was structured so as to investigate response levels, in addition to the maximums, that might be significant from the viewpoint of potential damage, and how these levels and their duration are affected by the earthquake duration.

Detailed information regarding the relationship between building damage and structural response levels and durations is not available. Attempts, however, are being made to estimate the influence of structural response level and its duration on building damage by low-cycle fatigue.[20]

B. ANALYTICAL APPROACH

A recently developed technique of period-amplitude-time (PAT) contour mapping[21] of response time-histories was used in these studies.

The pseudo absolute acceleration response time-histories of a family of single-degree-of-freedom systems with different natural periods and 2% damping ratio subjected to a ground motion were generated and the response amplitudes enveloped to obtain response envelope time-histories. The response envelope contours corresponding to a number of response levels were then plotted on a period-elapsed time plane. The PAT plots thus generated were advantageous in studying the duration of various response levels for each earthquake. The number of cycles at a given response level were approximately determined by first obtaining the total time extent of the response level contour for a given period and then taking the ratio of the time extent to the period.

C. PAT PLOT STUDIES AND RESULTS

Eight different accelerograms generated by four important earthquakes were selected for the PAT plot studies (Table 9). The PAT plots for these accelerograms, normalized to a 1.0g maximum ground acceleration, for a 0.02 damping ratio are in Appendix D as Figures D1 through D8. It can be seen from Table 9 that the El Centro and Taft accelerograms have a fairly long strong motion duration and the Helena and Golden Gate Park have relatively short durations. The PAT plot studies of these accelerograms are indicative of the duration effects of a range of strong motion durations.

The results of the PAT plot studies of the selected accelerograms are summarized in Tables 10 through 17. The predominant periods for these accelerograms are those with fairly large DAFs (see the response spectrum shapes in Appendix A). The total durations of different response levels for each period were scaled from the PAT plots. The DAF values corresponding to the periods are also listed.

D. OBSERVATIONS

- Although Helena and Golden Gate Park records are dominant in the 0.10 to 0.20 sec period range, El Centro (NS) is also strong in this range.
- All records participate in the 0.10 to 0.50 sec period range.
- El Centro and Taft are dominant for periods longer than 0.5 sec.
- The number of cycles decreases with period, as expected.
- Normalized responses as great as 4.0 or more appear out to 0.5 sec period.

The above observations lead to the following interpretation:

- Both the short and long duration motions show significant and comparable dynamic amplification for periods shorter than 0.4 sec. Thus, the duration effect on the response spectrum shape for periods shorter than 0.5 sec -- a significant period range for nuclear power plant structures -- can be considered relatively small. For longer periods, however, the short duration records show significantly smaller dynamic amplification than the long duration records. The spectrum shapes for longer periods would thus generally tend to be higher for long duration motions than the short duration motions. This trend is reasonable because short duration shaking cannot contain significant long period motion nor permit the longer response build-up times required for major response of long period structures.

- The total durations of various normalized response levels for a given period are generally longer for the long duration accelerograms than those for short duration motion. This indicates that the almost-free vibrations that ensue after the strong shaking are quickly damped out and thus would not result in a prolonged large-amplitude response.

The above observations confirm the higher overall damage potential of long duration earthquakes because they would excite structures over a much wider range of frequencies. Large-amplitude structural responses would be more prolonged for long duration earthquakes, and damage once started, would tend to progress.

SUMMARY OF MAJOR FINDINGS

- The earthquake duration effect on the response spectrum shape for periods shorter than 0.4 sec -- a significant period range for nuclear power plant structures -- is small. The shape for longer periods, however, would generally tend to be higher for long duration motions than for short duration motions.

- Long duration earthquakes could be potentially more damaging than those of short duration because of the following reasons:

  1. Long duration earthquakes would excite structures and structure components over a much wider range of frequencies.

  2. Large-amplitude structural responses would be more prolonged for long duration earthquakes, and once damage is started, it would tend to progress.

  3. Short duration earthquakes appear to induce significantly fewer cycles of damaging response for periods less than 0.4 sec, than do longer duration earthquakes. For the purpose of this comparison, response accelerations greater than 0.5g are assumed to be damaging.

  4. Long duration earthquakes also induce a significant number of cycles of damaging response in periods greater than 0.4 sec.

TABLE 9

STRONG MOTION DURATIONS[3] OF THE ACCELEROGRAMS SELECTED FOR THE PAT PLOT STUDIES

Number	Accelerogram	Component	Strong Motion Duration, sec
1	El Centro, 1940	NS EW	24
2	Taft	N21°E S69°E	17
3	Helena	NS EW	4
4	Golden Gate Park, S.F.	N10°E N90°W	3

TABLE 10

RESULTS FROM PAT PLOT STUDIES OF EL CENTRO, 1940, NS

Number	Predominant Period, sec	Normalized Response in Excess of	Total Duration, sec	No. of Cycles	DAF
1	0.136	1.0	2.90	21	3.63
		2.0	0.90	7	
		3.0	0.15	1	
2	0.248	1.0	4.10	17	3.55
		2.0	0.90	4	
		3.0	0.20	1	
3	0.451	1.0	10.00	22	3.49
		2.0	5.00	11	
		3.0	1.10	2	
4	0.551	1.0	6.80	12	3.43
		2.0	4.40	8	
		3.0	0.70	1	
5	0.900	1.0	8.5	10	2.12

TABLE 11

RESULTS FROM PAT PLOT STUDIES OF EL CENTRO, 1940, EW

Number	Predominant Period, sec	Normalized Response in Excess of	Total Duration, sec	No. of Cycles	DAF
1	0.248	1.0	17.4	70	4.36
		2.0	7.0	28	
		3.0	2.7	11	
		4.0	0.8	3	
2	0.302	1.0	21.1	70	2.90
		2.0	3.3	11	
3	0.451	1.0	12.4	28	3.84
4	0.551	1.0	7.7	14	3.79
		2.0	6.7	12	
		3.0	2.5	5	
5	0.744	1.0	16.7	22	2.27
		2.0	5.6	8	
6	1.226	1.0	18.1	15	2.25
		2.0	3.7	3	
7	2.10	1.0	8.5	4	1.47

TABLE 12

RESULTS FROM PAT PLOT STUDIES

OF TAFT, N21°E

Number	Predominant Period, sec	Normalized Response in Excess of	Total Duration, sec	No. of Cycles	DAF
1	0.244	1.0	9.6	43	3.67
		2.0	2.2	10	
		3.0	1.2	5	
2	0.369	1.0	10.3	28	4.30
		2.0	5.0	14	
		3.0	3.2	9	
		4.0	0.3	1	
3	0.499	1.0	9.0	18	2.87
		2.0	2.0	4	
4	0.673	1.0	11.8	18	3.28
		2.0	0.8	1	
5	0.822	1.0	18.1	22	2.3
		2.0	2.9	4	

TABLE 13

RESULTS FROM PAT PLOT STUDIES

OF TAFT, S69°E

Number	Predominant Period, sec	Normalized Response in Excess of	Total Duration, sec	No. of Cycles	DAF
1	0.203	1.0	12.2	60	3.58
		2.0	8.8	43	
		3.0	0.8	4	
2	0.334	1.0	18.1	54	4.25
		2.0	5.3	16	
		3.0	1.2	4	
		4.0	0.2	1	
3	0.451	1.0	12.4	28	4.58
		2.0	4.0	9	
		3.0	2.2	5	
		4.0	0.6	1	
4	0.609	1.0	10.7	18	2.10
		2.0	0.7	1	
5	0.822	1.0	7.2	9	2.11
		2.0	1.8	2	

TABLE 14
RESULTS FROM PAT PLOT STUDIES
OF HELENA, NS

Number	Predominant Period, sec	Normalized Response in Excess of	Total Duration, sec	No. of Cycles	DAF
1	0.111	1.0	3.6	32	3.33
		2.0	1.6	14	
		3.0	0.1	1	
2	0.150	1.0	3.8	25	5.09
		2.0	1.9	13	
		3.0	1.1	7	
		4.0	0.6	4	
3	0.408	1.0	5.4	13	2.45
		2.0	1.7	4	

TABLE 15
RESULTS FROM PAT PLOT STUDIES
OF HELENA, EW

Number	Predominant Period, sec	Normalized Response in Excess of	Total Duration, sec	No. of Cycles	DAF
1	0.183	1.0	3.5	19	3.86
		2.0	2.5	13	
		3.0	0.5	3	
2	0.274	1.0	3.2	12	3.64
		2.0	1.3	5	
		3.0	0.8	3	
3	0.369	1.0	5.1	14	3.28
		2.0	1.9	5	
		3.0	0.6	2	

TABLE 16

RESULTS FROM PAT PLOT STUDIES

OF GOLDEN GATE PARK, N10°E

Number	Predominant Period, sec	Normalized Response in Excess of	Total Duration, sec	No. of Cycles	DAF
1	0.111	1.0	3.0	27	2.97
		2.0	1.3	11	
2	0.150	1.0	2.6	17	3.74
		2.0	1.8	12	
		3.0	0.5	3	
3	0.248	1.0	3.8	15	3.71
		2.0	2.4	10	
		3.0	1.2	5	

TABLE 17

RESULTS FROM PAT PLOT STUDIES

OF GOLDEN GATE PARK, N80°W

Number	Predominant Period, sec	Normalized Response in Excess of	Total Duration, sec	No. of Cycles	DAF
1	0.136	1.0	1.6	12	4.78
		2.0	1.3	10	
		3.0	1.0	7	
		4.0	0.6	4	
2	0.244	1.0	4.1	18	4.32
		2.0	2.0	9	
		3.0	1.1	5	
		4.0	0.5	2	
3	0.408	1.0	2.3	6	1.54

VI. RECOMMENDED SPECTRUM SHAPES

A. INTRODUCTION

Nuclear power plants are structures of paramount importance because they are sources of power and because enormous potential risks are involved in the case of partial or total structural failure due to inadequate seismic resistance. Ideally, statistical predictions of seismic forces, structural behavior, and potential damage and loss should form a basis for design optimization to achieve minimum potential risk.[22] Designs of nuclear power plant structures, based on seismic design conditions having sufficiently low probabilities of exceedance considerably reduce or eliminate the risks of structural failure.

Pseudo absolute acceleration response spectra are quite important in representing the severity and frequency content of the seismic ground motions. As noted previously, they are also useful in determining the seismic forces induced in a structure. Statistical predictions of pseudo absolute acceleration response spectra should therefore provide a rational basis for probabilistically estimating the seismic input motion for structural designs.

Selection of spectrum shapes (i.e., pseudo absolute acceleration response spectra for ground motions normalized by the peak ground acceleration) is an important step in deriving the pseudo absolute acceleration response spectra. Recommendations for the use of spectrum shapes for damping ratios 0.005, 0.01, 0.02, 0.05, 0.07, and 0.10 are presented at the end of this chapter. The recommended spectrum shapes are based on the probability distributions considered suitable for the spectrum shape ensemble data.

B. RECOMMENDED SPECTRUM SHAPES

In view of the relationship between the pseudo absolute acceleration spectrum and the DAF, probabilistic estimation of the peak ground accelerations and the spectrum shape values is necessary for predicting the pseudo absolute acceleration spectra. Such peak ground accelerations and spectrum shapes then should be combined probabilistically to derive the spectra. It must be noted that deterministic estimates of very high peak ground accelerations based on a postulated extreme earthquake occurrence when directly combined with spectrum shapes representing fairly low probabilities of exceedance could result in extreme seismic conditions and hence unduly conservative designs. Pseudo absolute acceleration response spectra, S_a, for different probabilities of exceedance can be derived by using probability density functions (pdf) of peak ground accelerations (a) and DAFs (D) as discussed herein.

Let random variables Z, X, and Y represent S_a, a, and D, respectively. Then, Equation (17) can be rewritten as:

$$Z = X \cdot Y \tag{19}$$

Because of the low correlation between X and Y noted in Chapter IV, these variables can be considered independent and their joint pdf can be derived by Equation (20).

$$f_{X,Y}(x, y) = f_X(x) \cdot f_Y(y) \tag{20}$$

in which

$f_{X,Y}(x, y)$ = joint pdf of X and Y

$f_X(x)$ = pdf of X, $x \geq 0$

$f_Y(y)$ = pdf of Y, $y \geq 0$

Now, the pdf of Z, $f_Z(z)$ can be derived by Equation (21).

$$f_Z(z) = \frac{d}{dz}\left[\int_0^{\infty}\int_0^{z/y} f_{x,y}(\zeta,\eta)\, d\zeta\, d\eta\right],\ z \geq 0 \tag{21}$$

in which

ξ, ζ, η = dummy variables of integration

The pdf of Z or S_a can be used to derive different probabilities for S_a.

Probabilistic estimation of the peak ground accelerations is not within the scope of the present study. Probability estimation for DAFs are presented below.

- Probability Estimation for DAF

As discussed in Chapter III, the spectrum shape ensemble statistics, such as mean, median, and standard deviation were computed for 108 different periods in the period range under consideration. The coefficient of skewness, or third moment, and the coefficient of kurtosis, or fourth moment, were also determined for these periods. It is not surprising that the third and fourth moments varied considerably from period to period in view of the nature of response spectrum shapes, which tend to have pronounced peaks and valleys, especially at low damping values.

The skewness coefficients are positive, which indicates a distribution with a pronounced tail to the right, in this case away from the zero value. This is acceptable because response spectra are constructed with absolute peak values. The values of skewness vary widely between the general limits of 0 and 4. However, the middle period range of, say 0.02 to 0.75 seconds, has skewness values much less than either the shorter or longer periods, indicating for this range that the distribution is closer to the normal distribution symmetry. Over a range of damping values, the skewness coefficient averages about 0.3 to 0.4 for periods from 0.10 to 0.75 seconds and about 1.00 to 1.40 for other periods. The coefficient of kurtosis or flatness also is less in the middle period range with average values of about 2.3. This indicates more peaked distribution than normal. At the other periods, however, the kurtosis coefficient averages greater than 3, indicating flatter than the normal peaks.

These data, plus comparisons of mean and median values, indicate that there is more variation in the short and long period ranges than between 0.20 and 0.75 seconds. In general, a skewed distribution, with a zero lower limit, occurs over the whole period range of interest.

It is apparent from these observations that any one of several distributions would be effective. Three of these distributions, namely normal or Gaussian with appropriate truncation in view of the postulated absolute value for DAF, log normal, and extreme type II, were tried on the DAF ensemble for 0.02 damping ratio. All of these distributions are statistically acceptable within the range of the data.

The log normal distribution, given by Equation (22), was considered the most desirable because it is convenient to use and has been found effective for ground motions generated by underground explosions.[23]

$$D\,(T_j,\ \zeta;\ y) = \breve{m}_D(T_j,\zeta)\cdot\left[\beta\,(T_j,\ \zeta)\right]^{y} \tag{22}$$

in which

y = standardized normal variable

$\beta(T_j,\ \zeta)$ = geometric deviation for period, T_j, and damping ratio, ζ

$\breve{m}_D(T_j,\ \zeta)$ = median DAF for period, T_j, and damping ratio, ζ, computed by using the mean and standard deviation of DAF (as shown below). It differs only slightly from the median described in Chapter III

$D\,(T_j,\ \zeta;\ y)$ = DAF for period, T_j, and damping ratio, ζ, associated with the standardized normal variable, y.

The parameters, $\breve{m}_D$ and β are computed by using the ensemble mean and standard deviation as shown in Equations (23) and (24).

$$\breve{m}_D(T_j,\ \zeta) = m_D(T_j,\zeta)\ \exp\left[-\tfrac{1}{2}s_D^2(T_j,\zeta)\right] \tag{23}$$

$$\beta(T_j,\zeta) = \exp\left\{\sqrt{\ln\left[\left(\frac{s_D(T_j,\zeta)}{m_D(T_j,\zeta)}\right)^2 + 1\right]}\right\} \tag{24}$$

in which

$m_D(T_j,\zeta)$ = mean DAF for period, T_j, and damping ratio, ζ

$s_D(T_j,\zeta)$ = standard deviation DAF for period, T_j, and damping ratio, ζ

$\ln$ = natural logarithm

exp = exponentiation

The parameters, $\overline{m}_D$ and β were computed for all 108 different periods to derive the spectrum shapes for different y values of 0.0, 1.0, 1.645, and 2.0 corresponding to probabilities of exceedance of 50%, 15.8%, 5% and 2.3%, and for all damping ratios. These spectrum shapes are presented in Appendix E as Figures E1 through E6. Equation (22) shows that the y = 0 curve is the median shape.

These spectrum shapes are smooth when compared with spectrum shapes of individual accelerograms and form the basis for the recommended spectrum shapes.

The spectrum shapes in Appendix E for the above y values consistently follow a basic shape shown in Figure 3.

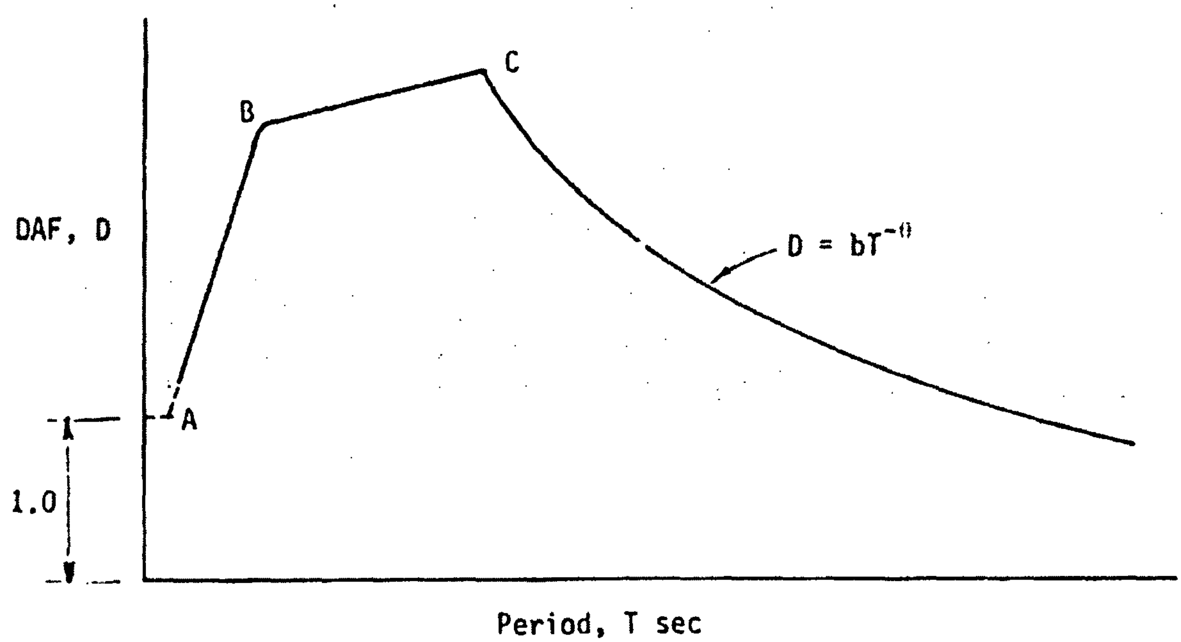

FIGURE 3. BASIC SPECTRUM SHAPE

A moderate amount of smoothing was required to derive smooth spectrum shapes from those in Appendix E. The amount of smoothing decreased rapidly with smaller γ values, longer periods, and higher damping ratios. It is noted that these spectrum shapes were not obtained by enveloping but by appropriate visual fitting to the different γ-value curves.

Three spectrum shapes, defined as large (50%), small (15.8%), and negligible (2.3%) probabilities of being exceeded, were developed corresponding to γ-values of 0.0, 1.0, and 2.0 and are presented in Figures 4 through 6. Four-way log plots of the shapes are presented in Figure 7. In addition, numerical data for the shapes, including the control points, A, B, and C, and parameters b and β are listed in Table 18 to facilitate the reconstruction of these curves. The curves in the vicinity of point A are extrapolations of the γ-curves in Appendix E because the original shapes, due to limitation of the input data, were computed to 25 cps frequency or 0.04 sec period. These extrapolations, however, do not result in any significant errors.

Comparisons of the recommended spectrum shapes for a 0.02 damping ratio with the current AEC criteria and other shapes proposed by Newmark[24], Housner[25], and Blume are presented in Figure 8.

The usefulness of the recommended spectrum shapes is demonstrated[26] by the fact that a time-history generated to match a spectrum curve for one damping-ratio shape matches quite well with the curves for other damping ratios. Such matching of spectrum shapes for different damping ratios by a single time-history has not been satisfactorily obtained so far and indicates the appropriateness of the recommended shapes with respect to damping ratio relationships.

C. MAJOR FINDINGS

The major findings from these analyses are:

- The log normal, truncated normal, and extreme type II probability distributions were found statistically acceptable for the spectrum shape ensemble data. The log normal distribution was adopted for the further analyses because it is the most convenient to use.

- The current AEC design spectrum shape for a 2% damping ratio is below the small probability of exceedance shape for periods shorter than 0.4 sec and for periods longer than 0.9 sec.

- The Newmark spectrum shape is consistently above the small probability of exceedance shape, except for a short interval in the vicinity of zero period.

- The Housner spectrum shape is below the large probability of exceedance shape for periods shorter than 0.4 sec, and it is above the latter for longer periods.

- The Blume F-factor spectrum shape for a 2% damping ratio and standardized normal variable value of 1.0 is consistently higher than the small probability of exceedance shape.

D. RECOMMENDATIONS

To minimize risk in the seismic design of important installations, such as nuclear power plants, the seismic load criteria should incorporate such factors as regional seismicity, geotectonics, etc. The following recommendations, pertinent to the spectrum shapes described herein, are intended to partly achieve the seismic design objective. Other ground motion characteristics, such as peak ground acceleration and strong motion duration, in the case of time-history analyses, should be given thorough consideration to fully satisfy the design objective. The following are recommended:

- The curves shown in Figure 4 should be considered as lower bound spectrum shapes for any site.

- For sites associated with relatively low risks, e.g., sites located in low seismicity areas, the design spectrum shapes for different damping ratios should not be lower than the small probability of exceedance spectrum shapes shown in Figure 5.

- For sites associated with relatively high risks, e.g., sites located in high seismicity areas, the design spectrum shapes for different damping ratios should not be lower than the negligible probability of exceedance spectrum shapes shown in Figure 6. Because these curves represent extreme ground motion amplification, their use should be carefully coordinated with the selection of the peak ground acceleration. Care must be exercised to ensure that the total seismic exposure for a site is compatible with the risk exposure involved and not unduly conservative.

- For sites judged to be significantly responsive to ground motion components with periods longer than 0.5 seconds, the above shapes should not be used without appropriate modifications for the particular site conditions.

TABLE 18

NUMERICAL DATA FOR RECOMMENDED SPECTPUM SHAPES

Probability of Being Exceeded	Damping Ratio	Point A		Point B		Point C		Parameters for the curve, $bT^{-\theta}$	
		T	DAF	T	DAF	T	DAF	b	θ
Large (50%)	0.005	0.03	1.0	0.12	3.2	0.35	4.0	1.20	1.46
	0.01	0.032	1.0	0.12	2.8	0.35	3.5	1.08	1.16
	0.02	0.034	1.0	0.12	2.5	0.35	2.9	0.93	1.075
	0.05	0.036	1.0	0.12	2.0	0.35	2.3	0.76	1.053
	0.07	0.038	1.0	0.12	1.85	0.35	2.0	0.67	1.038
	0.10	0.040	1.0	0.12	1.7	0.35	1.75	0.59	1.032
Small (15.8%)	0.005	0.028	1.0	0.11	5.1	0.35	6.2	2.34	0.928
	0.01	0.029	1.0	0.11	4.1	0.35	5.0	2.00	0.872
	0.02	0.030	1.0	0.11	3.5	0.35	4.2	1.73	0.843
	0.05	0.031	1.0	0.11	2.6	0.35	3.1	1.35	0.794
	0.07	0.032	1.0	0.11	2.2	0.35	2.6	1.13	0.790
	0.10	0.033	1.0	0.11	2.0	0.35	2.3	1.02	0.776
Negligible (2.3%)	0.005	0.025	1.0	0.09	8.1	0.35	9.6	4.32	0.761
	0.01	0.026	1.0	0.09	6.2	0.35	7.6	3.68	0.692
	0.02	0.027	1.0	0.09	4.8	0.35	5.9	3.12	0.604
	0.05	0.028	1.0	0.09	3.2	0.35	4.1	2.40	0.511
	0.07	0.029	1.0	0.09	2.6	0.35	3.4	2.03	0.489
	0.10	0.030	1.0	0.09	2.3	0.35	2.9	1.77	0.470

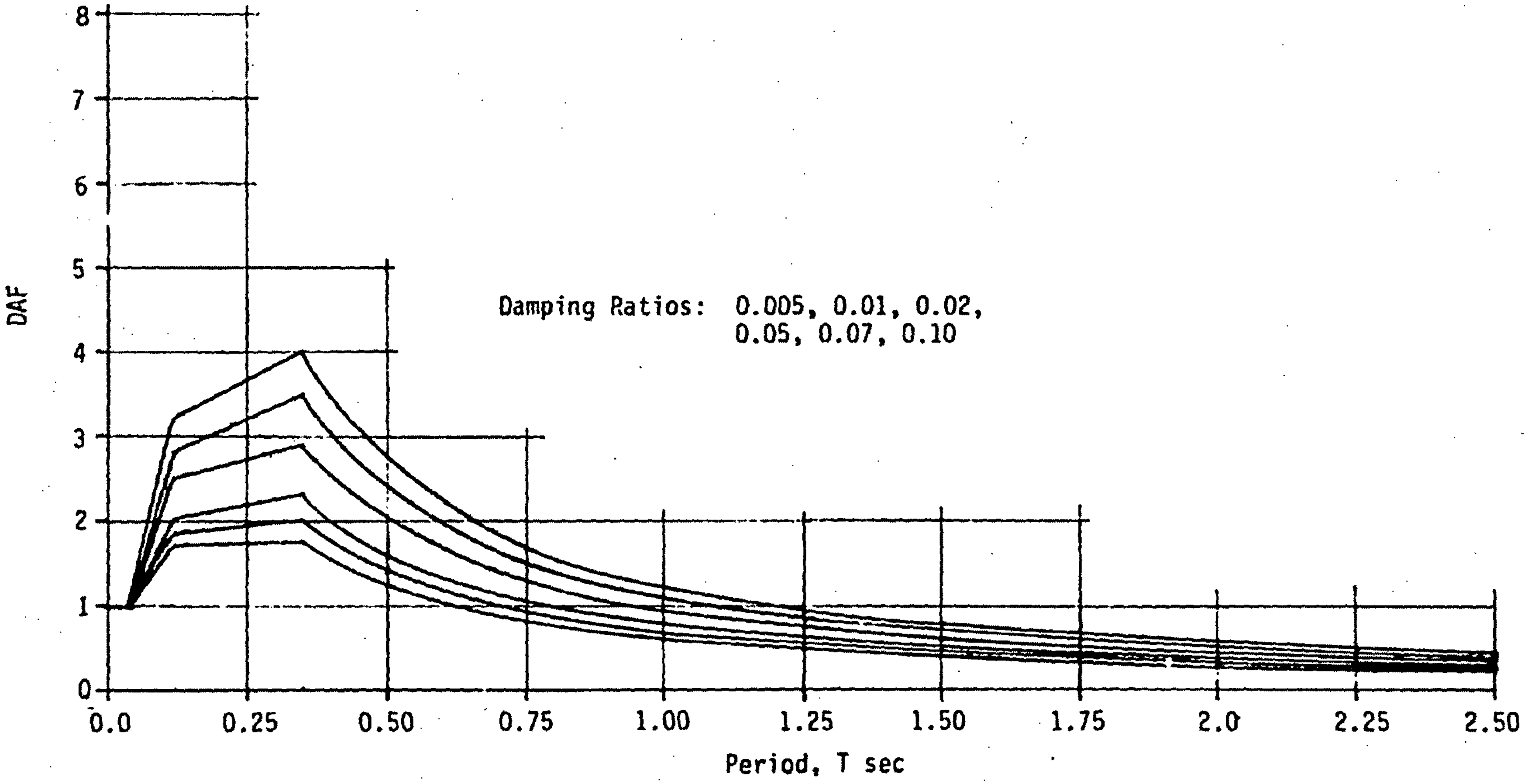

FIGURE 4a. RECOMMENDED SPECTRUM SHAPES FOR LARGE (50%) PROBABILITY OF EXCEEDANCE

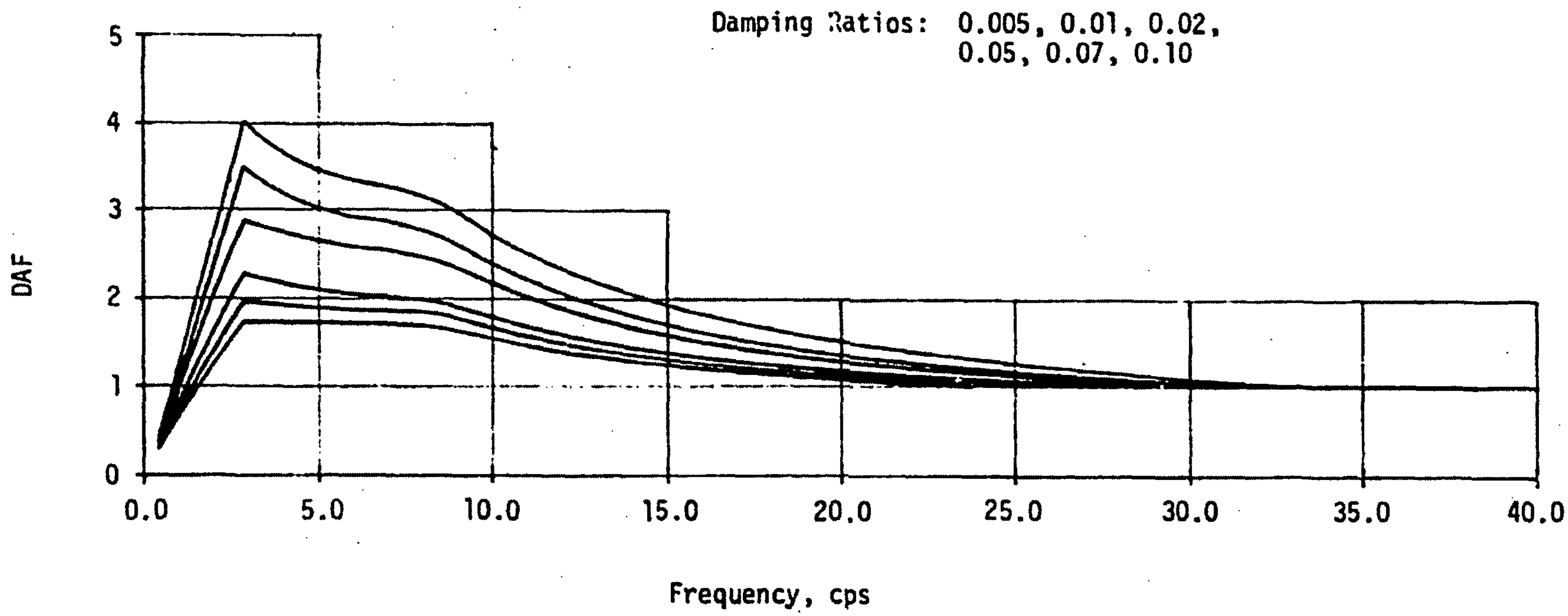

FIGURE 4b. RECOMMENDED SPECTRUM SHAPES FOR LARGE (50%) PROBABILITY OF EXCEEDANCE

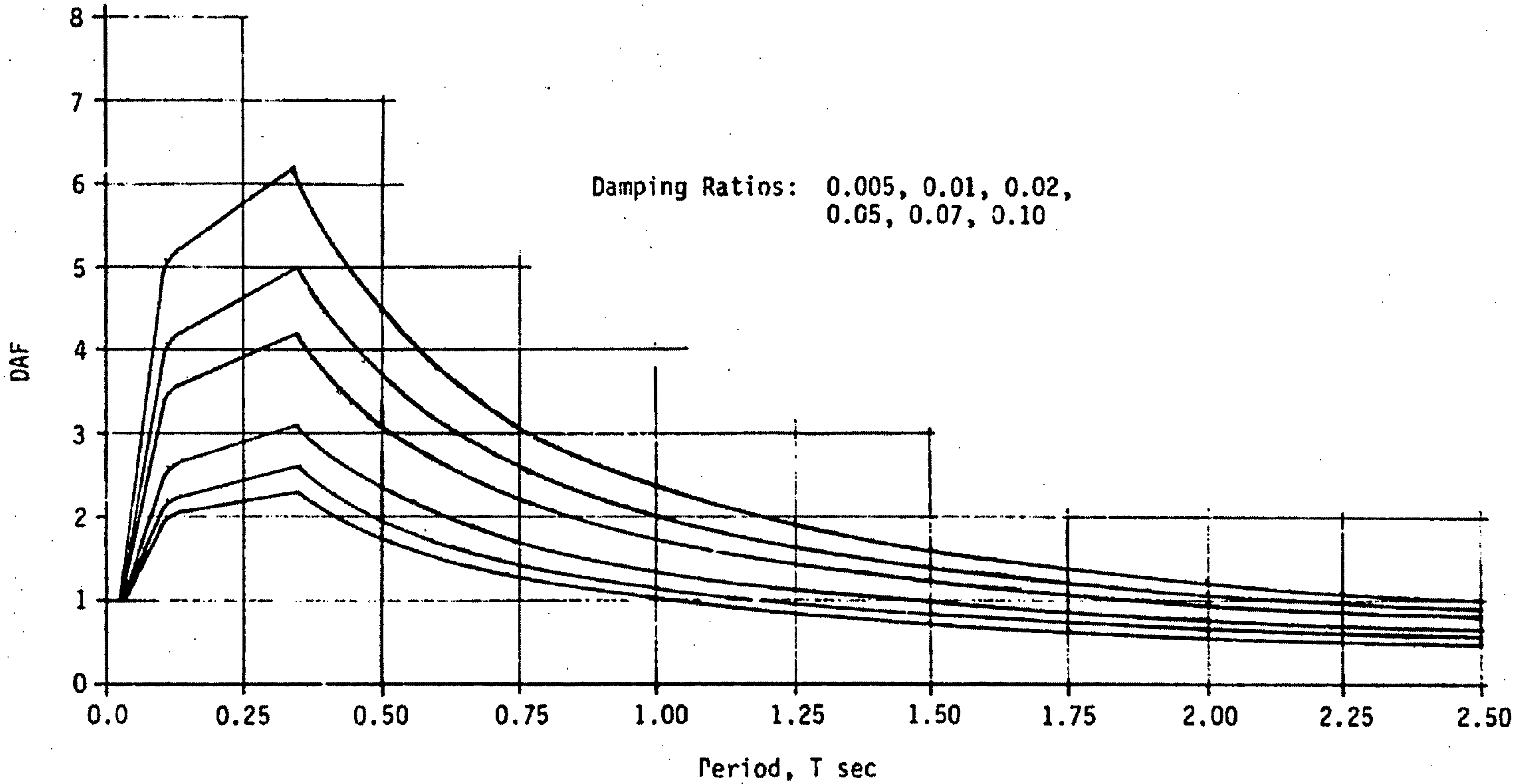

FIGURE 5a. RECOMMENDED SPECTRUM SHAPES FOR SMALL (15.8%) PROBABILITY OF EXCEEDANCE

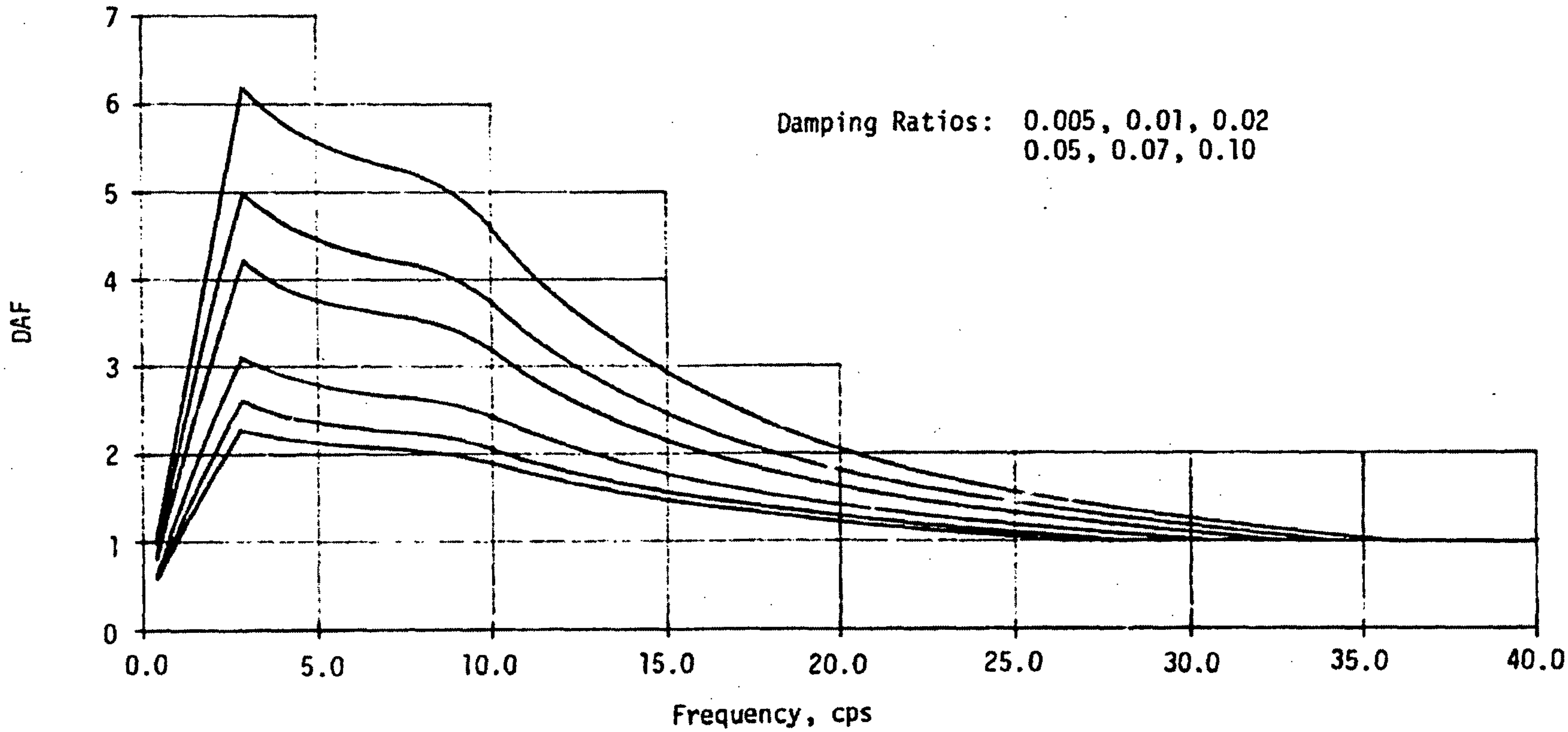

FIGURE 5b. RECOMMENDED SPECTRUM SHAPES FOR SMALL (15.8%) PROBABILITY OF EXCEEDANCE

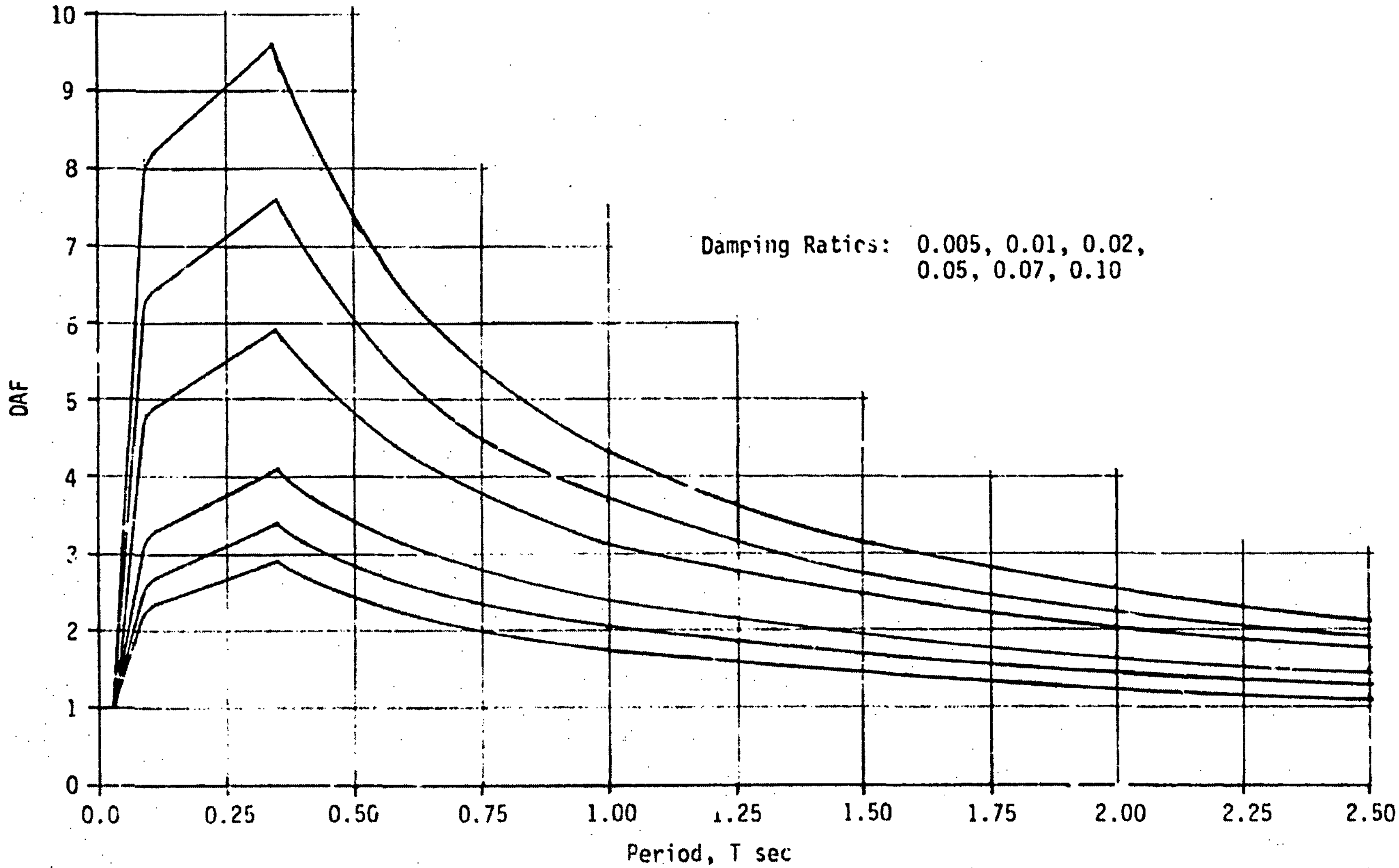

FIGURE 6a. RECOMMENDED SPECTRUM SHAPES FOR NEGLIGIBLE (2.3%) PROBABILITY OF EXCEEDANCE

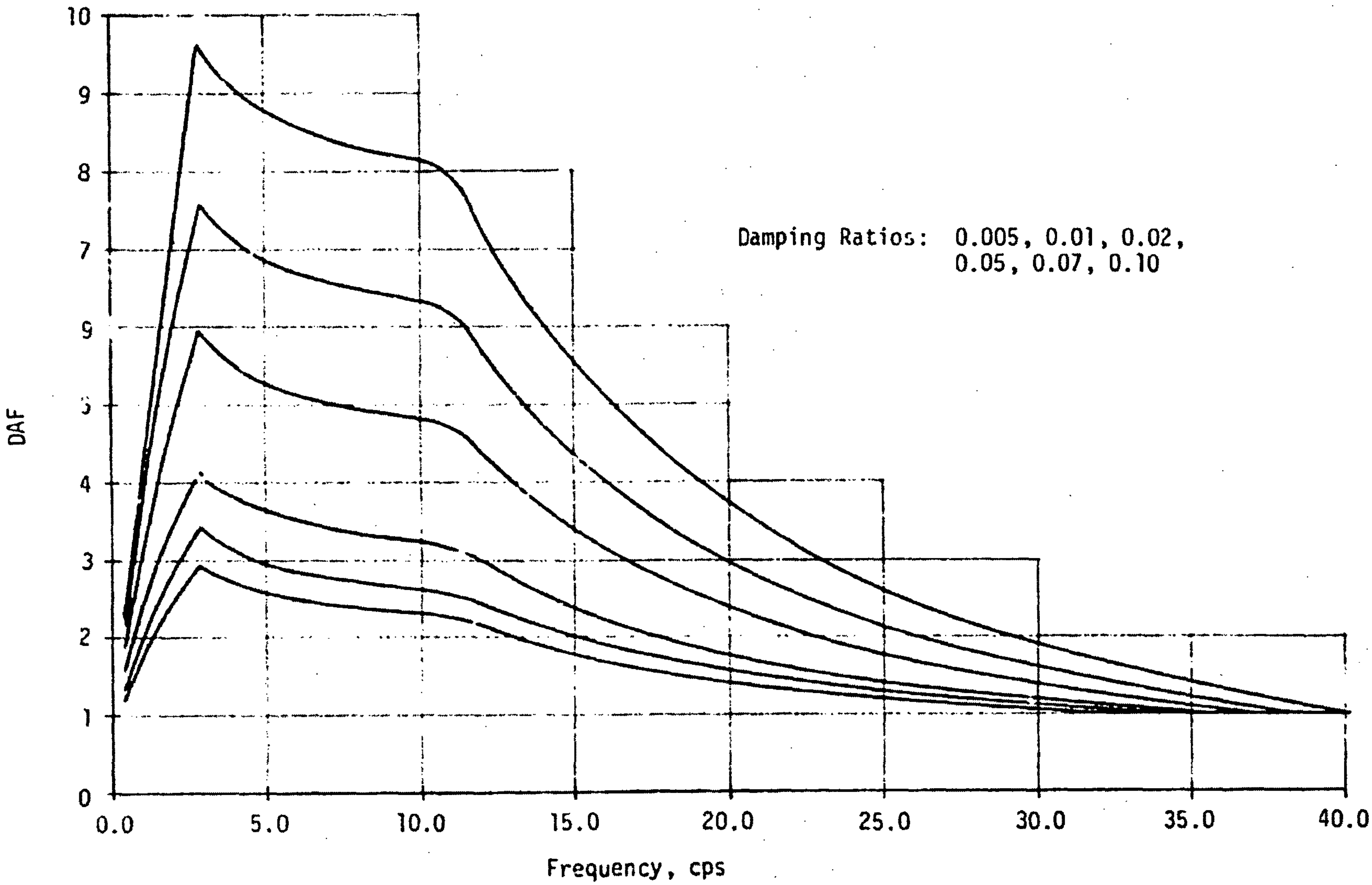

FIGURE 6b. RECOMMENDED SPECTRUM SHAPES FOR NEGLIGIBLE (2.3%) PROBABILITY OF EXCEEDANCE

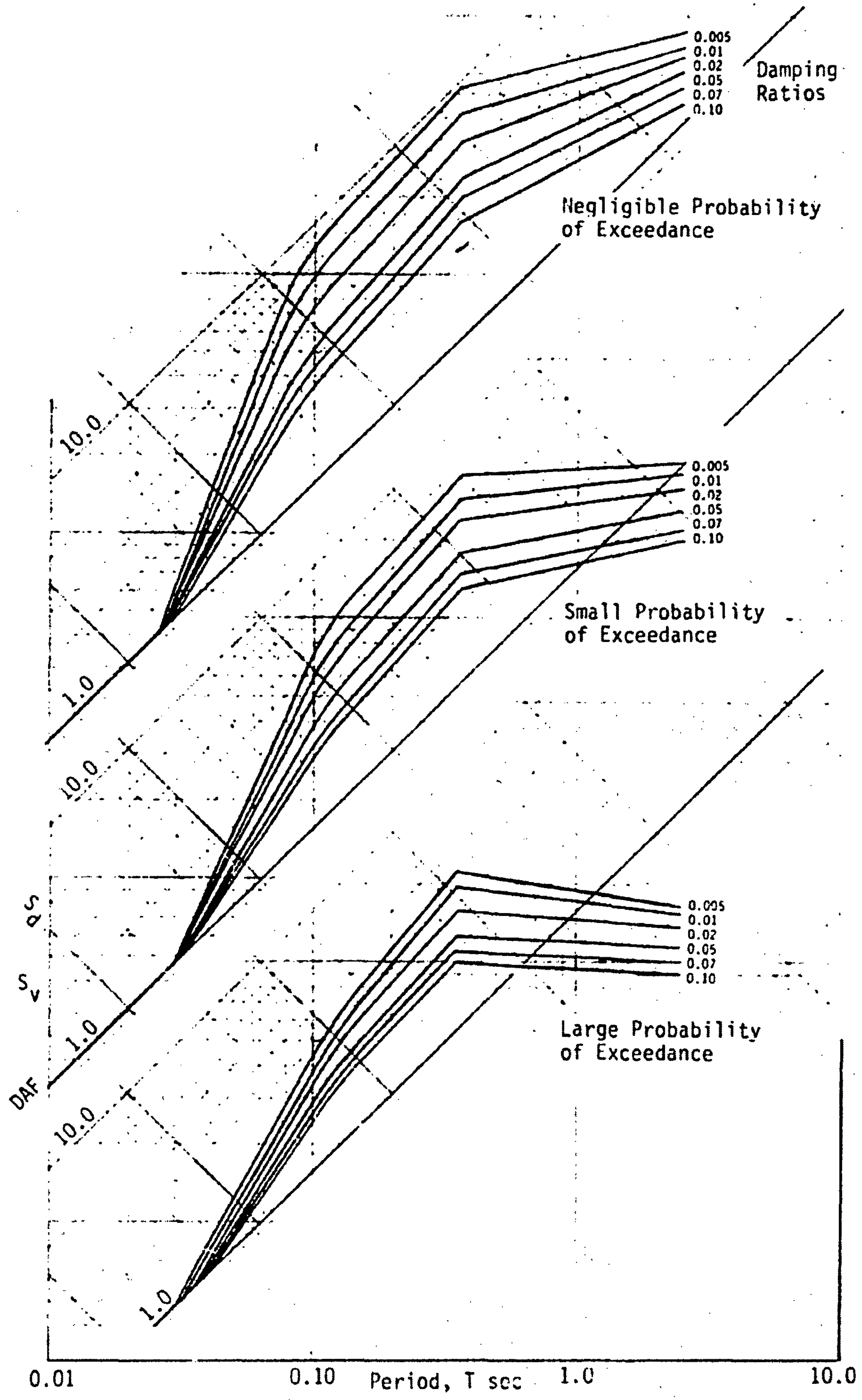

FIGURE 7. RECOMMENDED SPECTRUM SHAPES

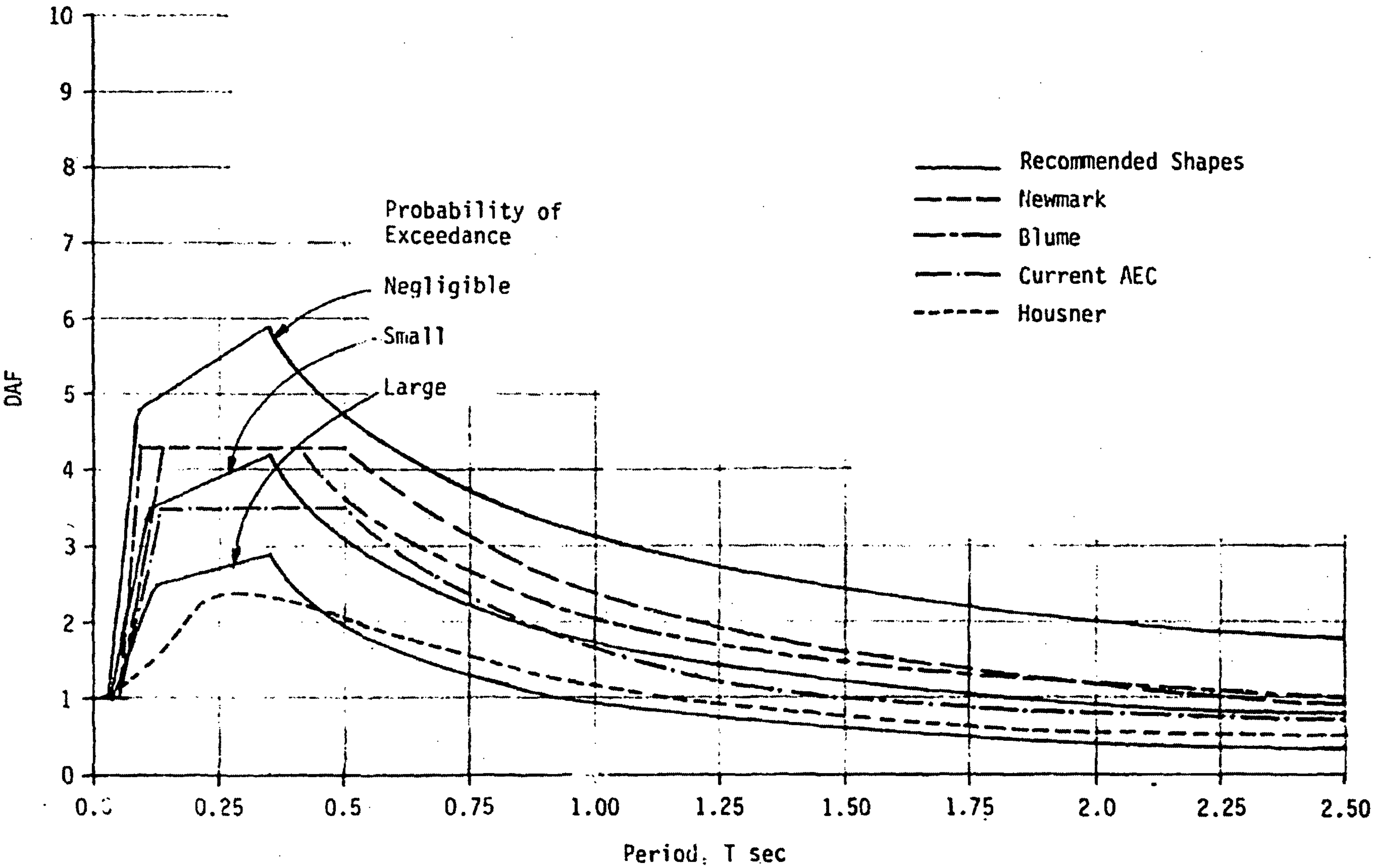

FIGURE 8. SPECTRUM SHAPE COMPARISONS; DAMPING RATIO = 0.02

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APPENDIX A

Response Spectrum Shapes

Figures A1 through A66

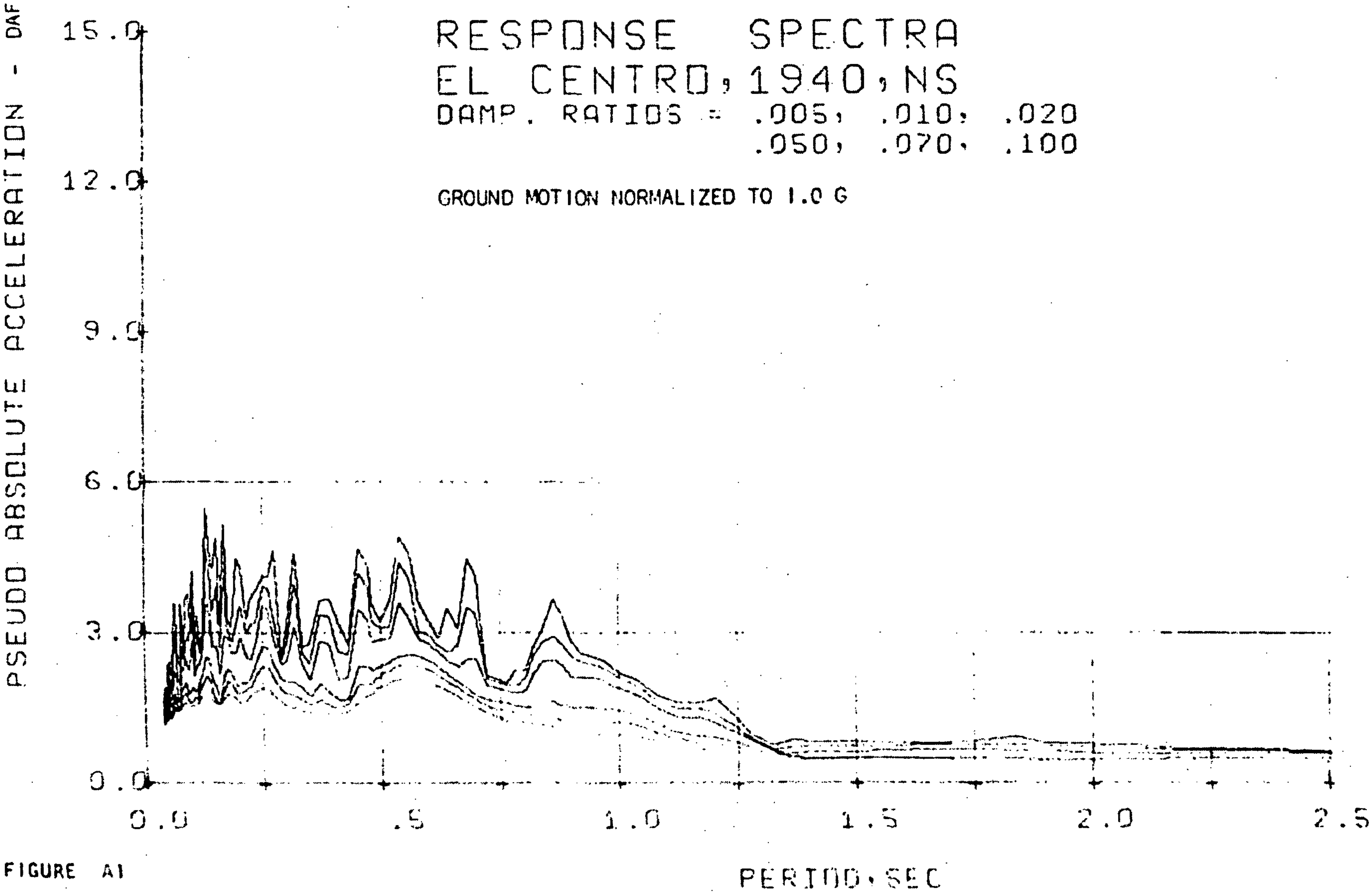

RESPONSE SPECTRA
EL CENTRO, 1940, NS
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A1

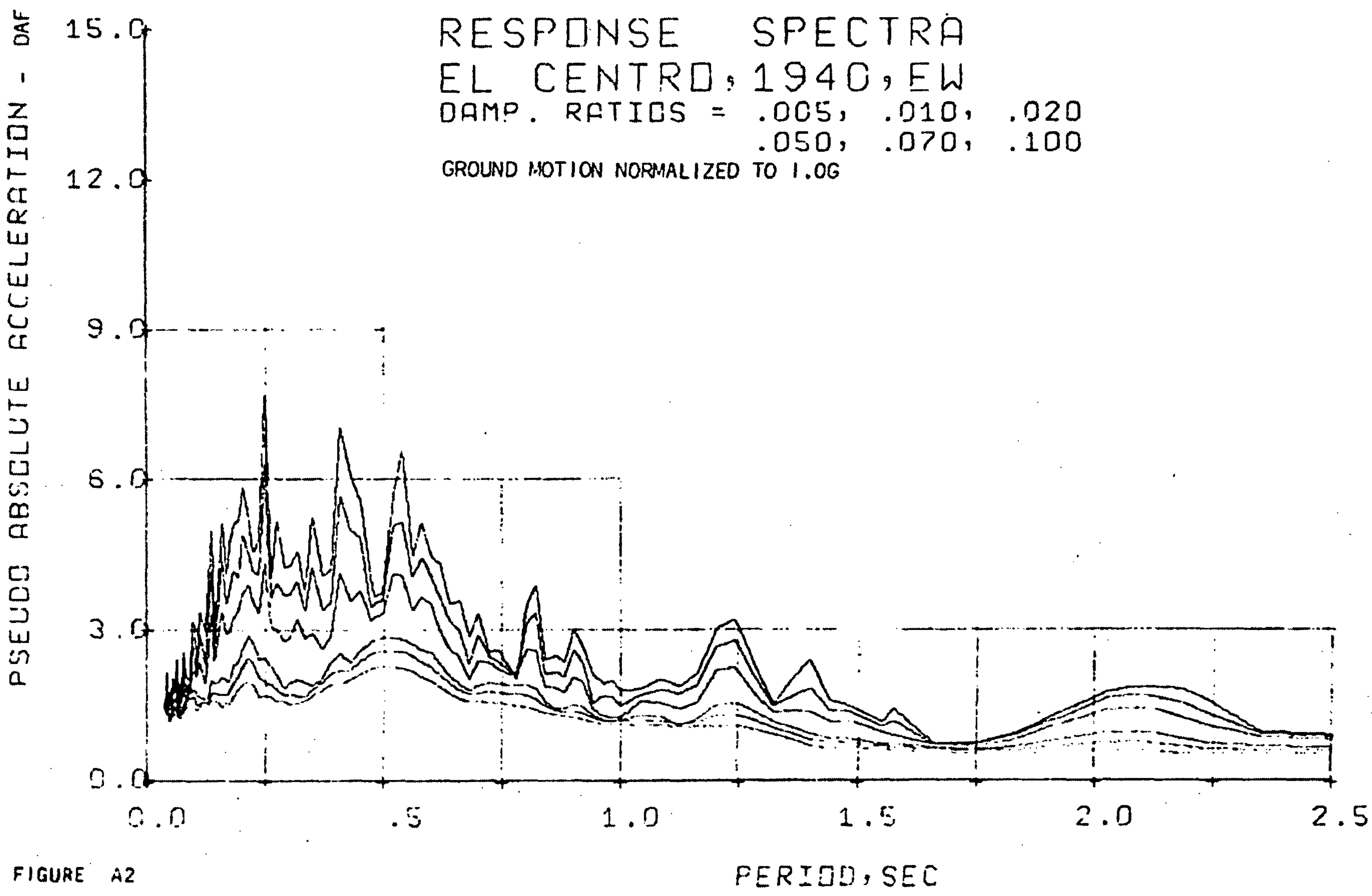
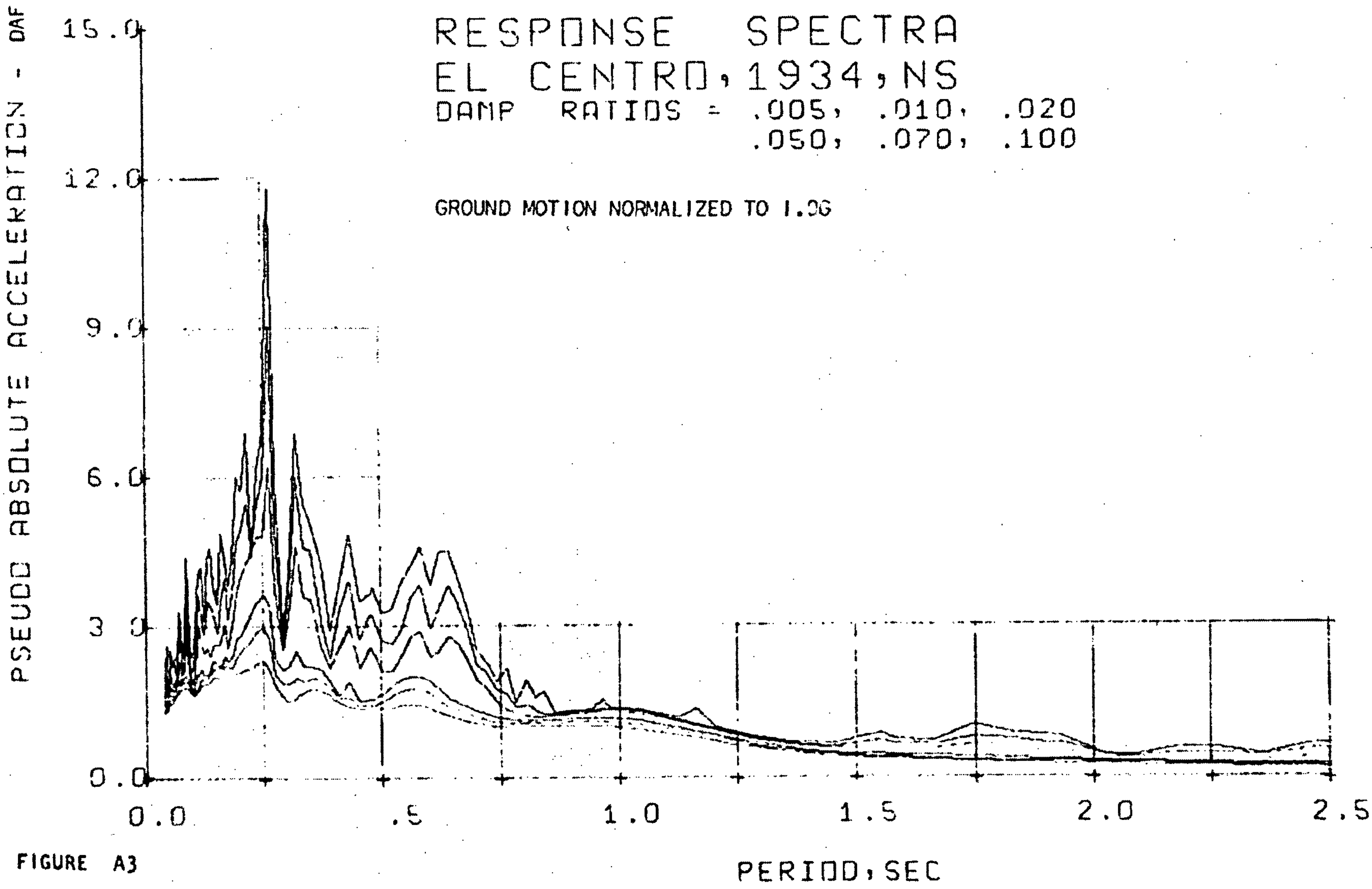

RESPONSE SPECTRA
EL CENTRO, 1940, EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A2



RESPONSE SPECTRA
EL CENTRO, 1934, NS
DAMP RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A3

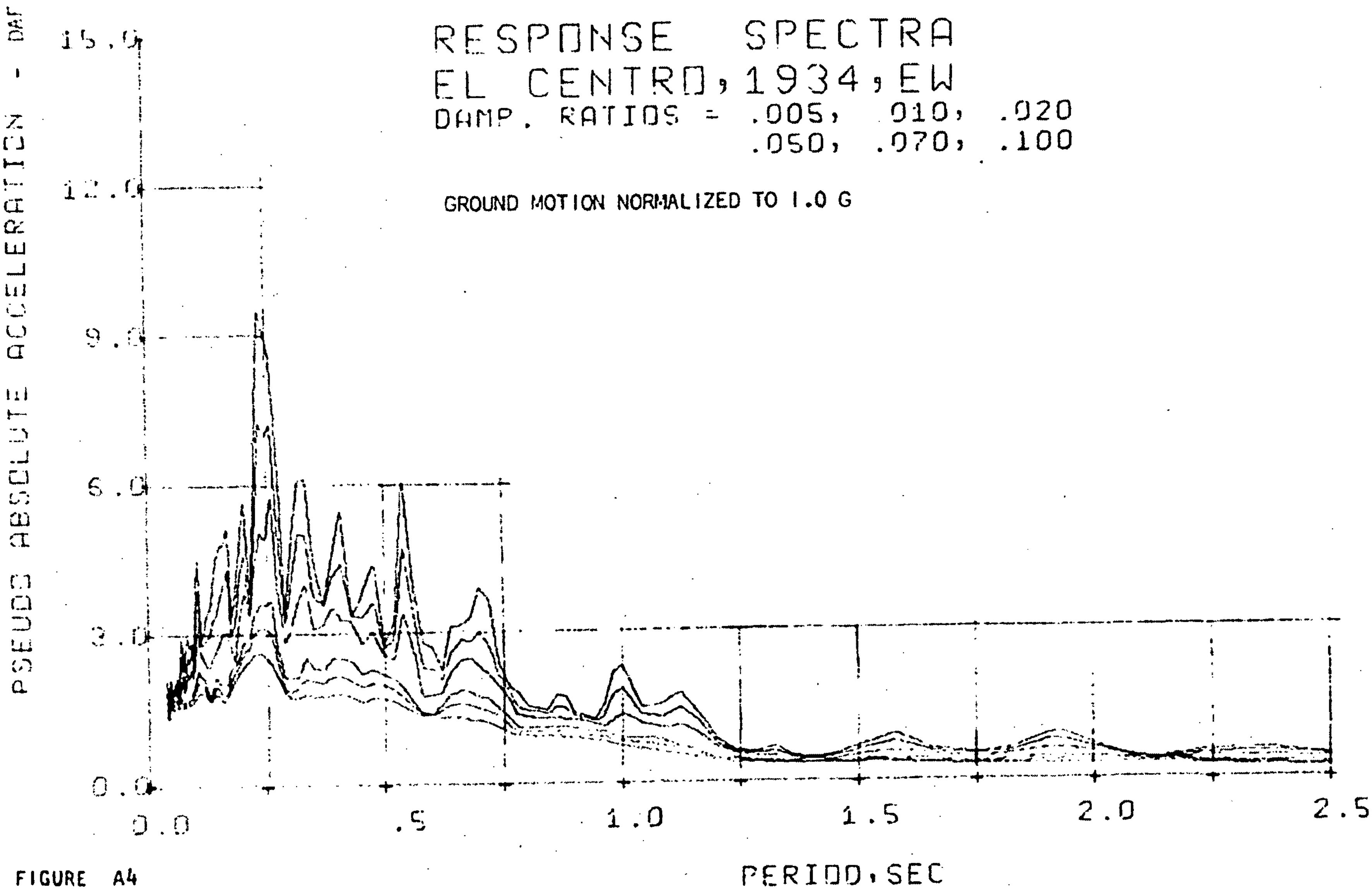
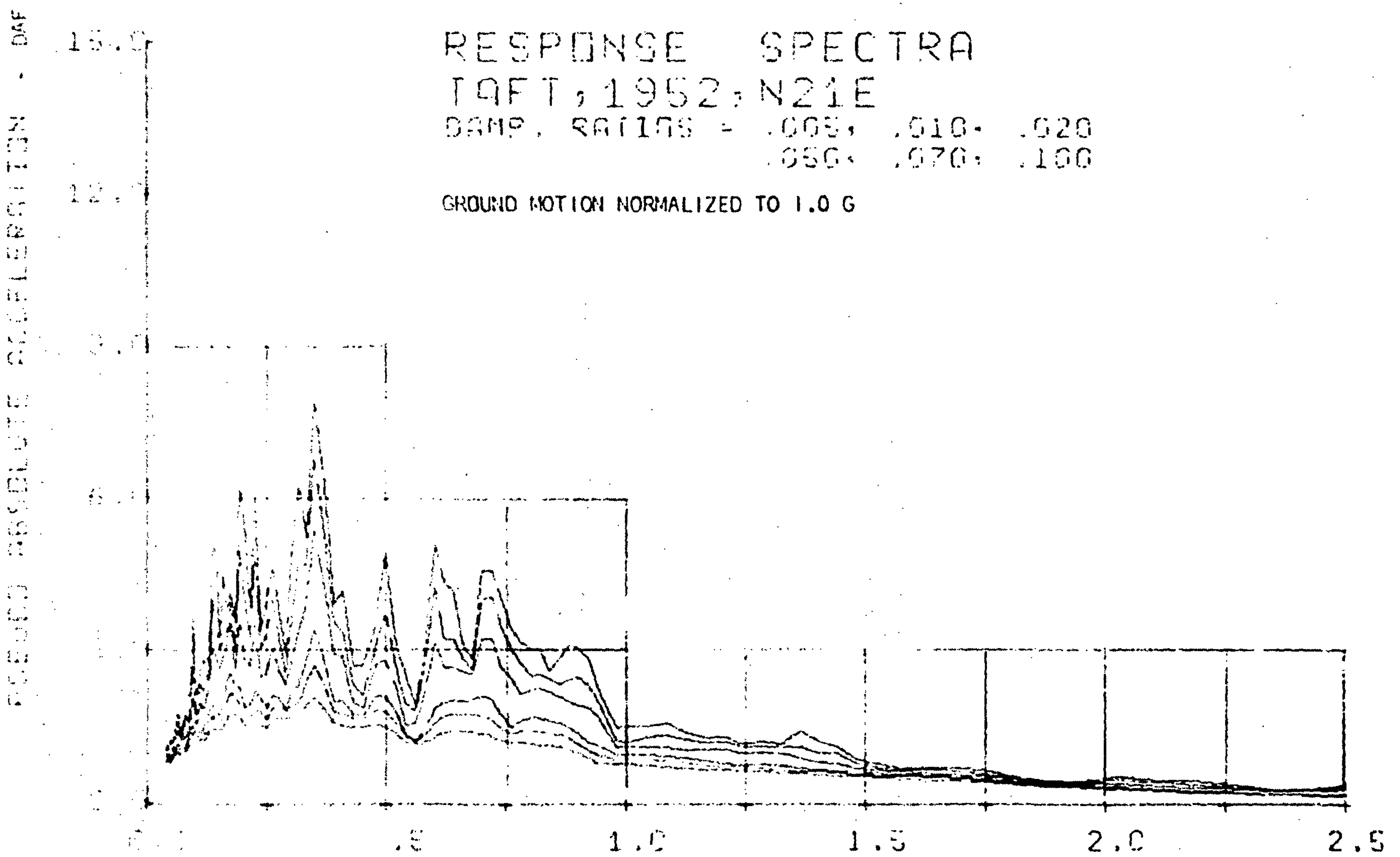
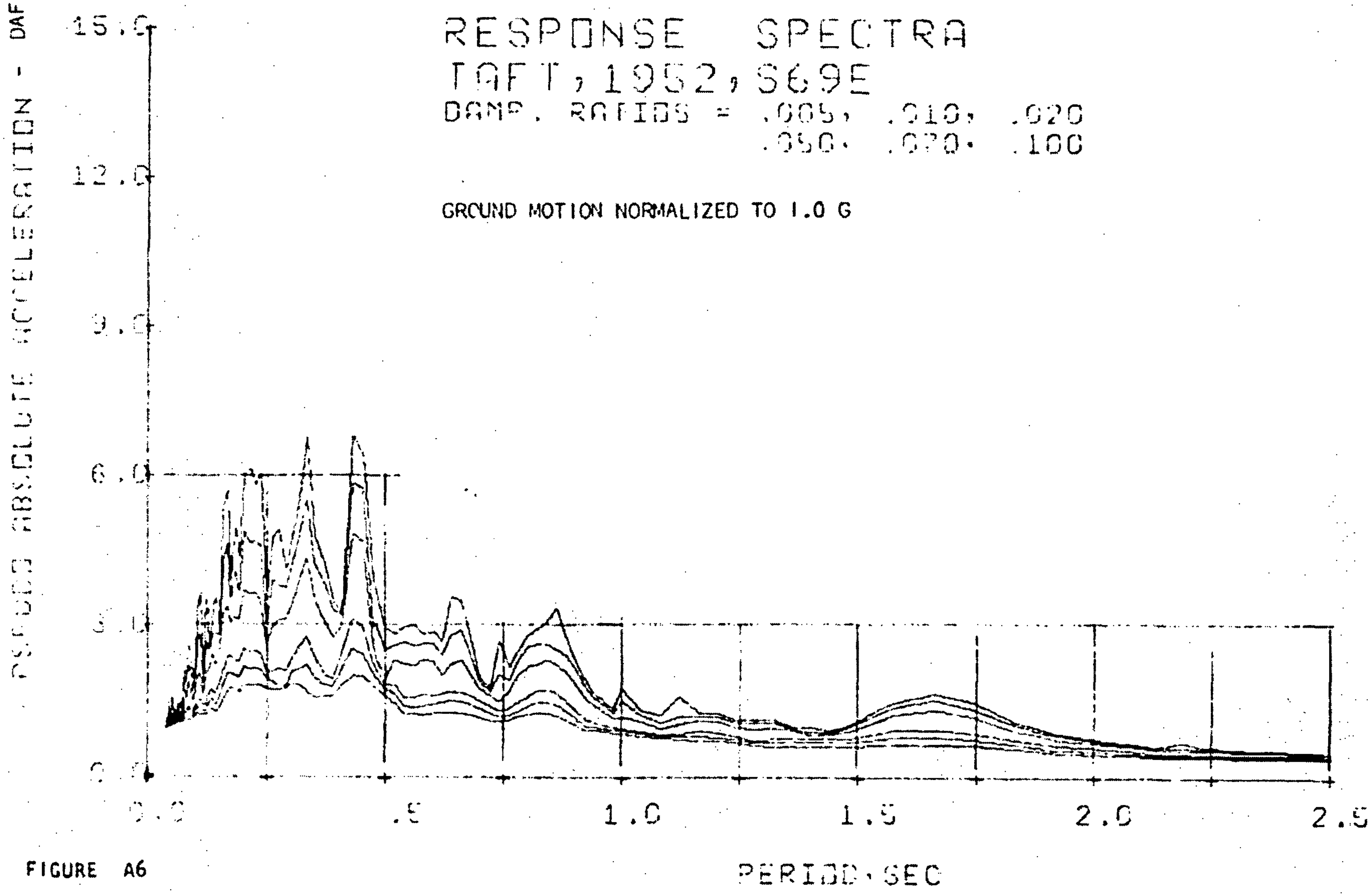

RESPONSE SPECTRA
EL CENTRO, 1934, EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A4



RESPONSE SPECTRA
TAFT, 1952, N21E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
PERIOD, SEC
1.0
1.5
2.0
2.5

FIGURE A5



RESPONSE SPECTRA
TAFT, 1952, S69E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A6

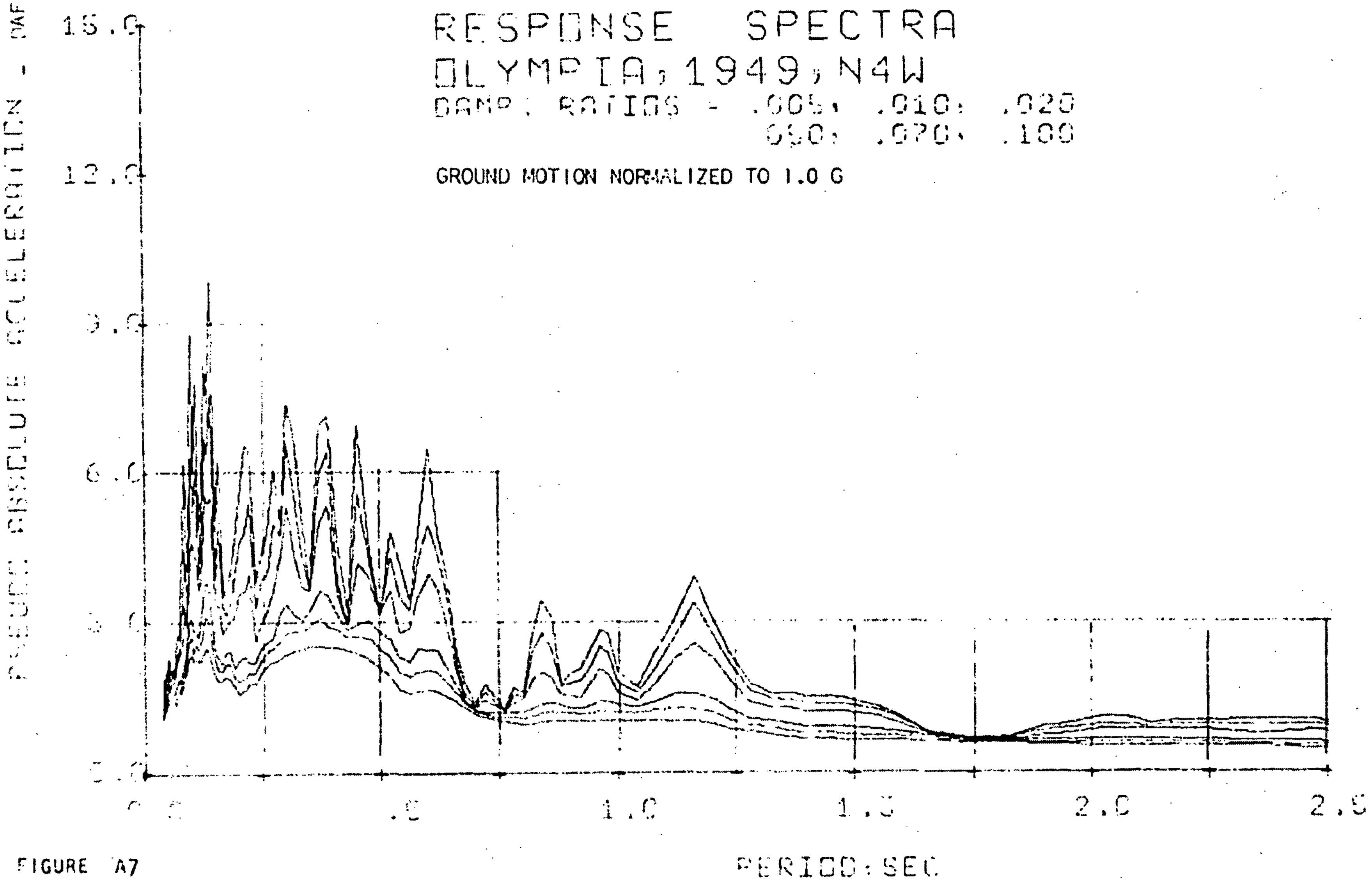

RESPONSE SPECTRA
OLYMPIA, 1949, N4W
DAMP. RATIOS - .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
15.0
12.0
9.0
6.0
0.0
.5
1.0
2.0
2.5
PSEUDO ABSOLUTE ACCELERATION - DAF
PERIOD: SEC

FIGURE A7

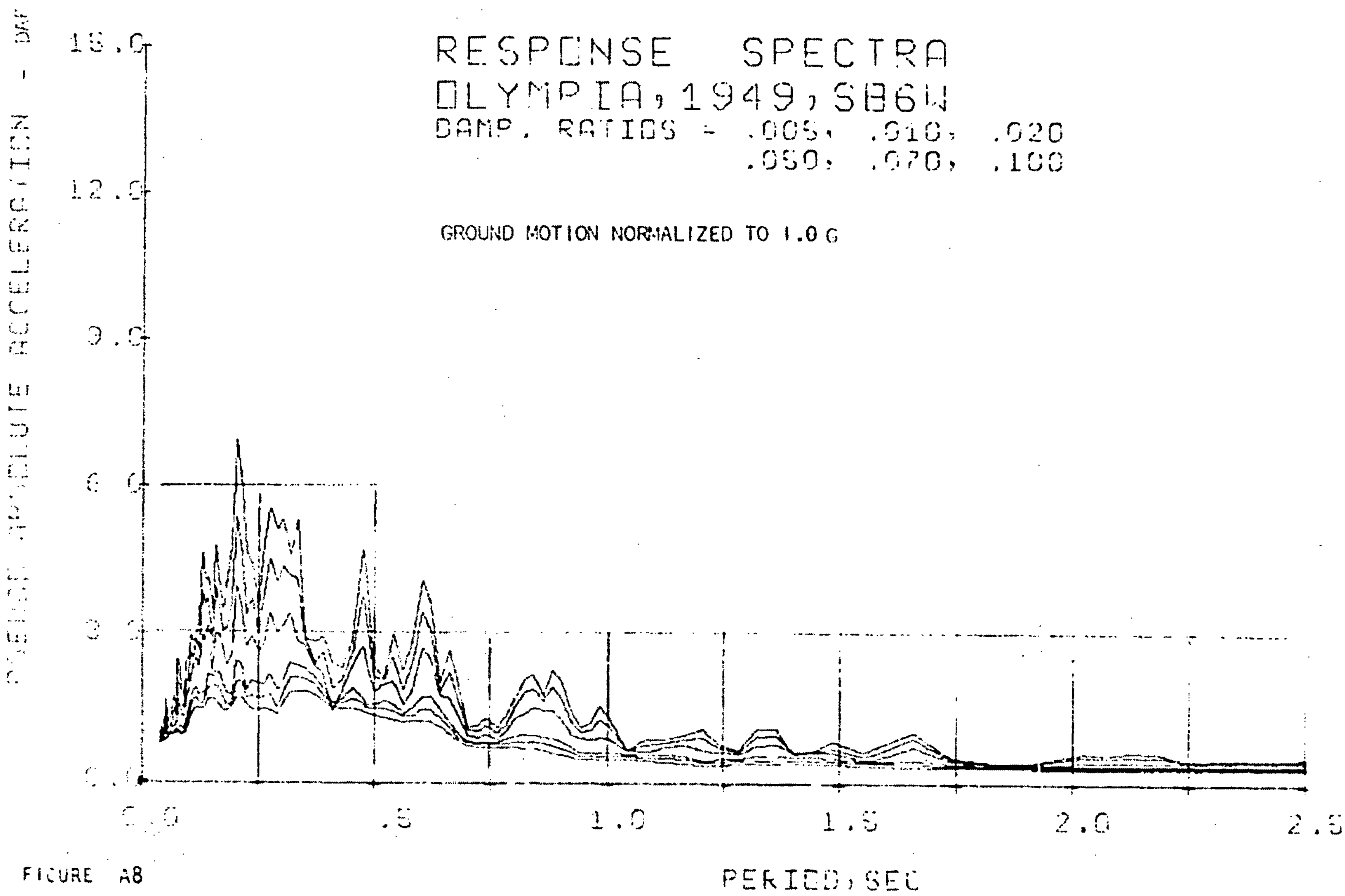

RESPONSE SPECTRA
OLYMPIA, 1949, S86W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
15.0
12.0
9.0
6.0
3.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A8

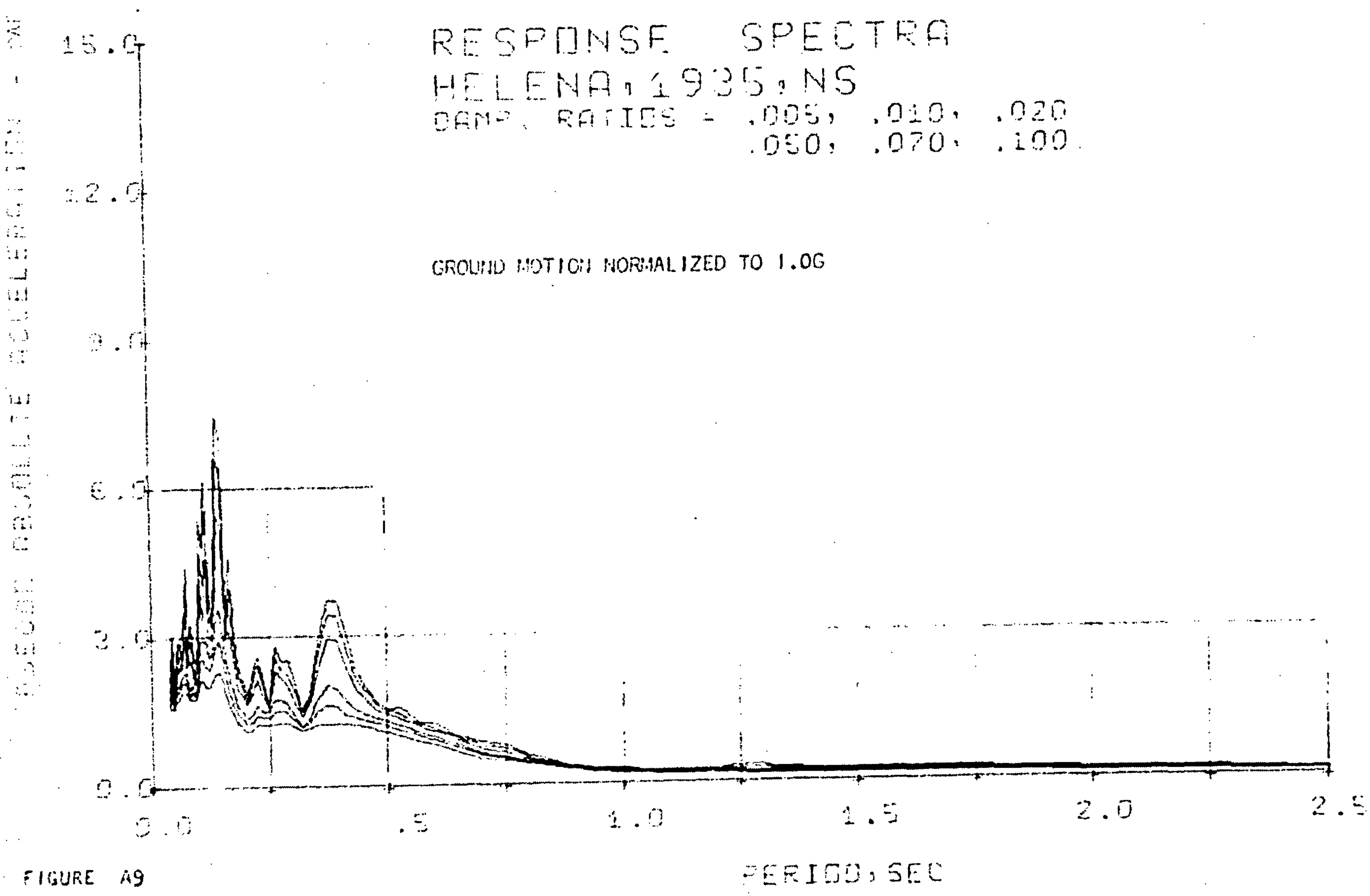
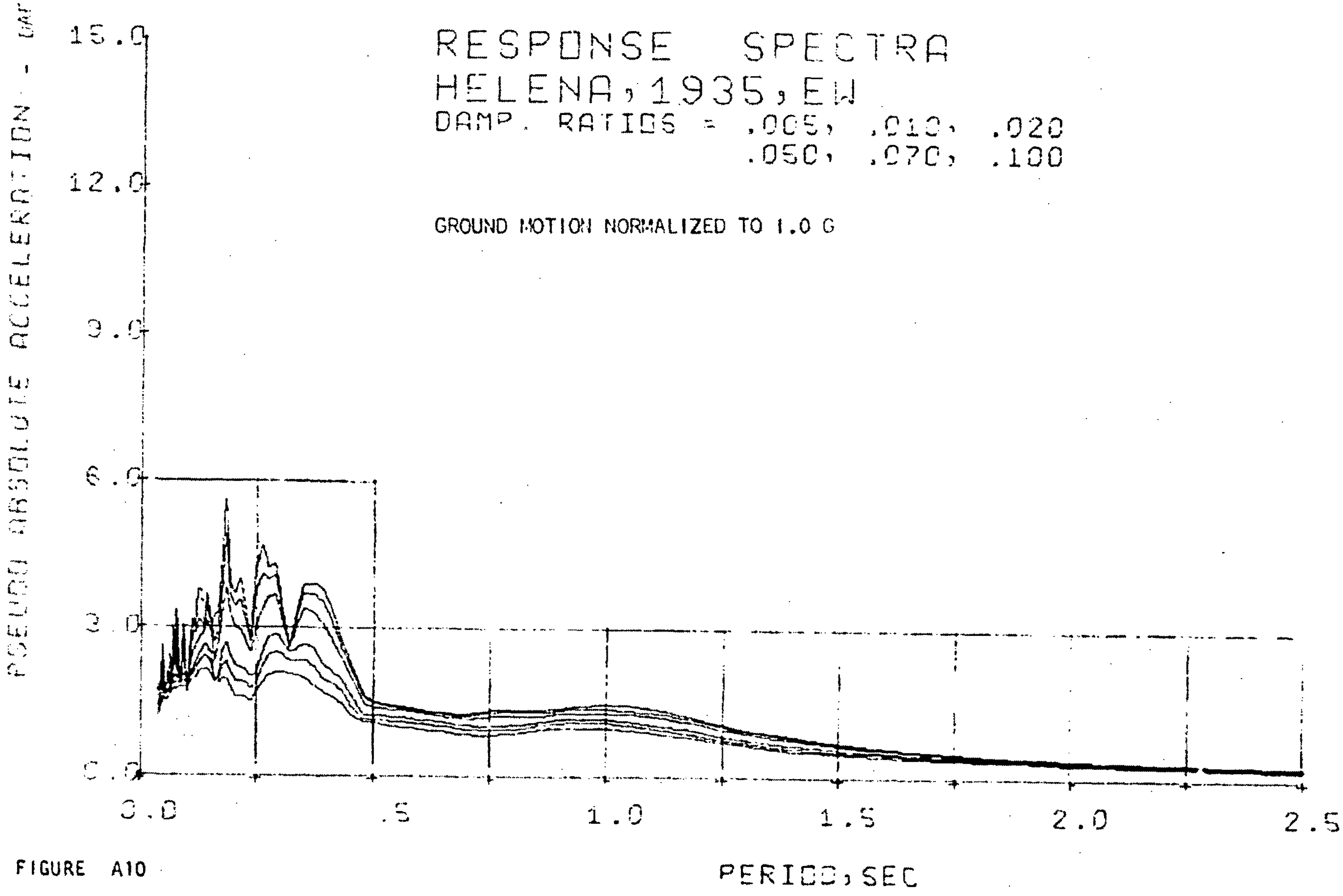

RESPONSE SPECTRA
HELENA,1935,NS
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0G
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A9



RESPONSE SPECTRA
HELENA, 1935, EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - G
15.0
12.0
9.0
6.0
3.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A10

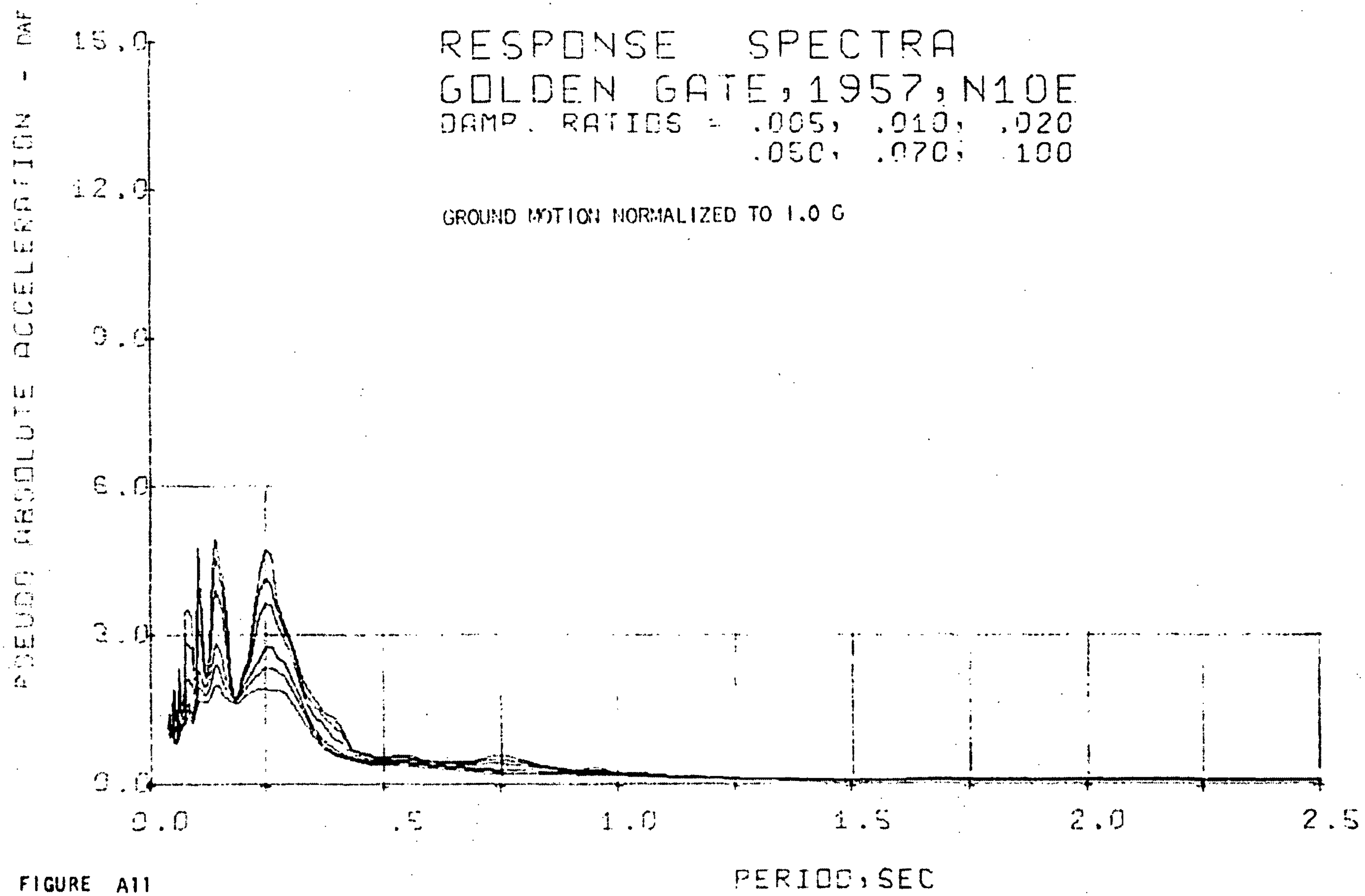

RESPONSE SPECTRA
GOLDEN GATE,1957,N10E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A11

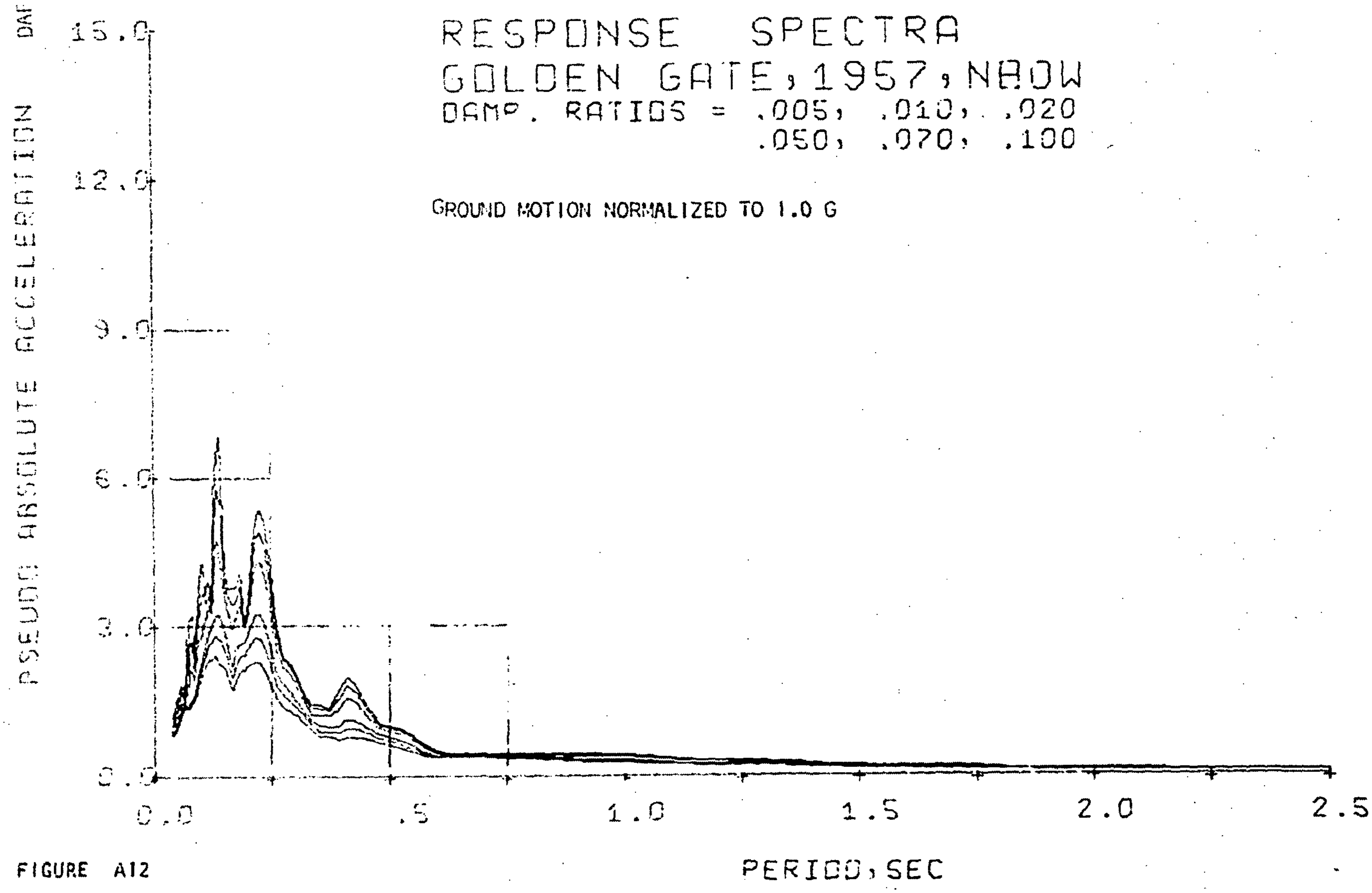

RESPONSE SPECTRA
GOLDEN GATE, 1957, N80W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
DAF
PSEUDO ABSOLUTE ACCELERATION
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A12

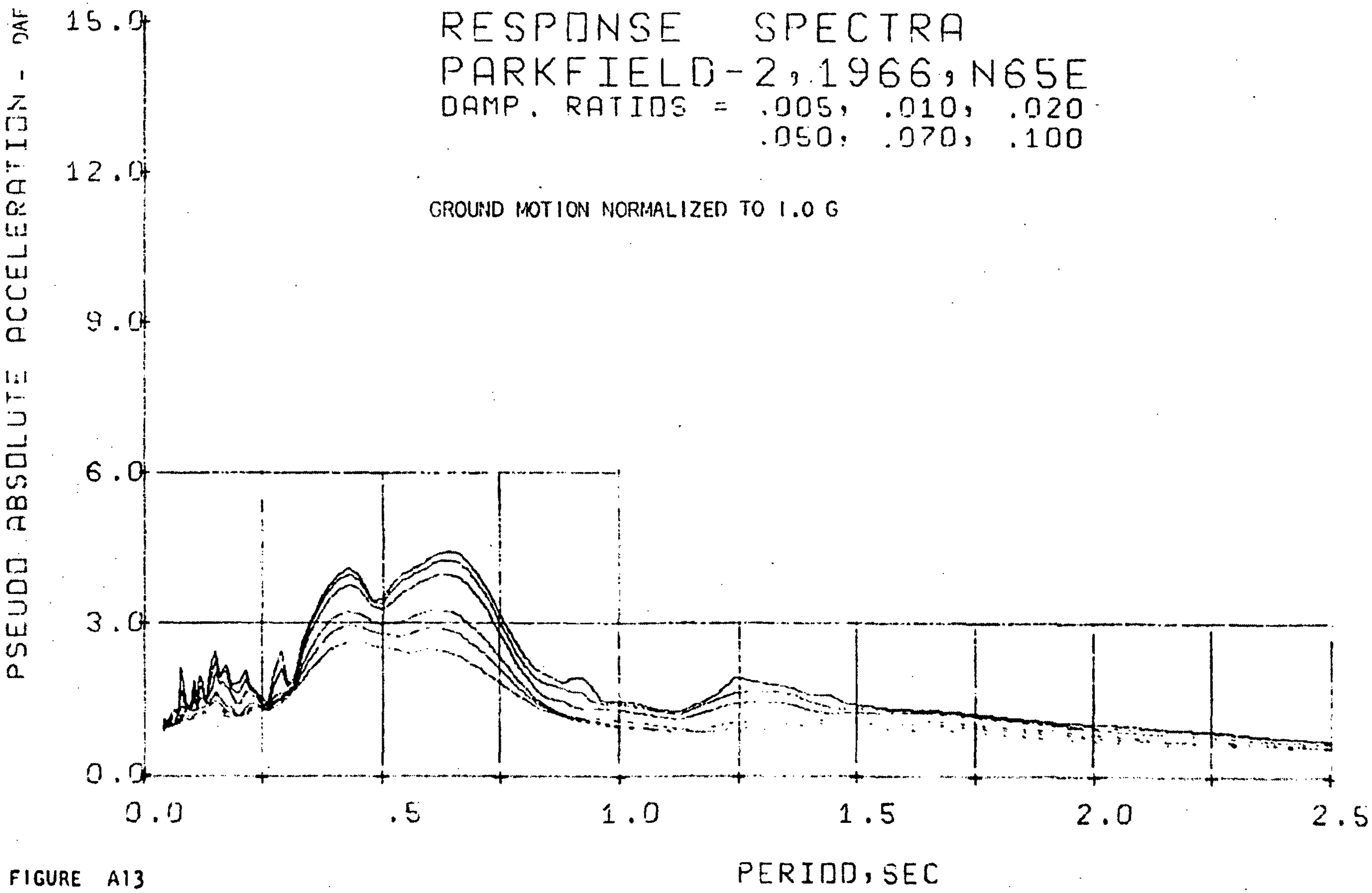

RESPONSE SPECTRA
PARKFIELD-2,1966,N65E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A13

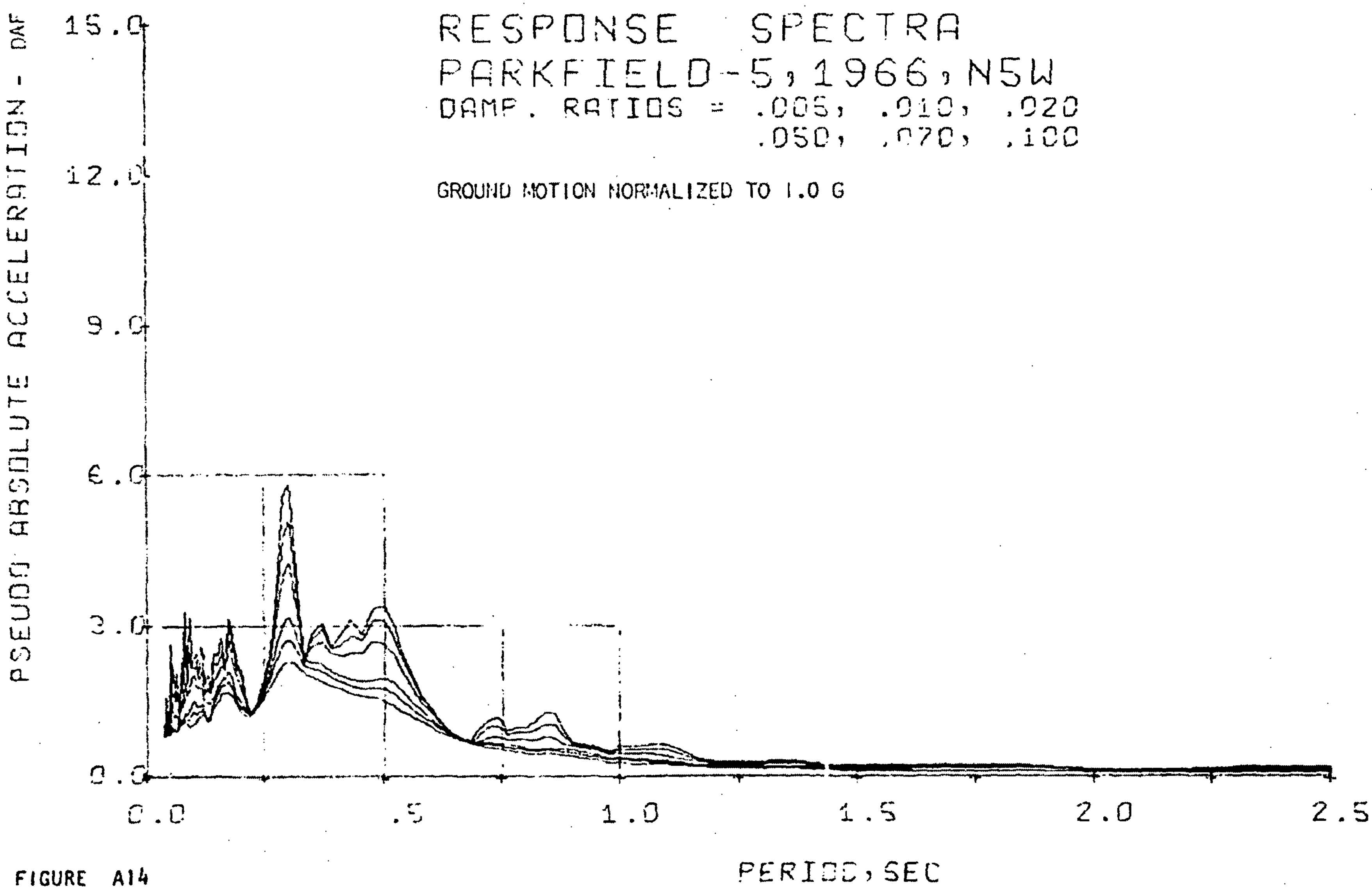

RESPONSE SPECTRA
PARKFIELD-5,1966,N5W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A14

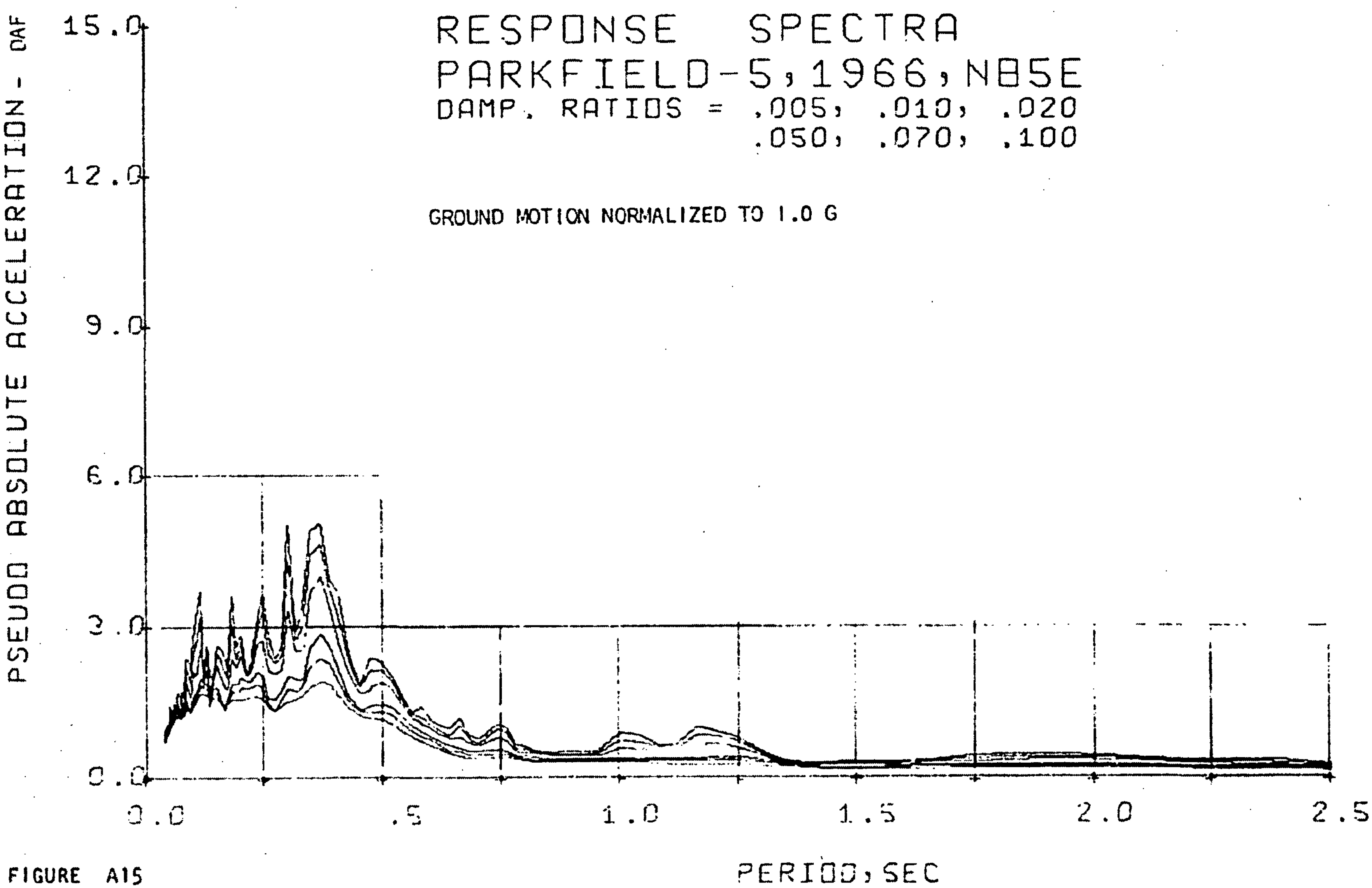

RESPONSE SPECTRA
PARKFIELD-5, 1966, N85E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A15

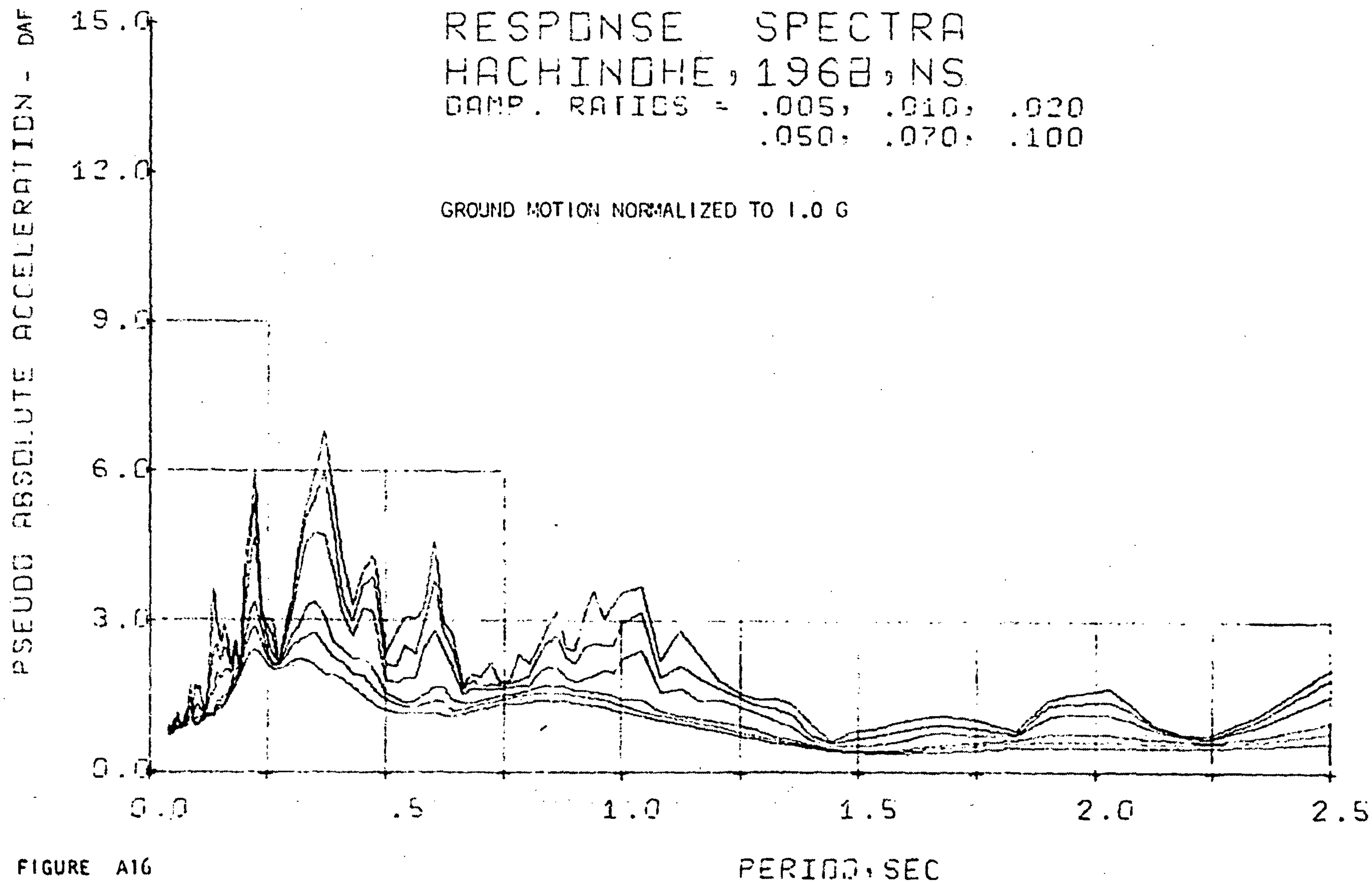

RESPONSE SPECTRA
HACHINOHE, 1968, NS
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A16

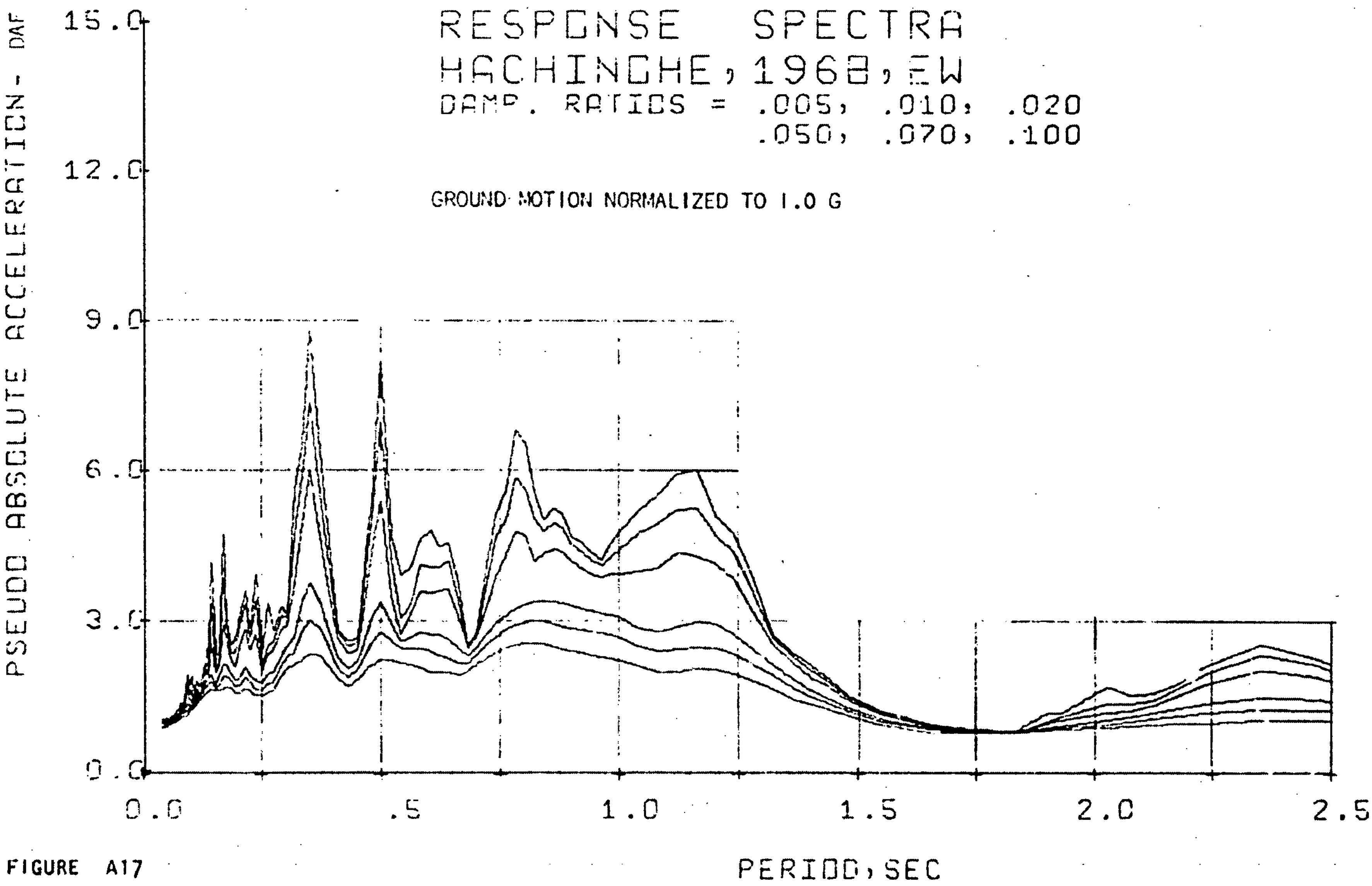

RESPONSE SPECTRA
HACHINOHE, 1968, EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A17

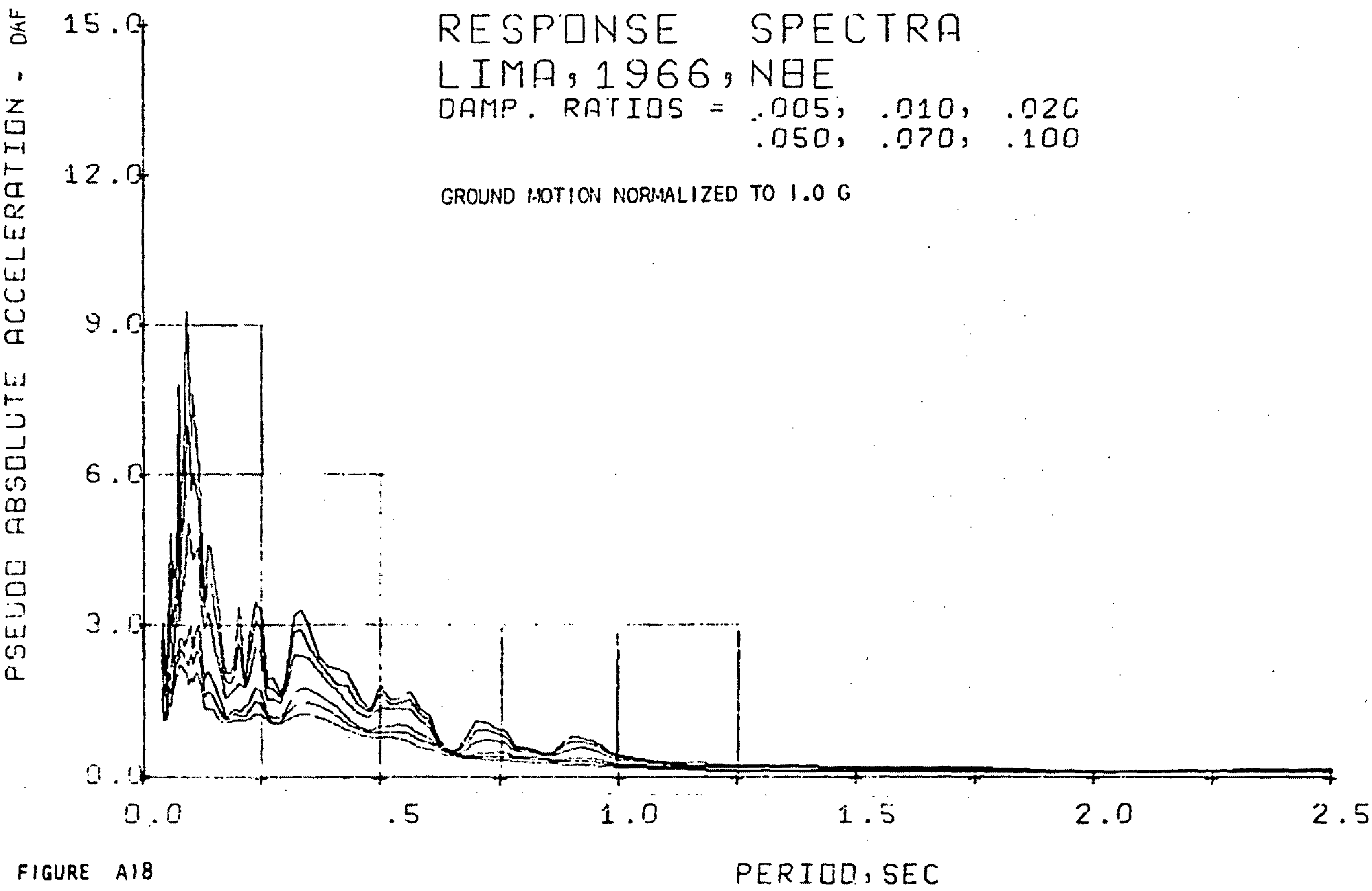

RESPONSE SPECTRA
LIMA, 1966, N8E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A18

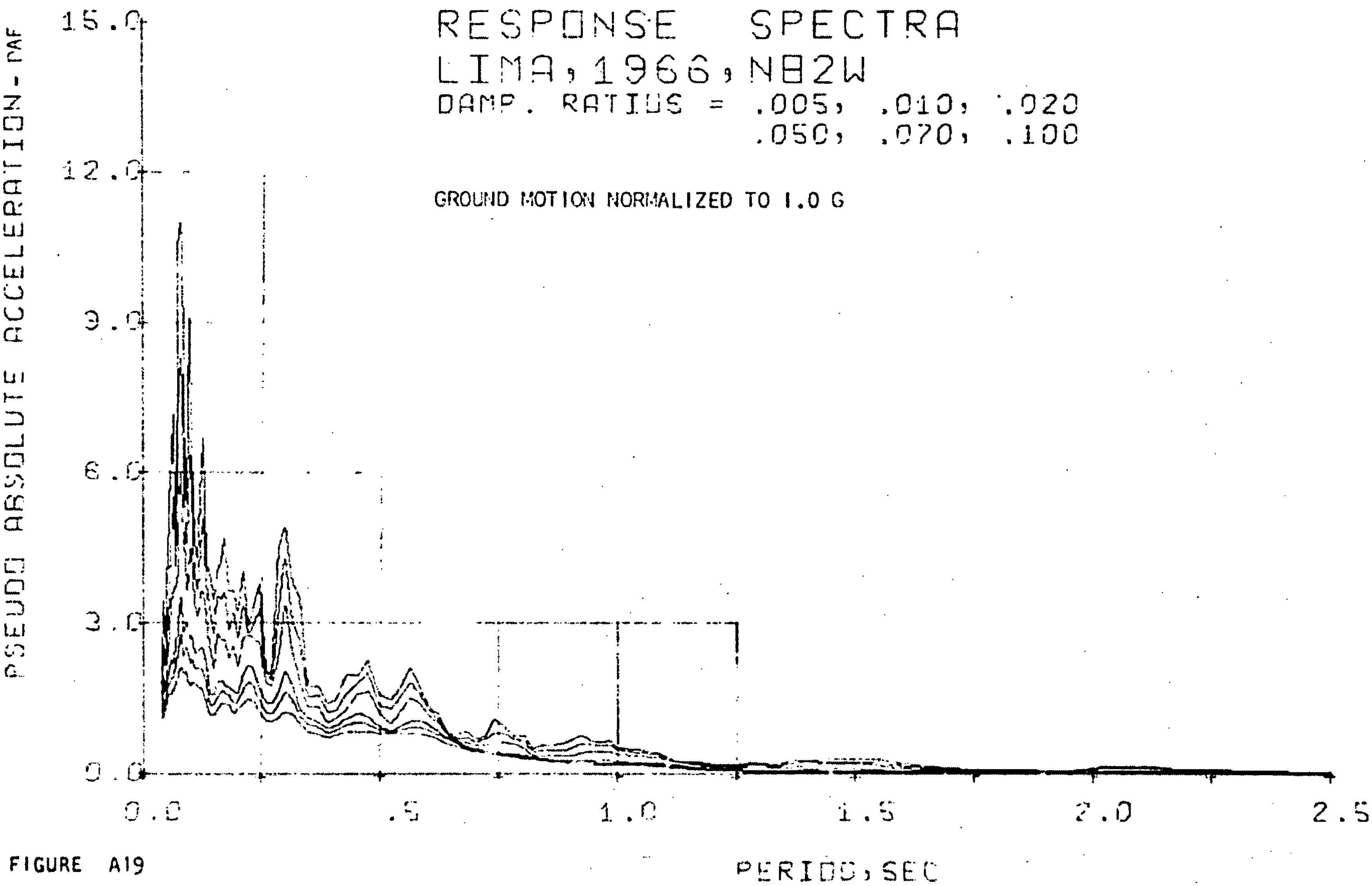

RESPONSE SPECTRA
LIMA,1966,N82W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - PAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A19

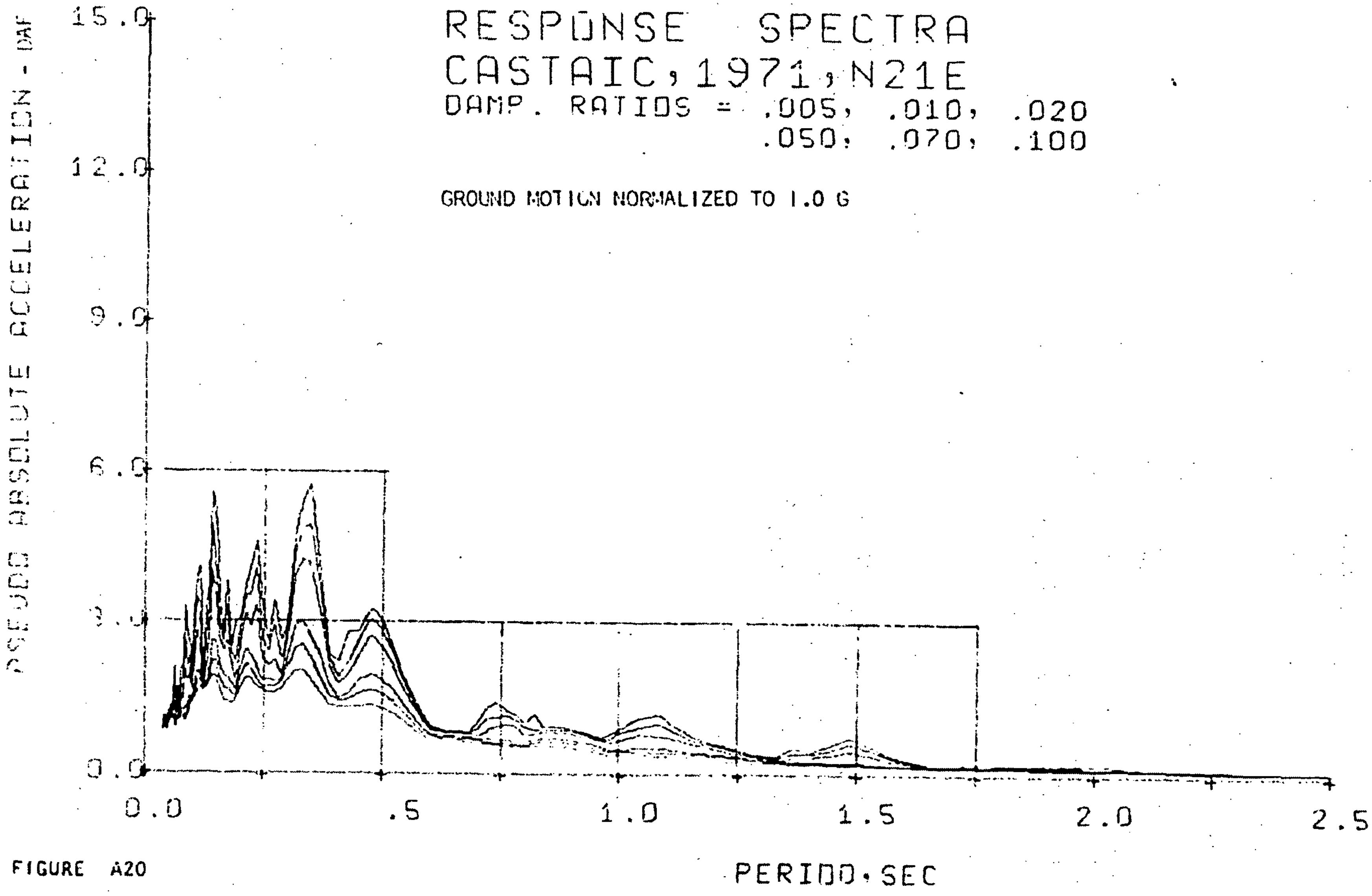
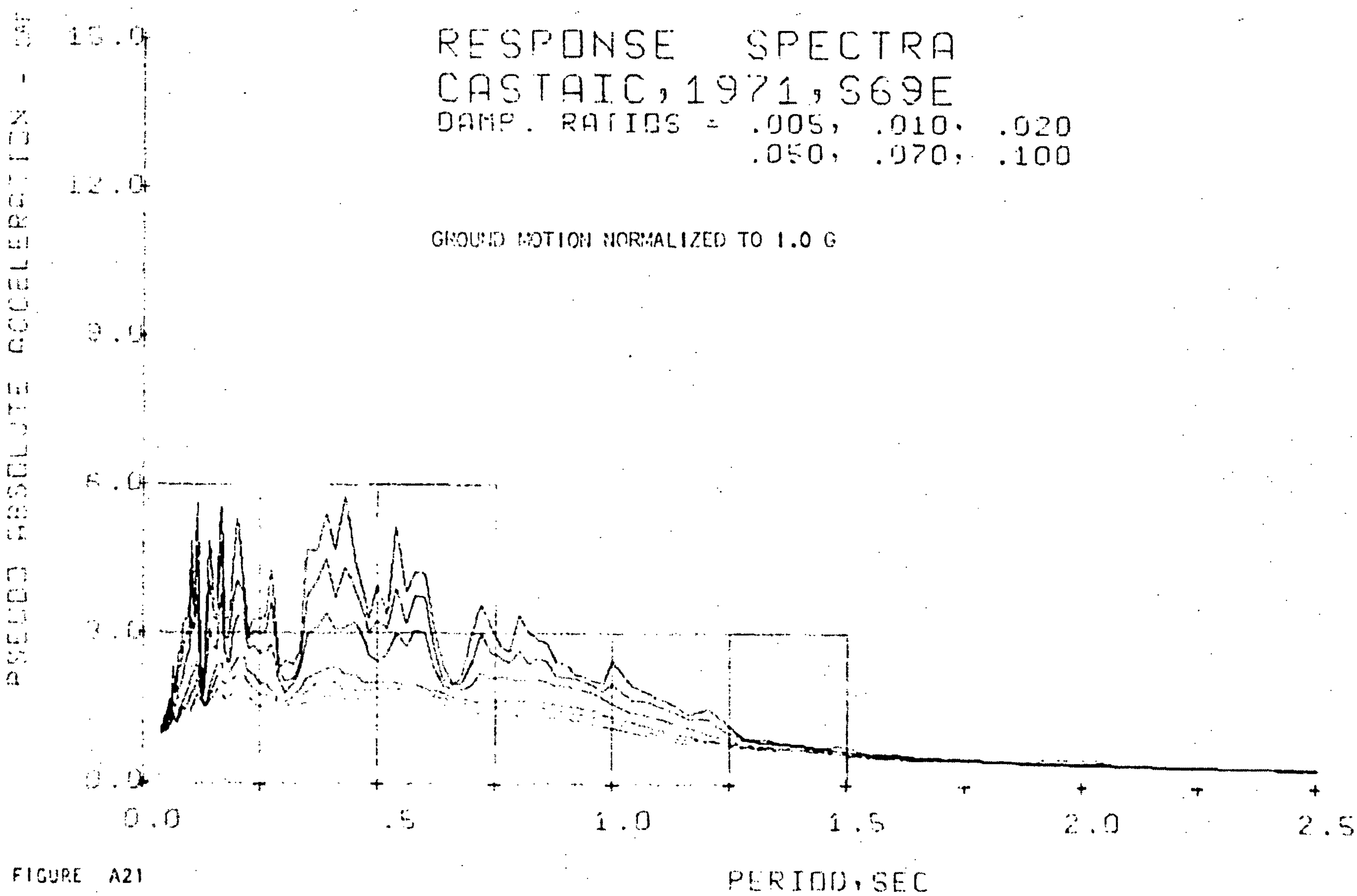

RESPONSE SPECTRA
CASTAIC, 1971, N21E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PSEUDO ABSOLUTE ACCELERATION - DAF
PERIOD, SEC

FIGURE A20



RESPONSE SPECTRA
CASTAIC, 1971, S69E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - G'S
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A21

2.3

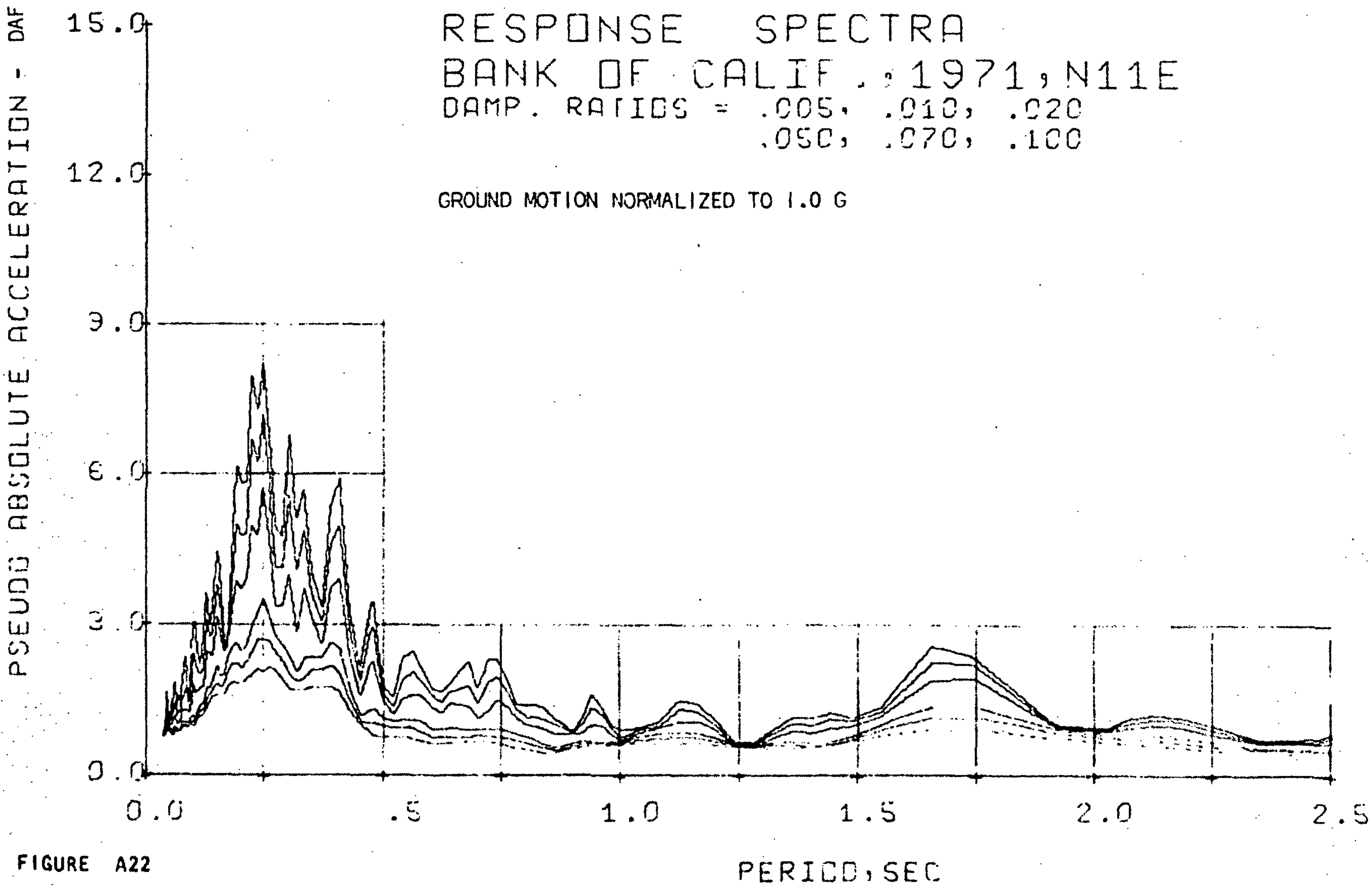

RESPONSE SPECTRA
BANK OF CALIF.,1971,N11E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A22

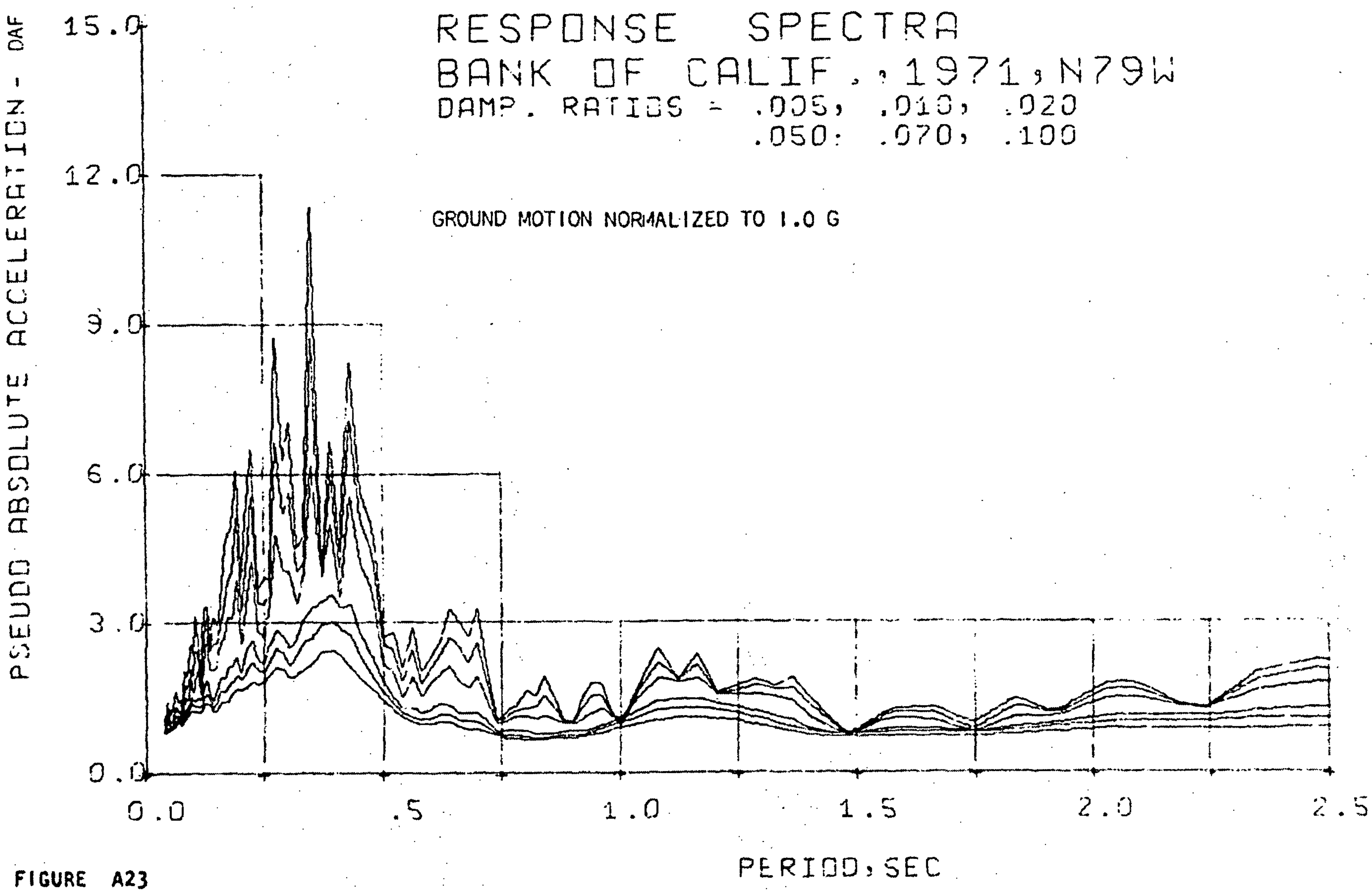
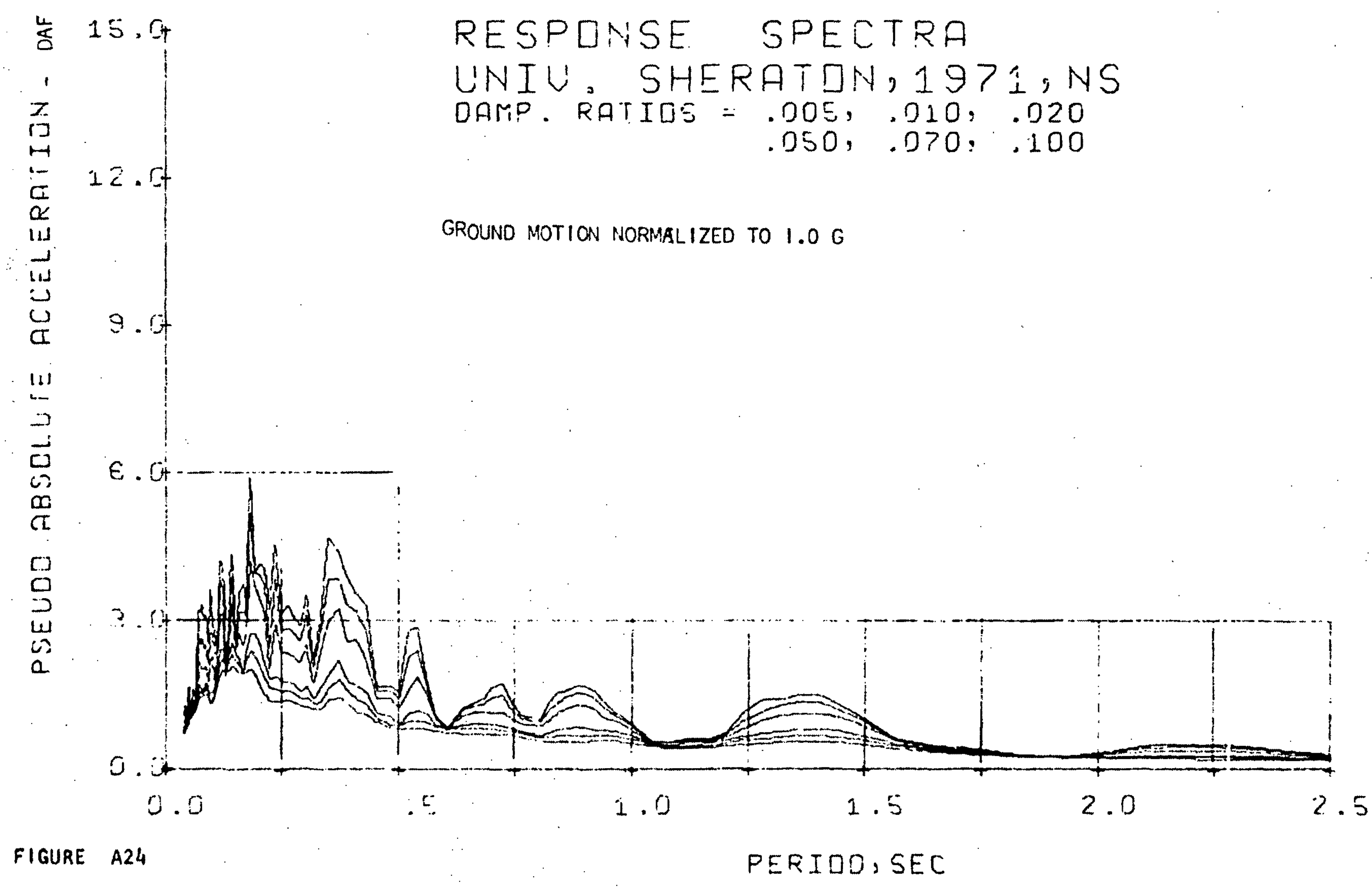

RESPONSE SPECTRA
BANK OF CALIF.,1971,N79W
DAMP. RATIOS = .005, .010, .020
.050: .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A23



RESPONSE SPECTRA
UNIV. SHERATON,1971,NS
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A24

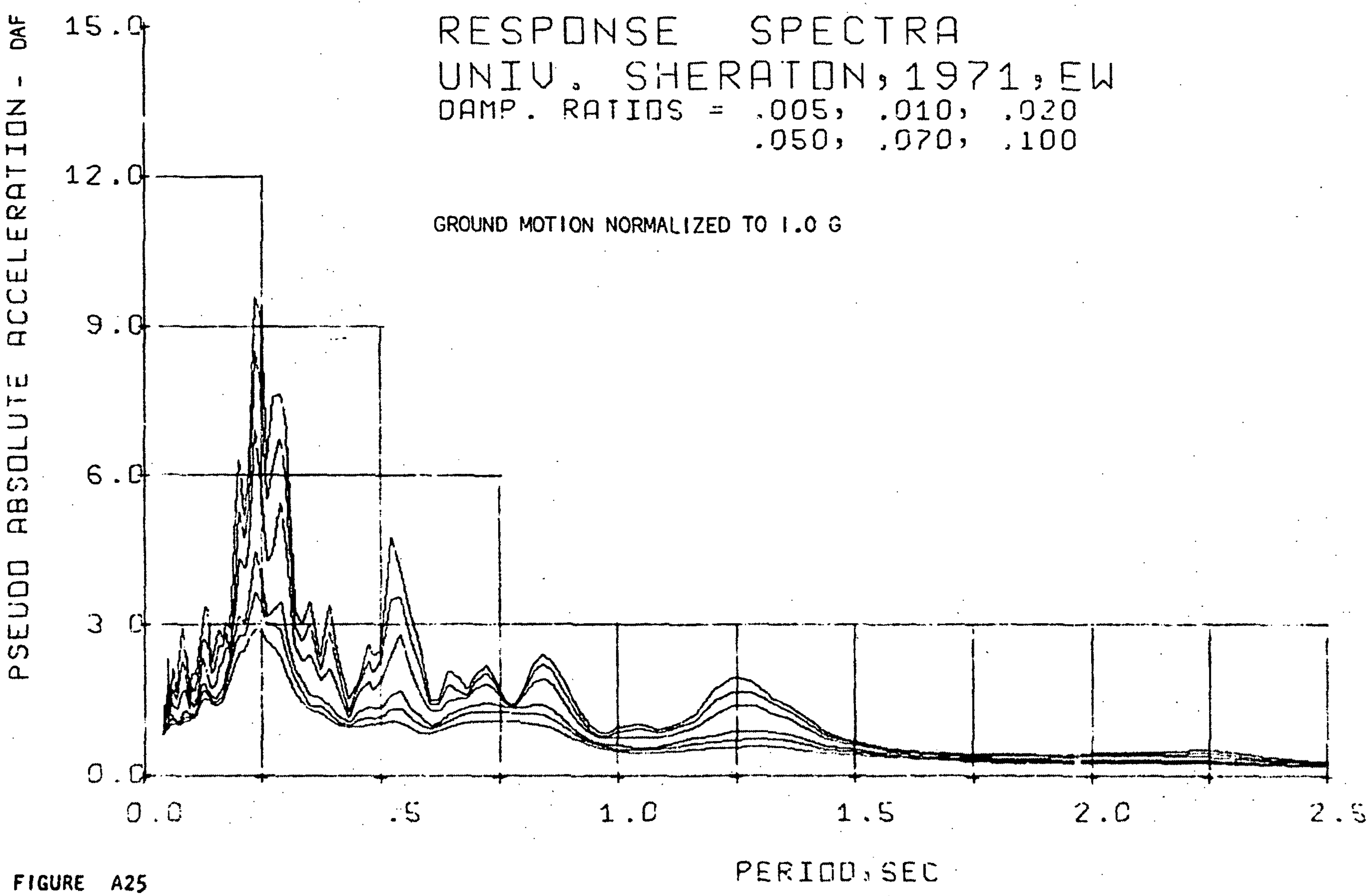

RESPONSE SPECTRA
UNIV. SHERATON,1971,EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A25

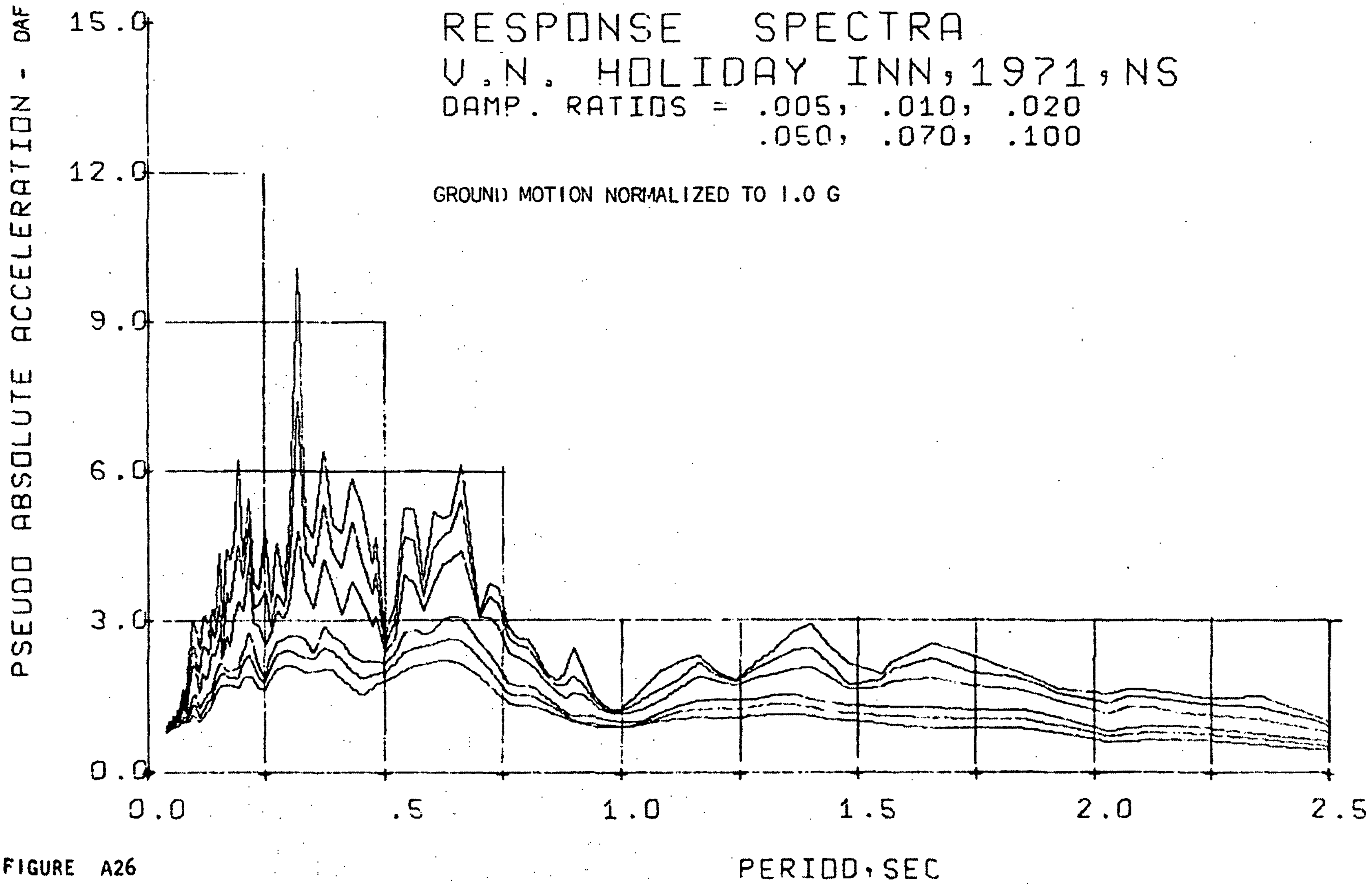
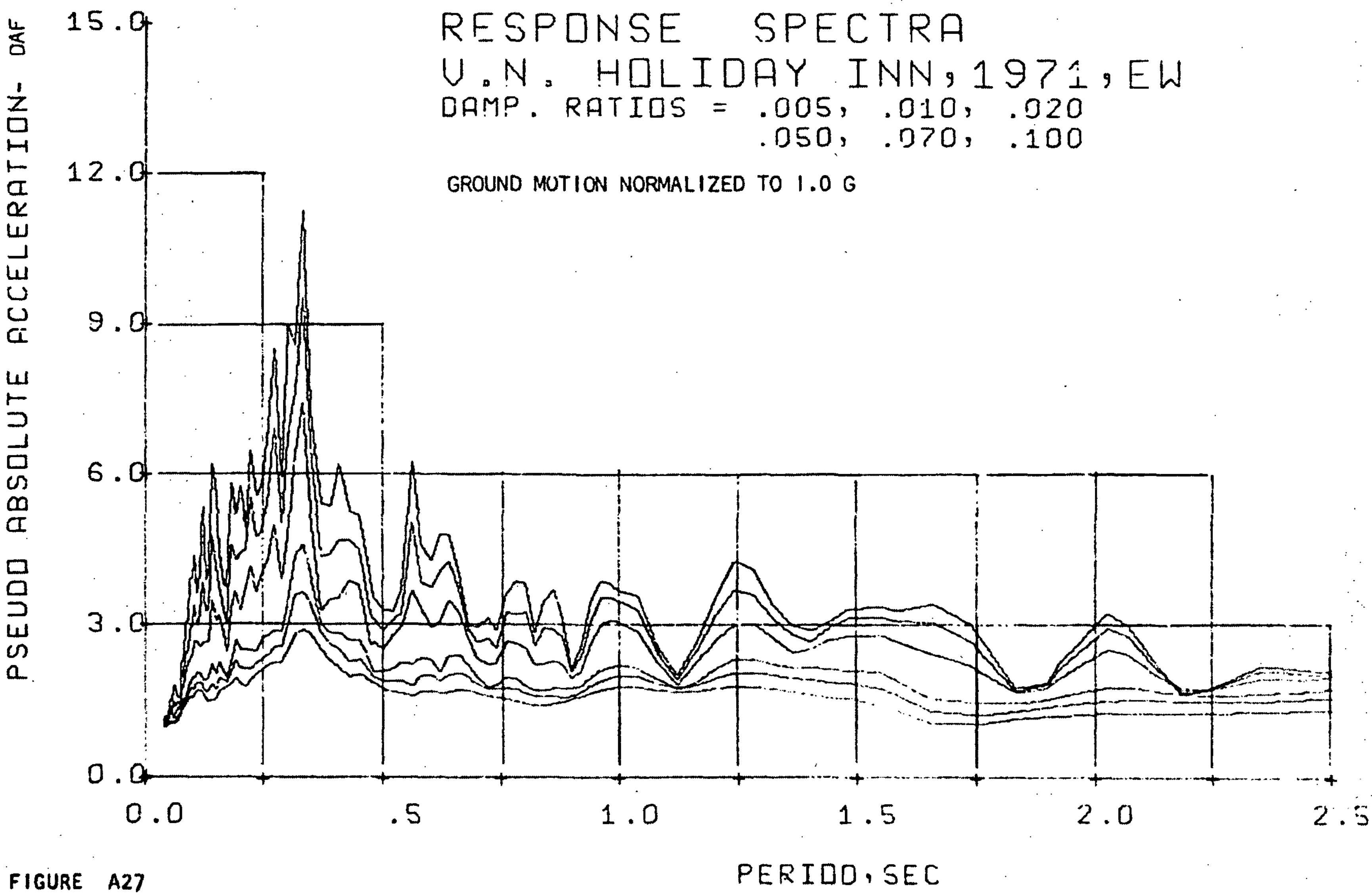
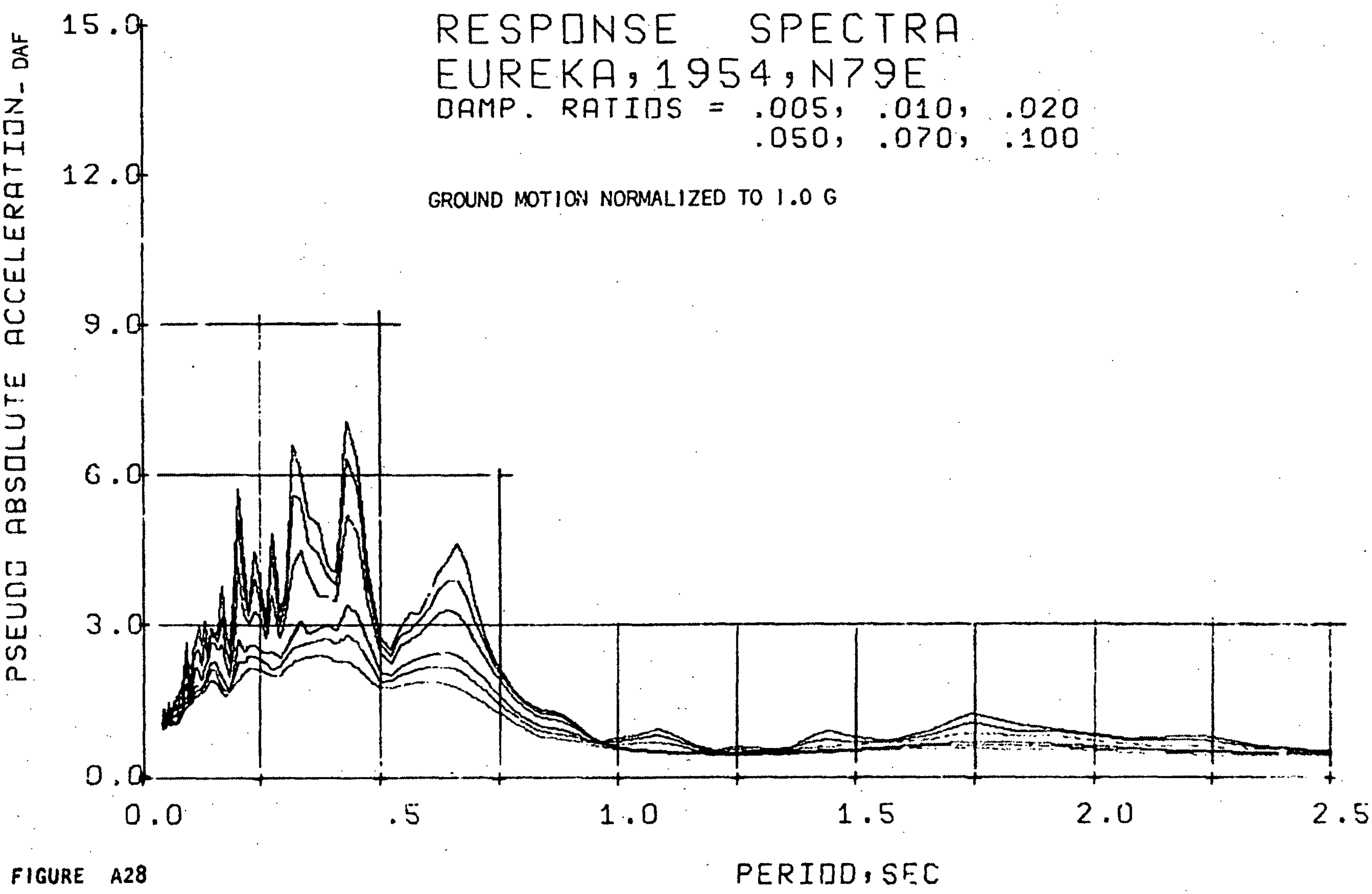

RESPONSE SPECTRA
V.N. HOLIDAY INN,1971,NS
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A26



RESPONSE SPECTRA
V.N. HOLIDAY INN,1971,EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION- DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A27



RESPONSE SPECTRA
EUREKA,1954,N79E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION_ DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A28

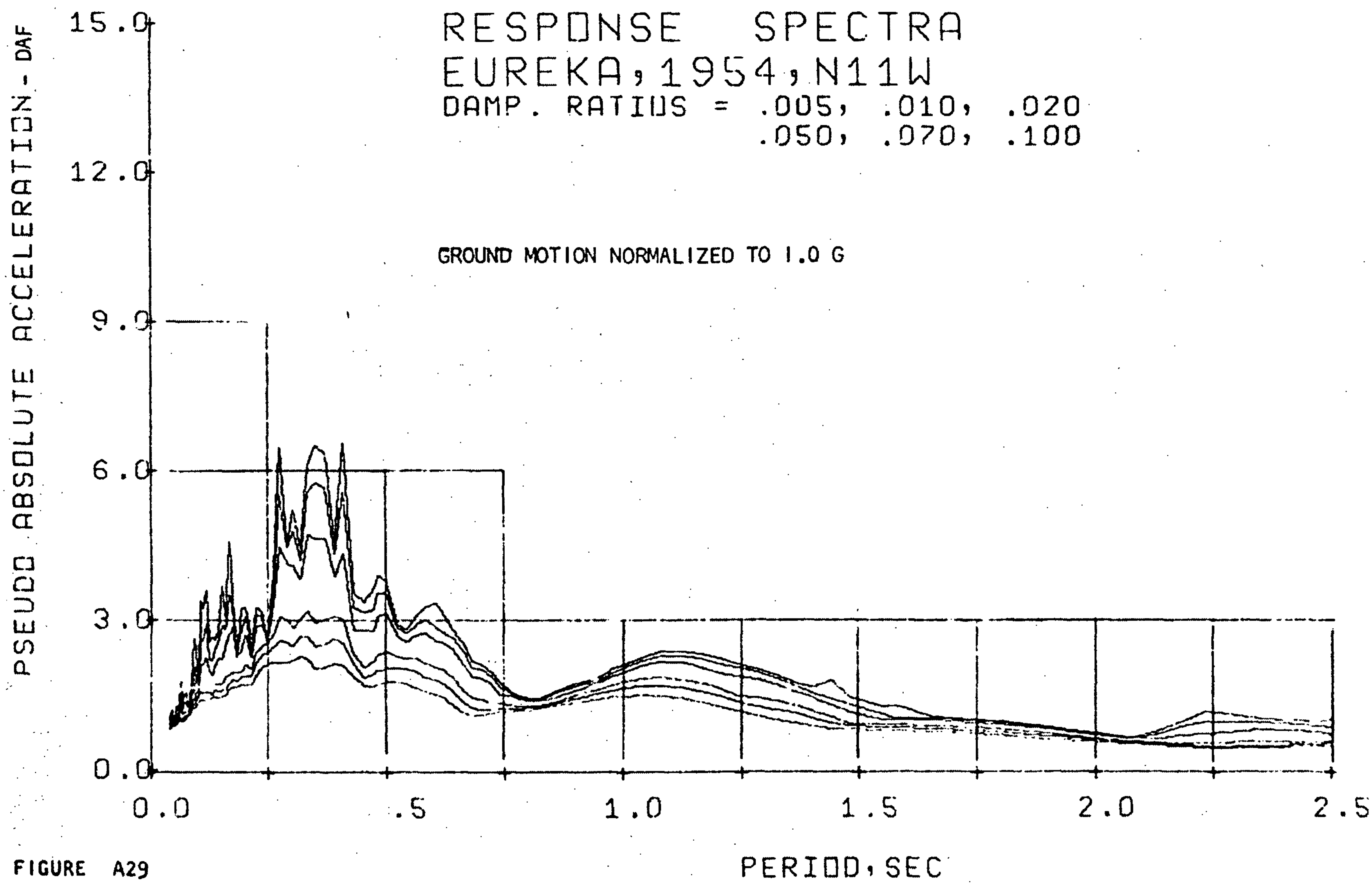
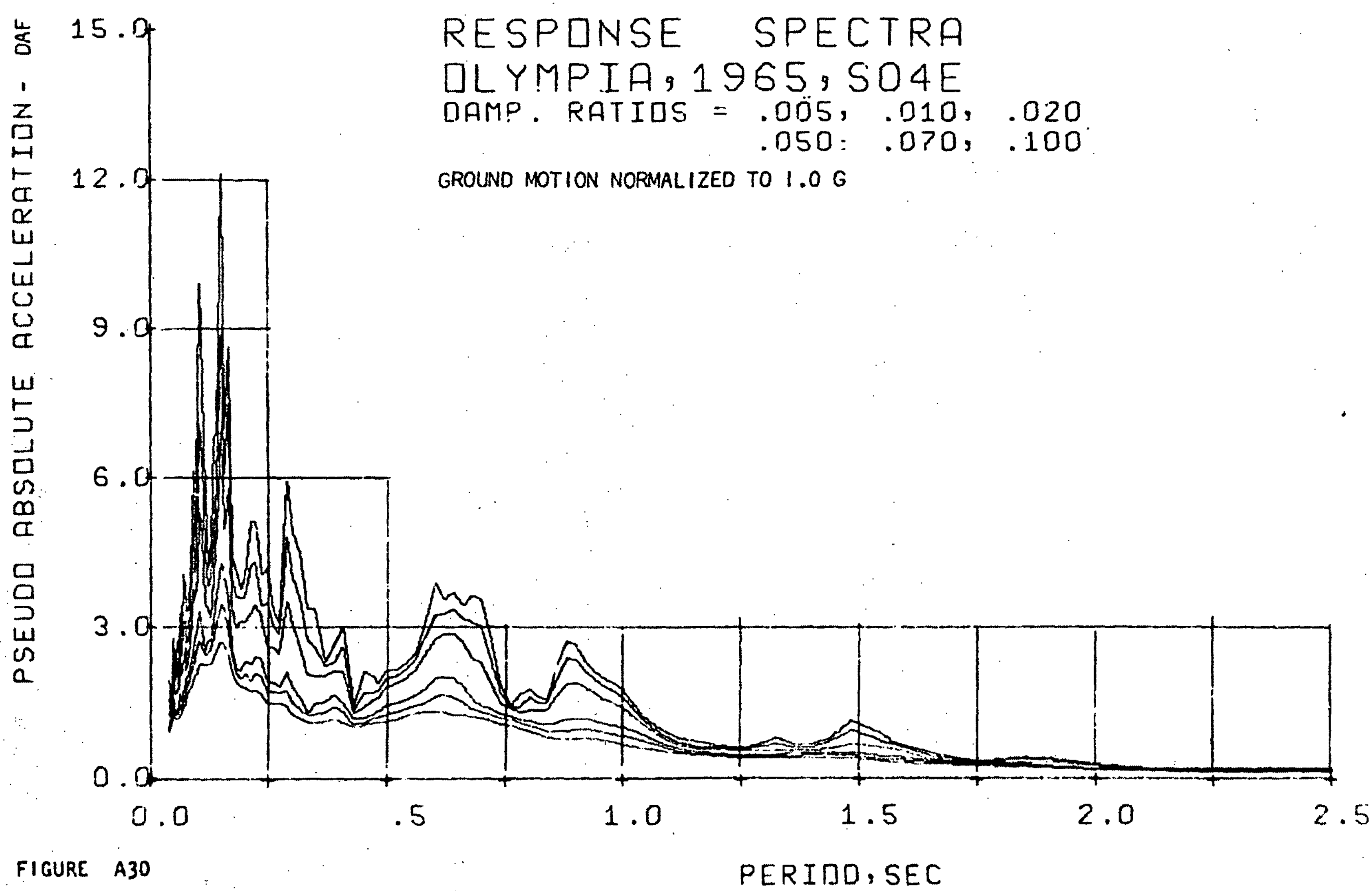

RESPONSE SPECTRA
EUREKA,1954,N11W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A29



RESPONSE SPECTRA
OLYMPIA, 1965, S04E
DAMP. RATIOS = .005, .010, .020
.050: .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A30

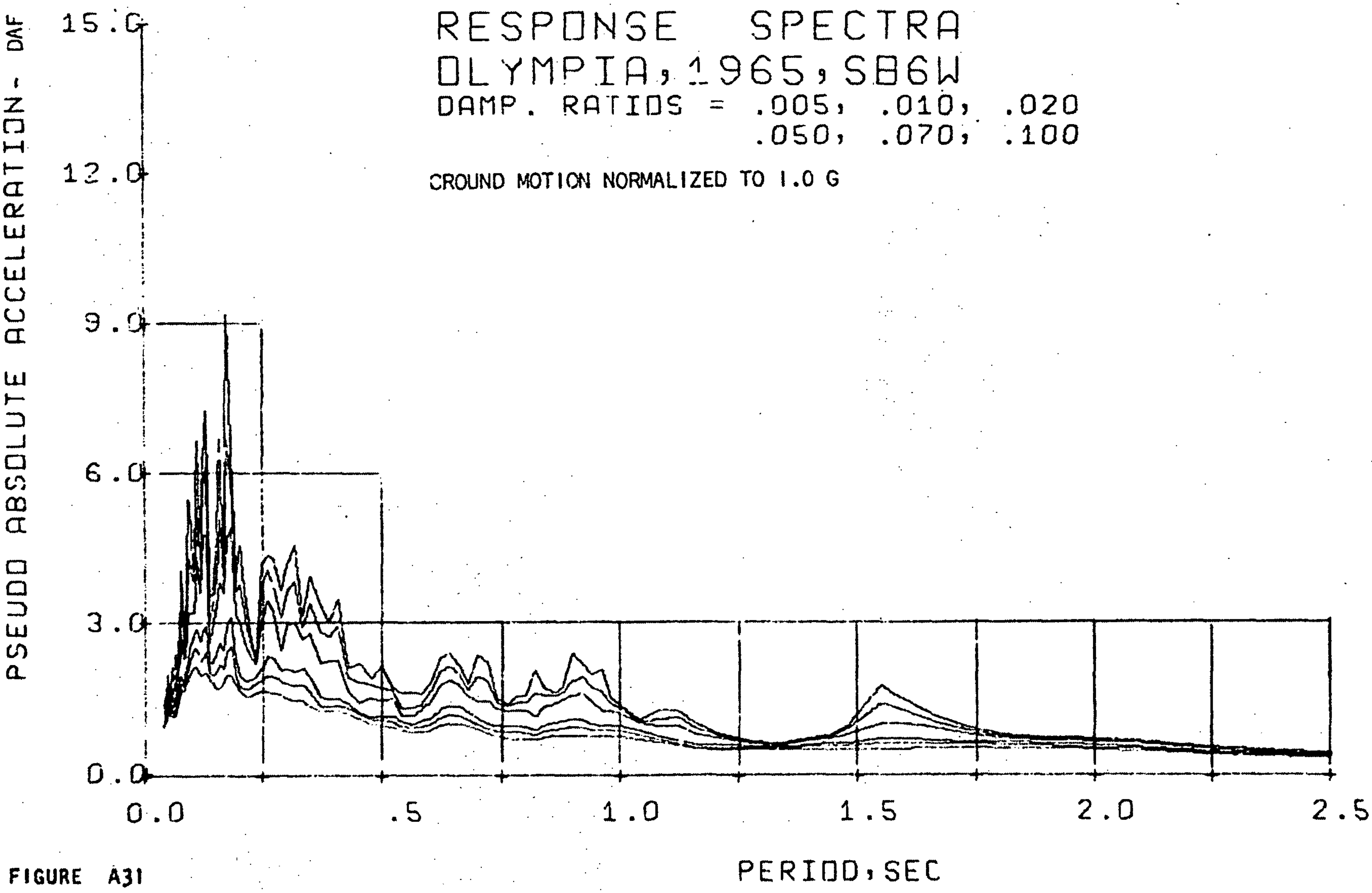

RESPONSE SPECTRA
OLYMPIA, 1965, SB6W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
CROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A31

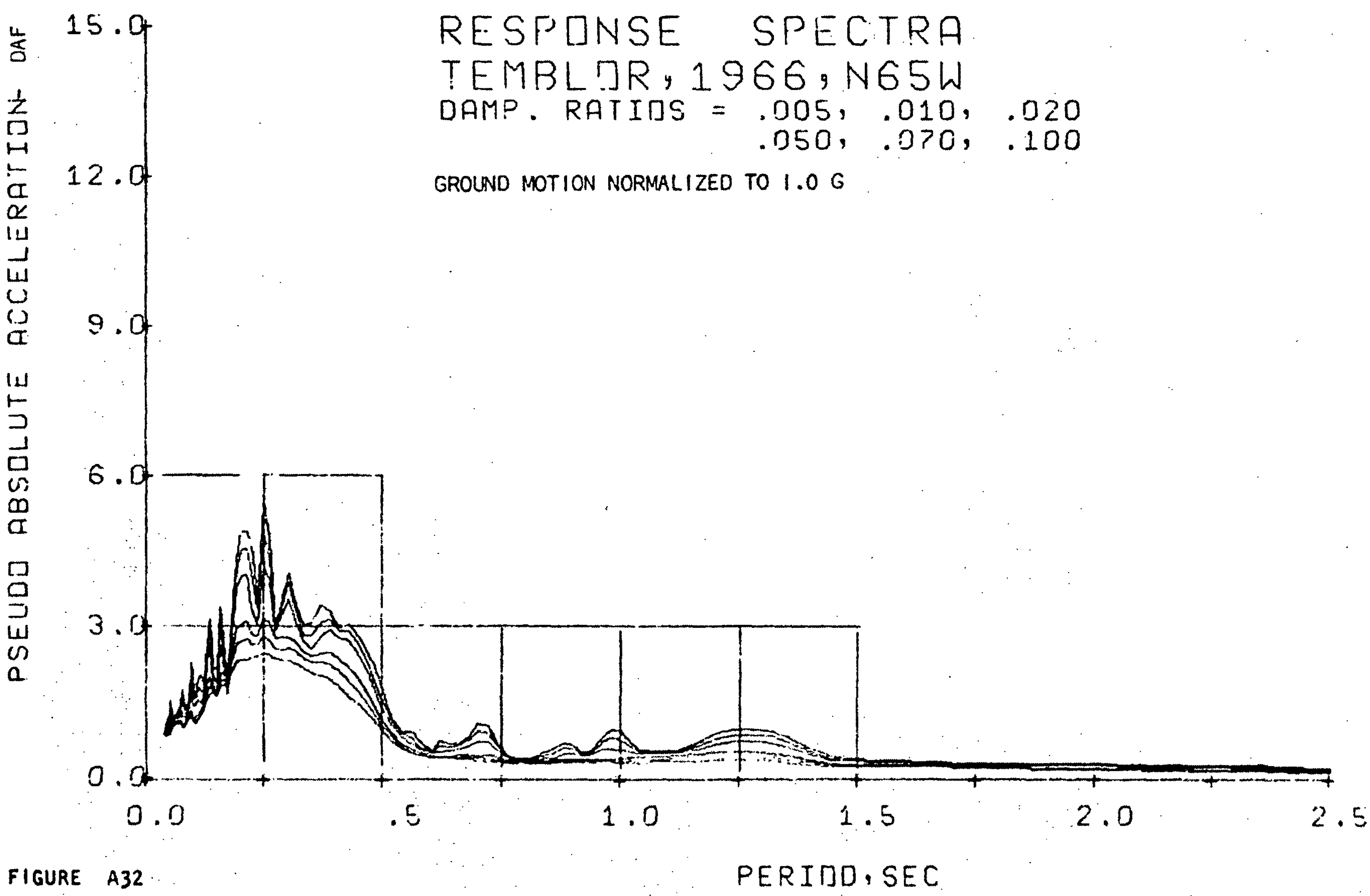
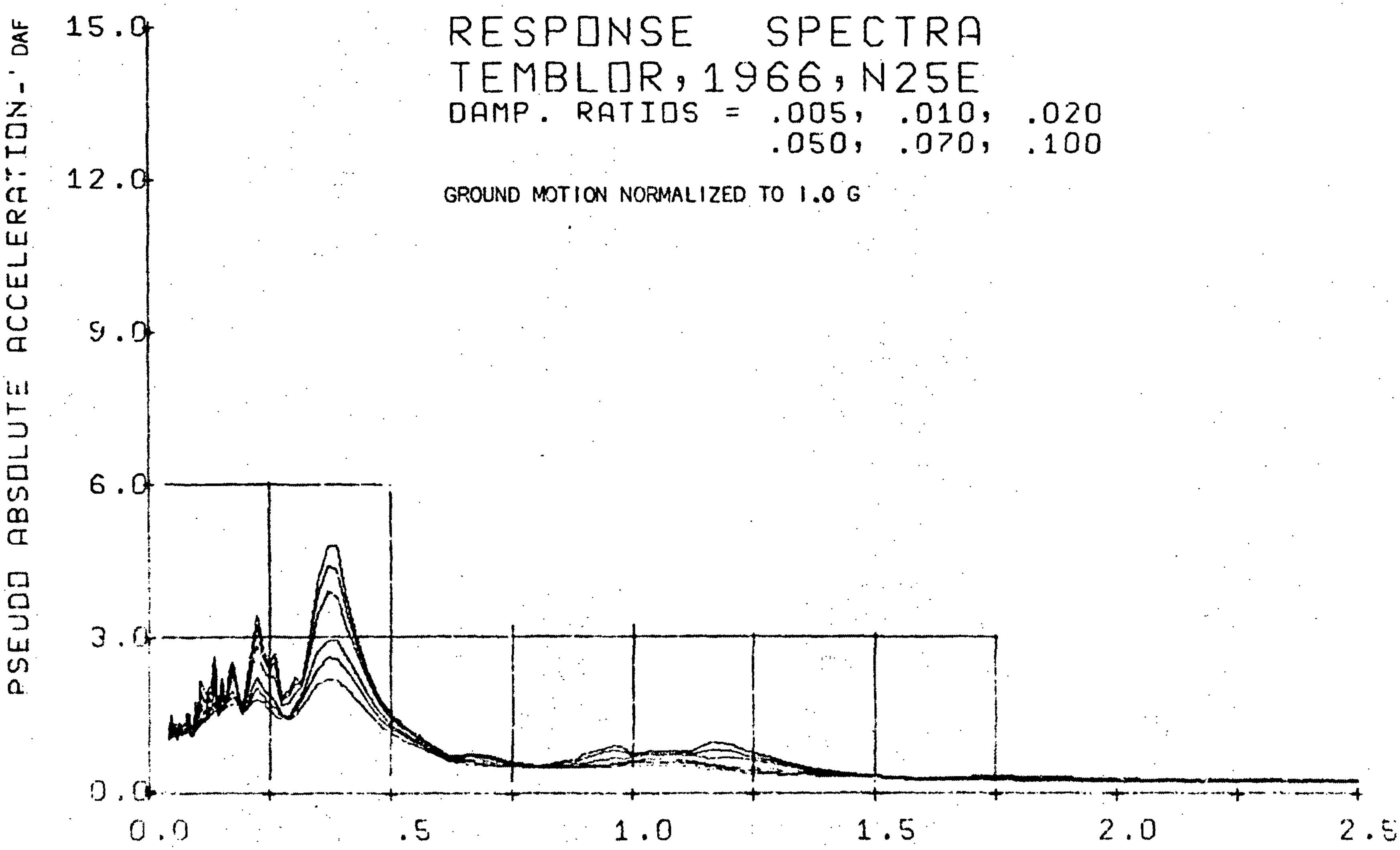

RESPONSE SPECTRA
TEMBLOR, 1966, N65W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION- DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE A32



RESPONSE SPECTRA
TEMBLOR,1966,N25E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION-' DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE A33

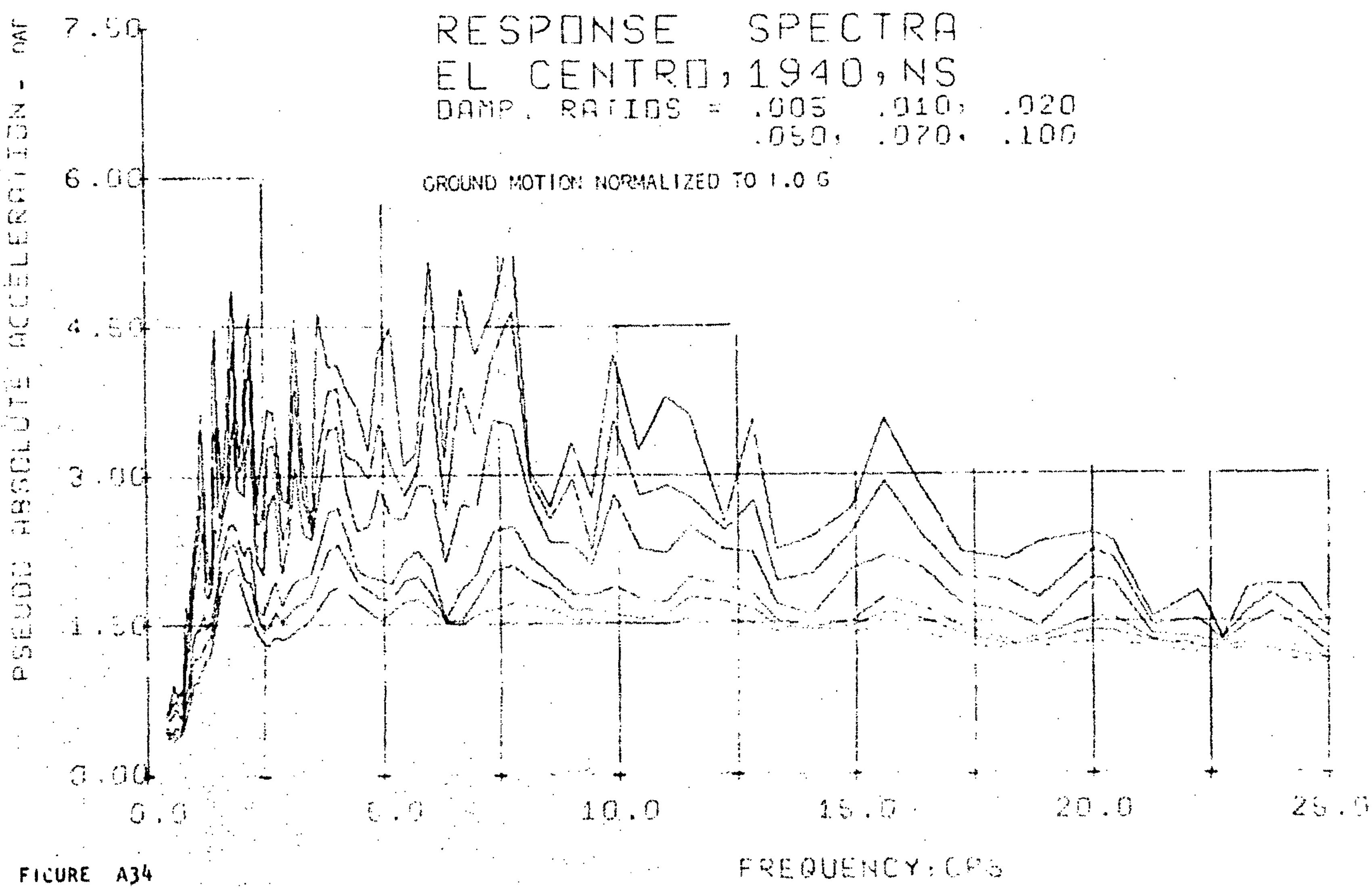

RESPONSE SPECTRA
EL CENTRO, 1940, NS
DAMP. RATIOS = .005 .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
7.50
6.00
4.50
3.00
1.50
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY: CPS

FIGURE A34

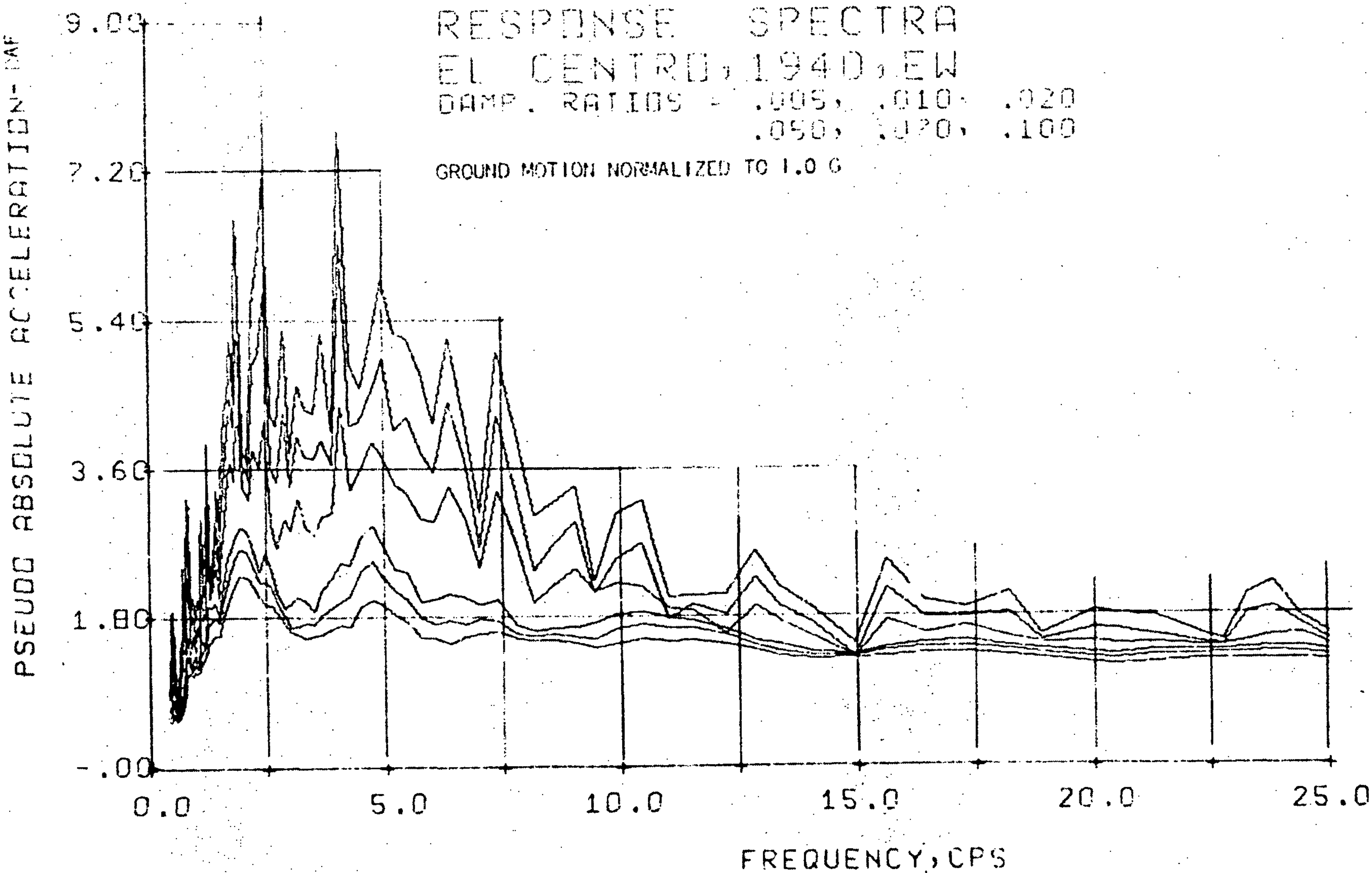
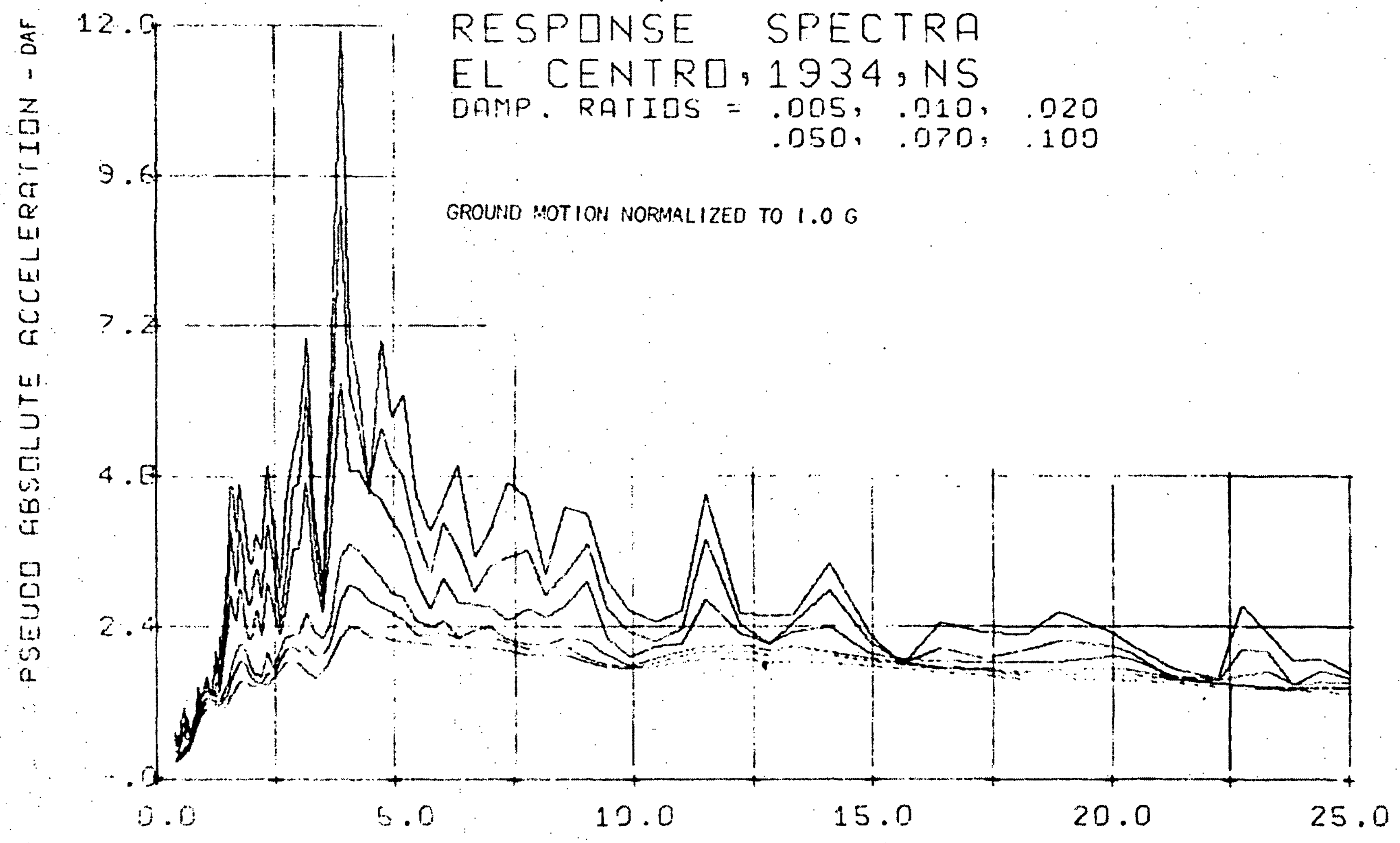
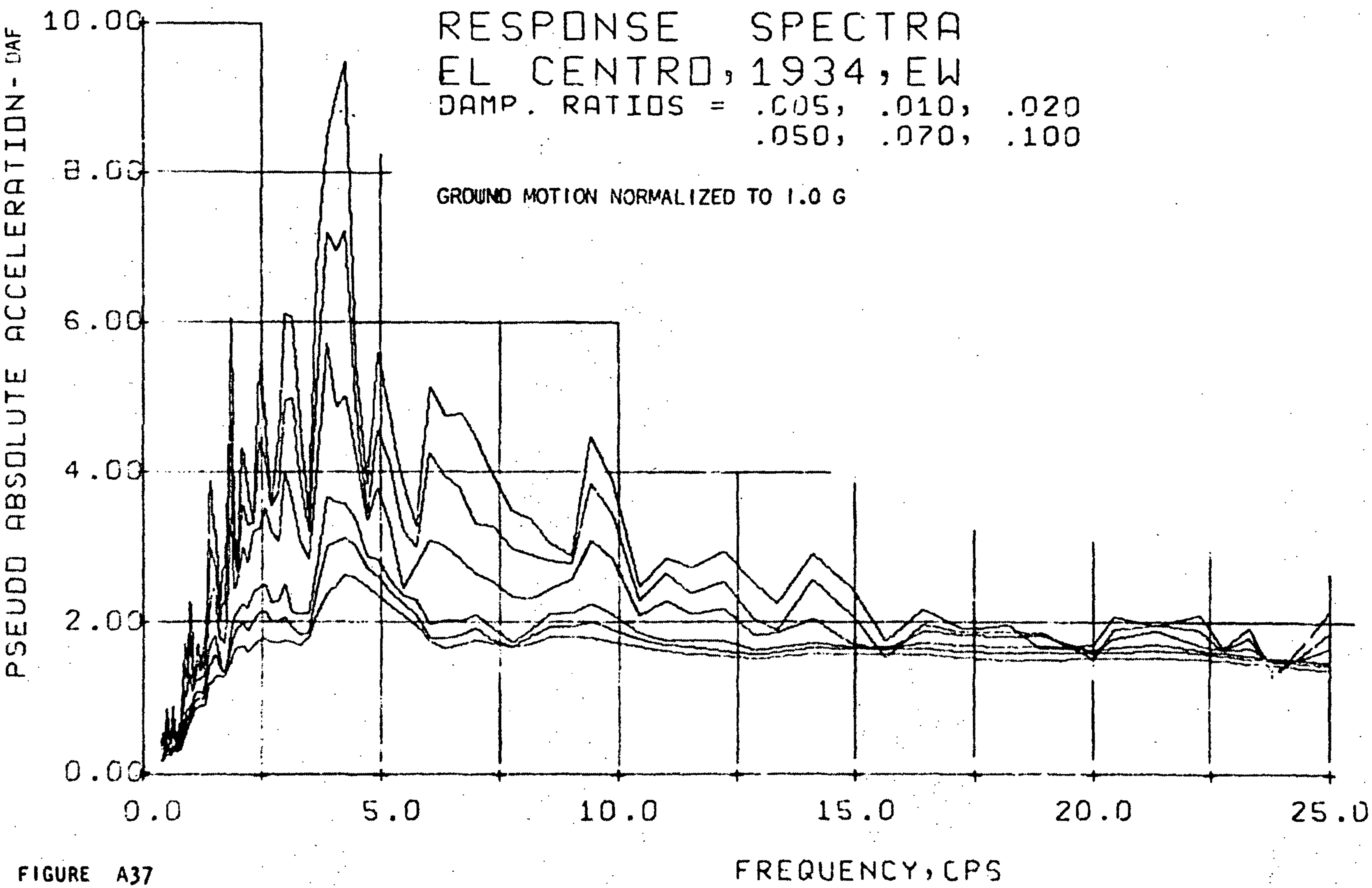

RESPONSE SPECTRA
EL CENTRO,1940,EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION-DAF
9.00
7.20
5.40
3.60
1.80
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A35



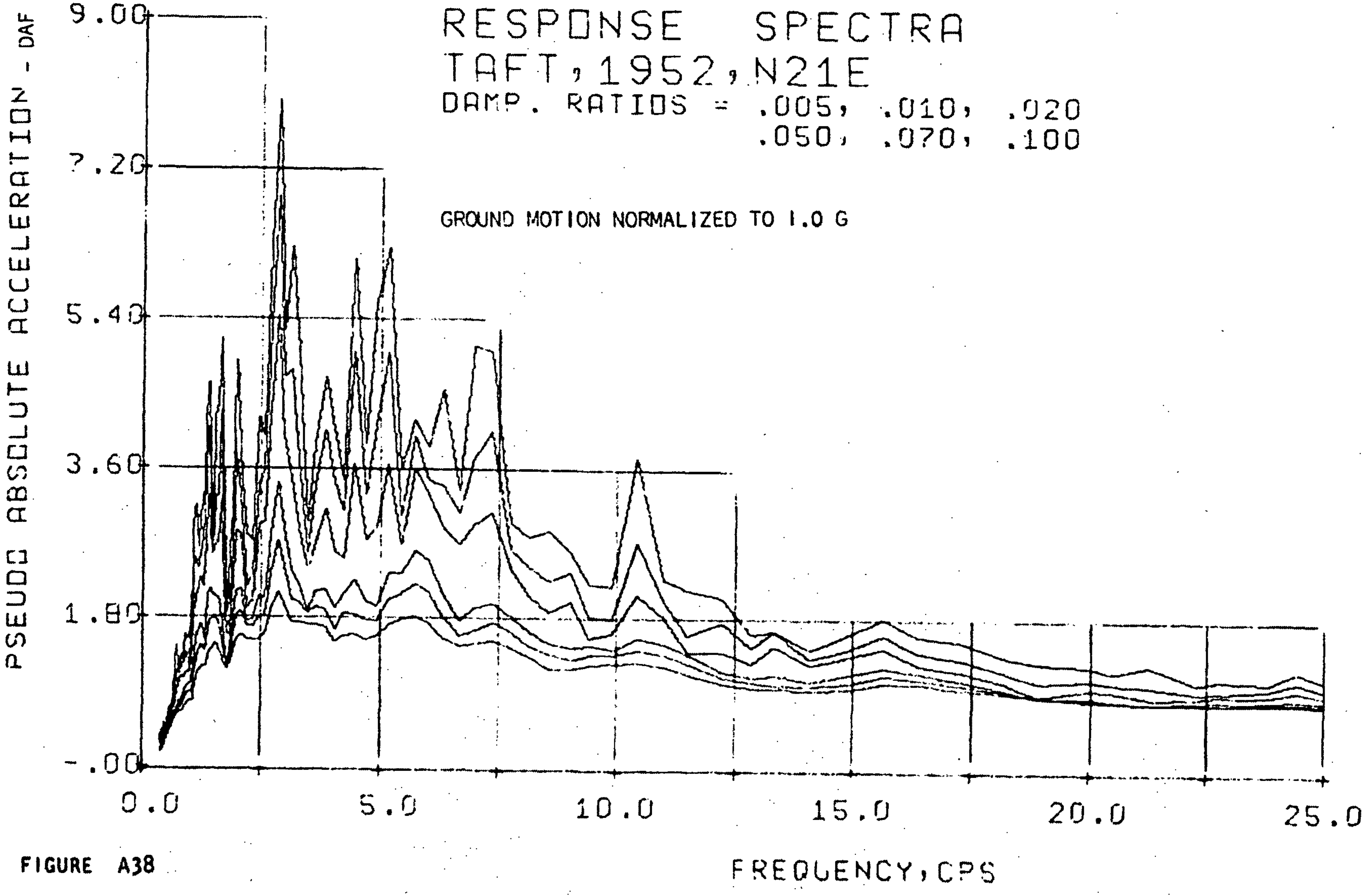
RESPONSE SPECTRA
EL CENTRO, 1934, NS
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
12.0
9.6
7.2
4.8
2.4
.0
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A36



RESPONSE SPECTRA
EL CENTRO, 1934, EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
10.00
8.00
6.00
4.00
2.00
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A37



RESPONSE SPECTRA
TAFT, 1952, N21E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
9.00
7.20
5.40
3.60
1.80
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A38

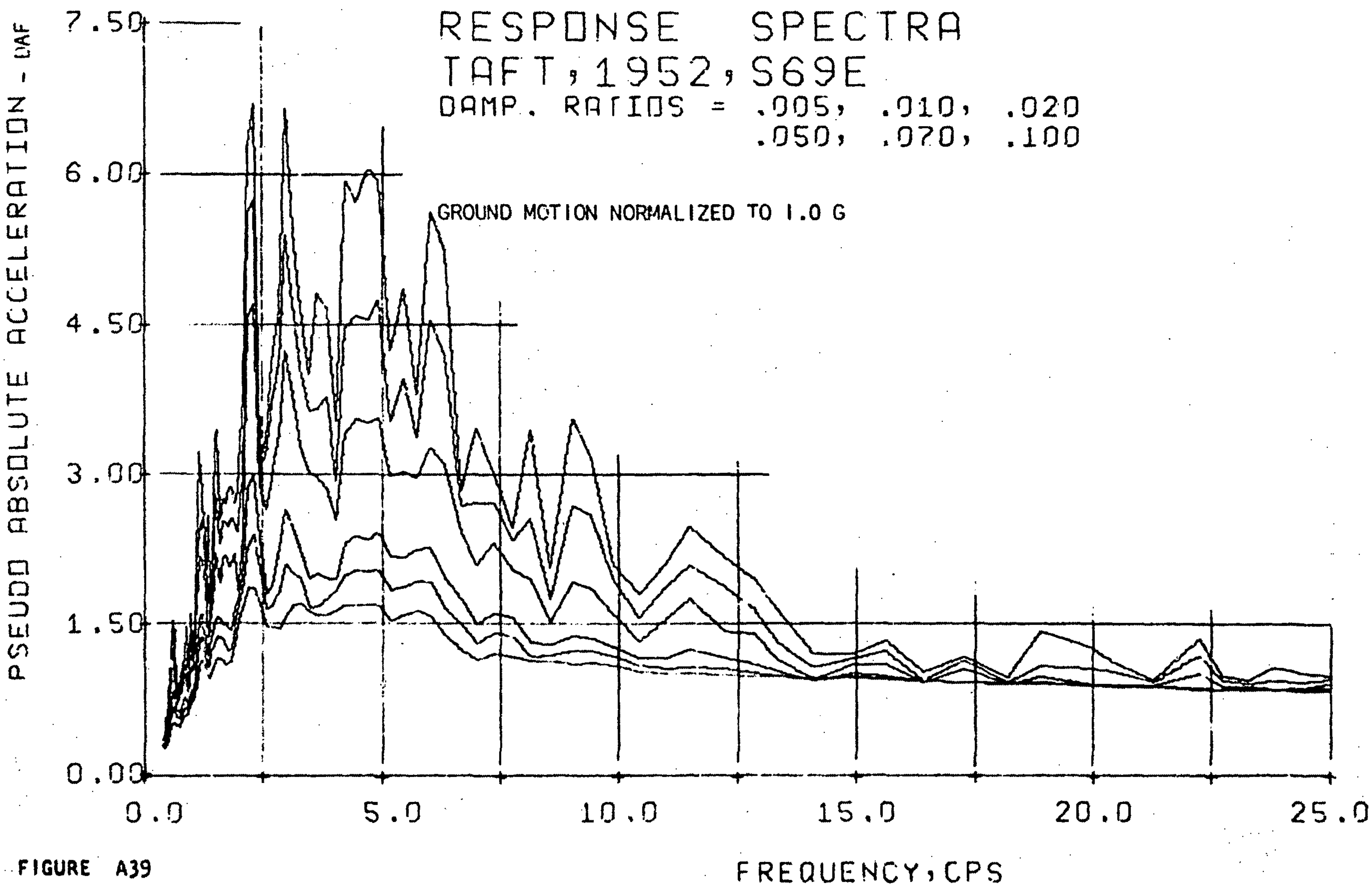

RESPONSE SPECTRA
TAFT,1952,S69E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
7.50
6.00
4.50
3.00
1.50
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A39

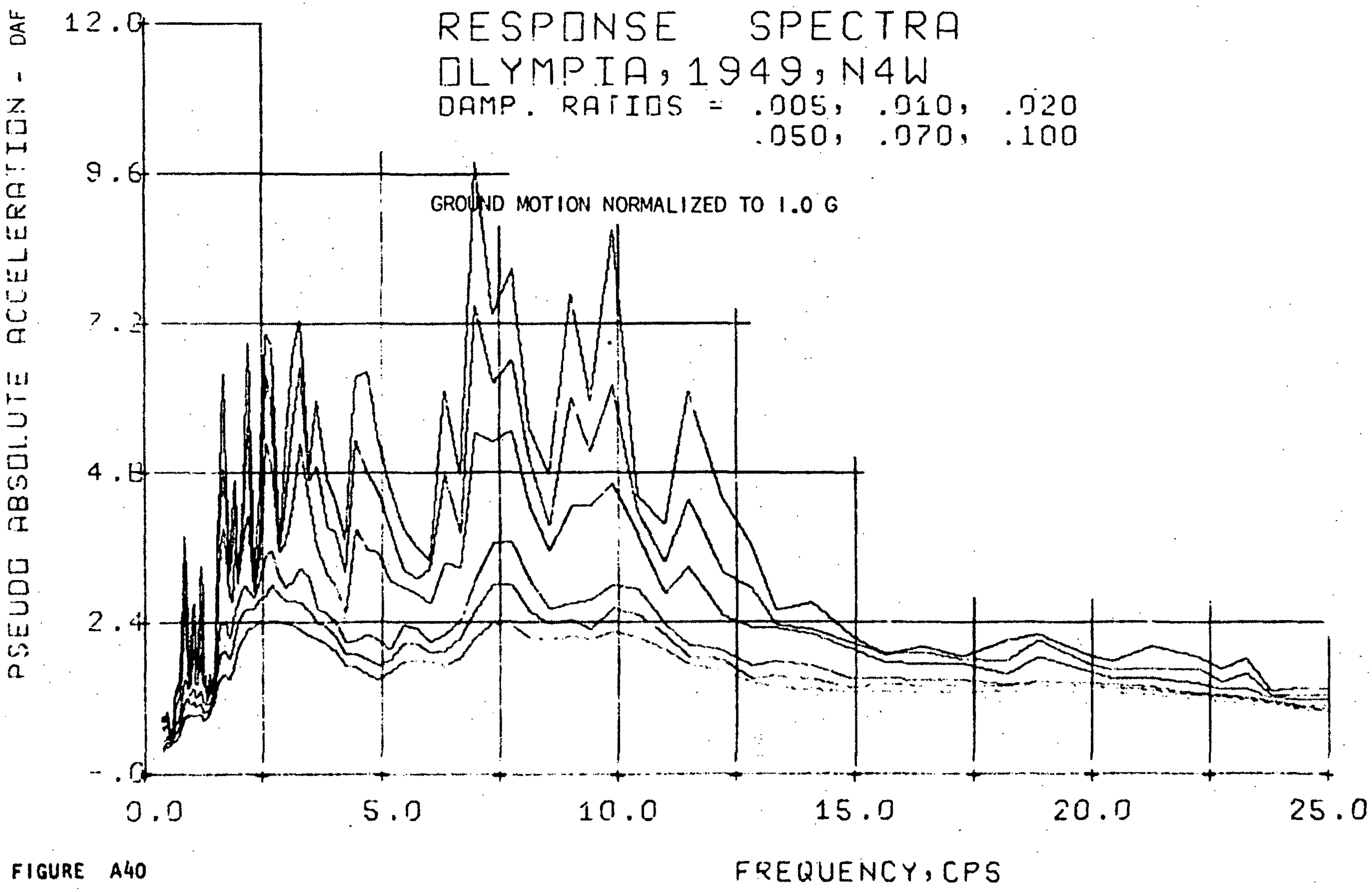
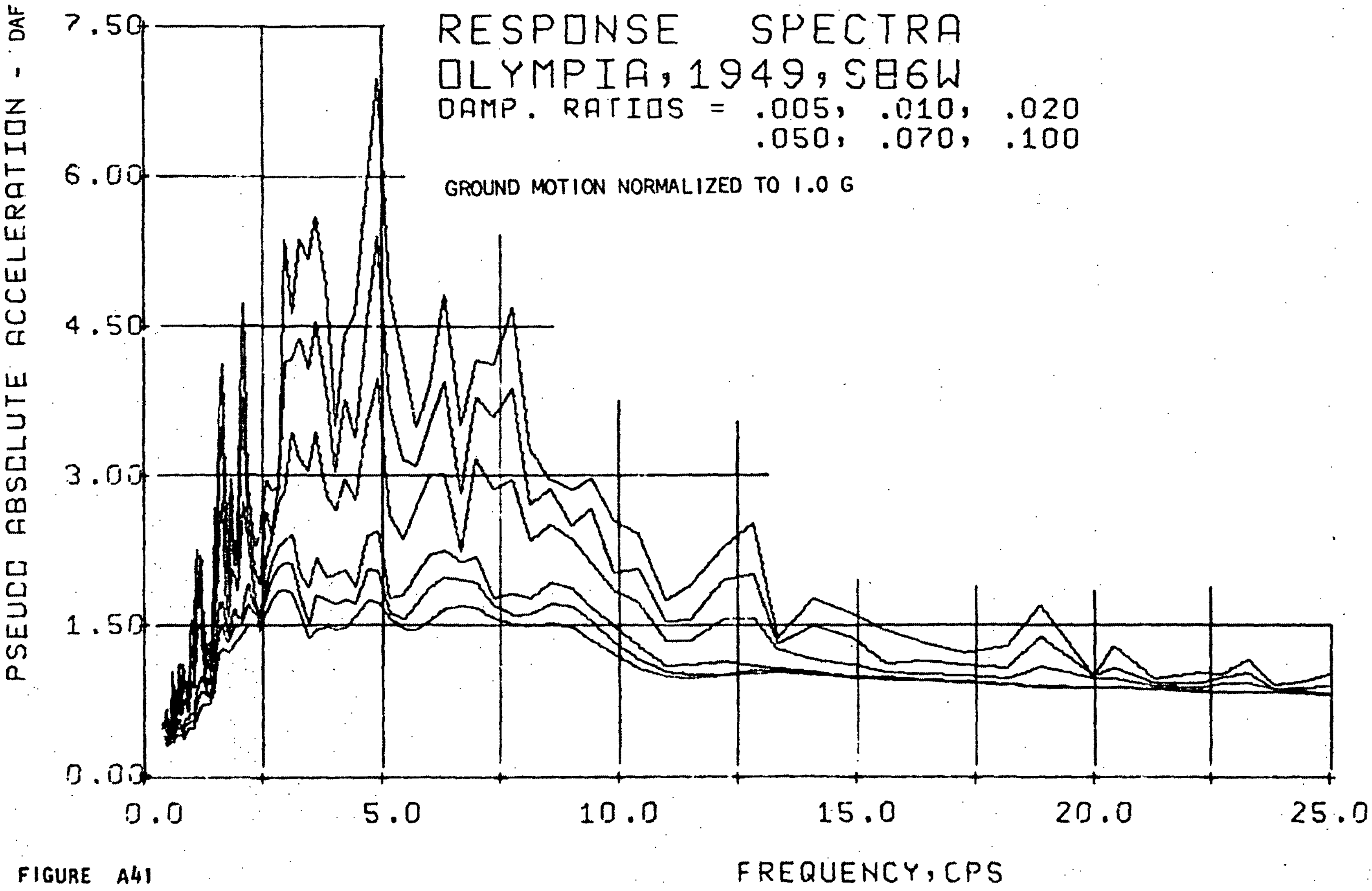

RESPONSE SPECTRA
OLYMPIA, 1949, N4W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
12.0
9.6
7.2
4.8
2.4
.0
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A40



RESPONSE SPECTRA
OLYMPIA, 1949, S86W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
7.50
6.00
4.50
3.00
1.50
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A41

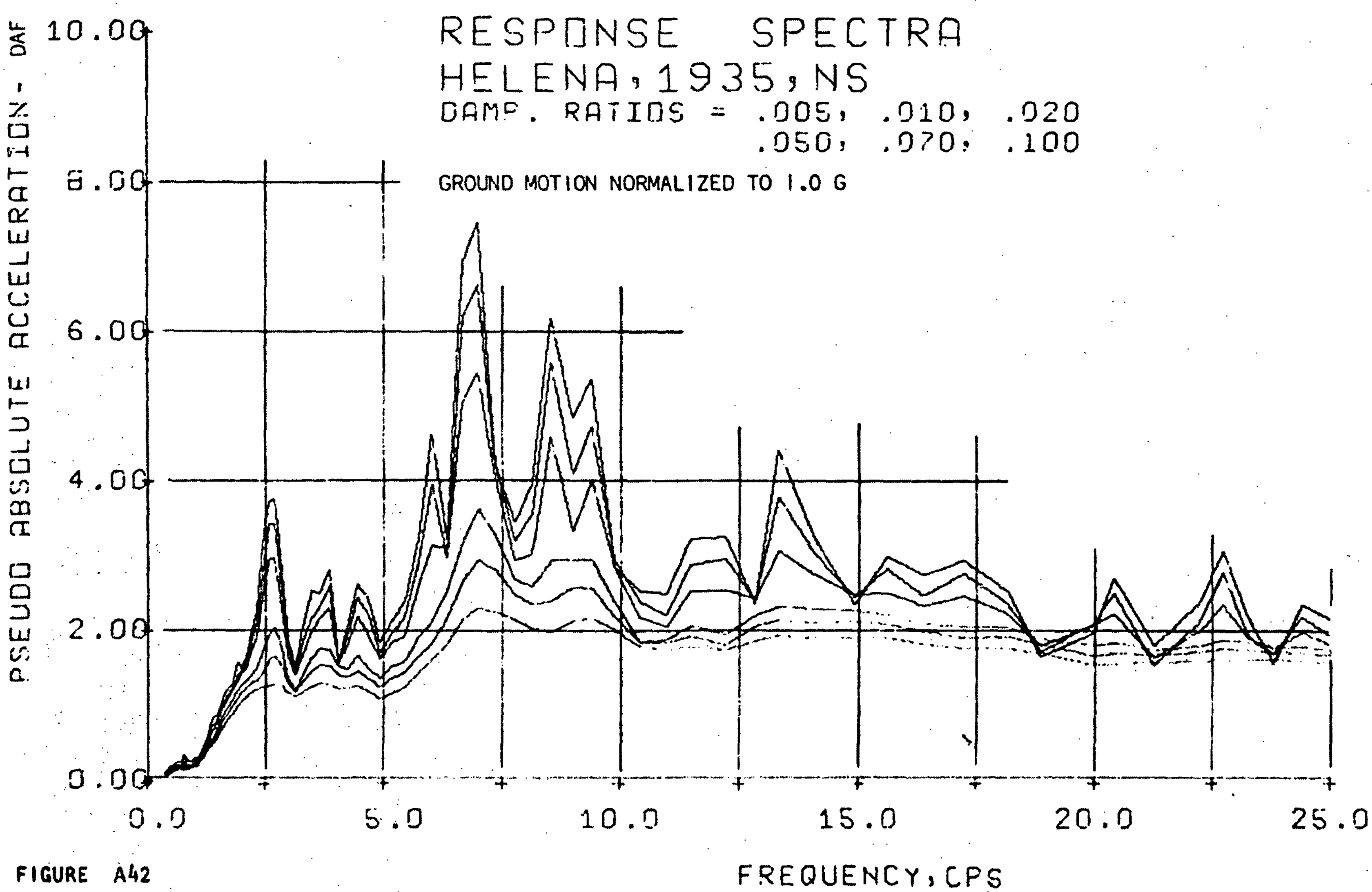

RESPONSE SPECTRA
HELENA,1935,NS
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
10.00
8.00
6.00
4.00
2.00
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A42

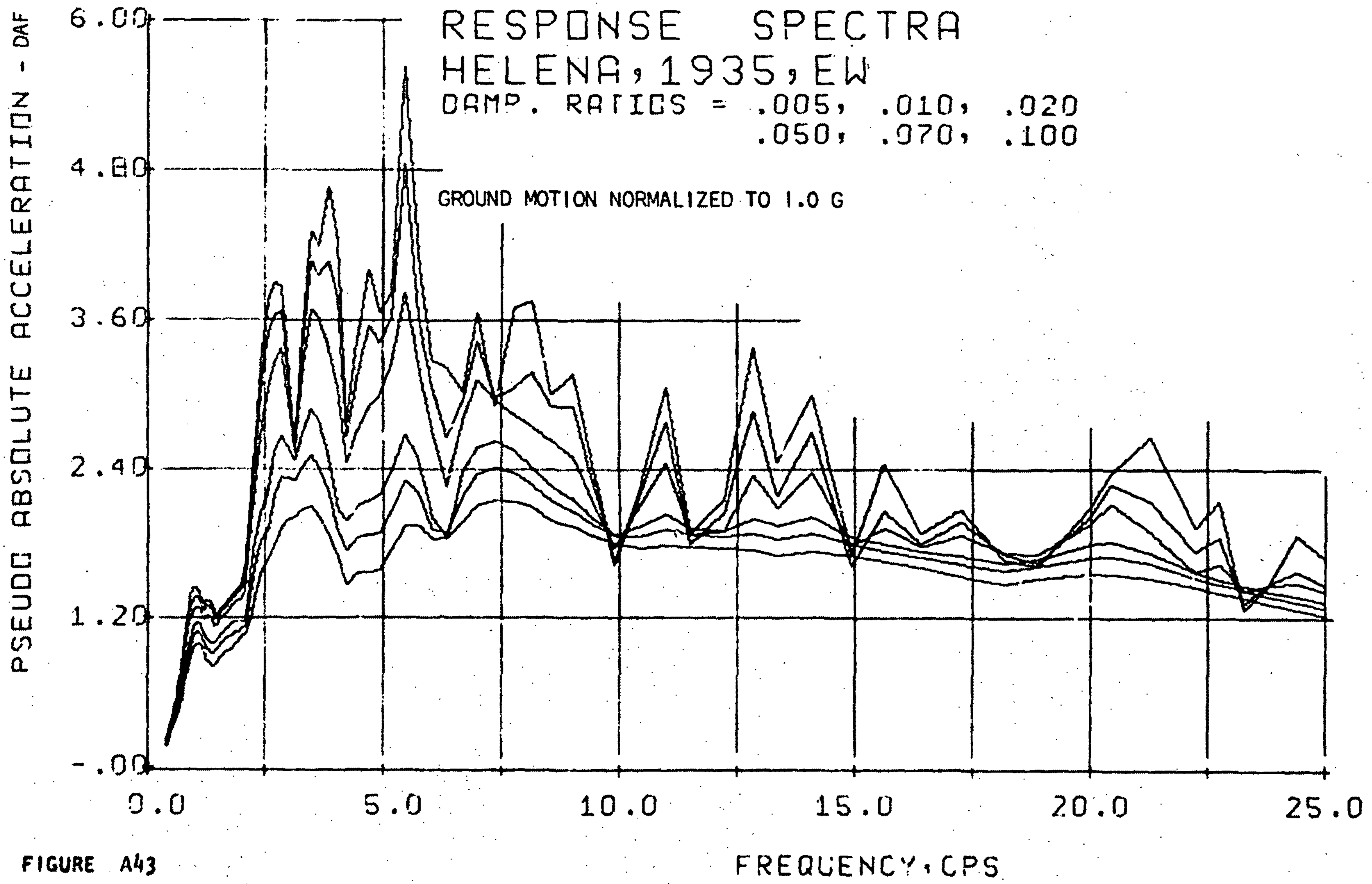

RESPONSE SPECTRA
HELENA, 1935, EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
6.00
4.80
3.60
2.40
1.20
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A43

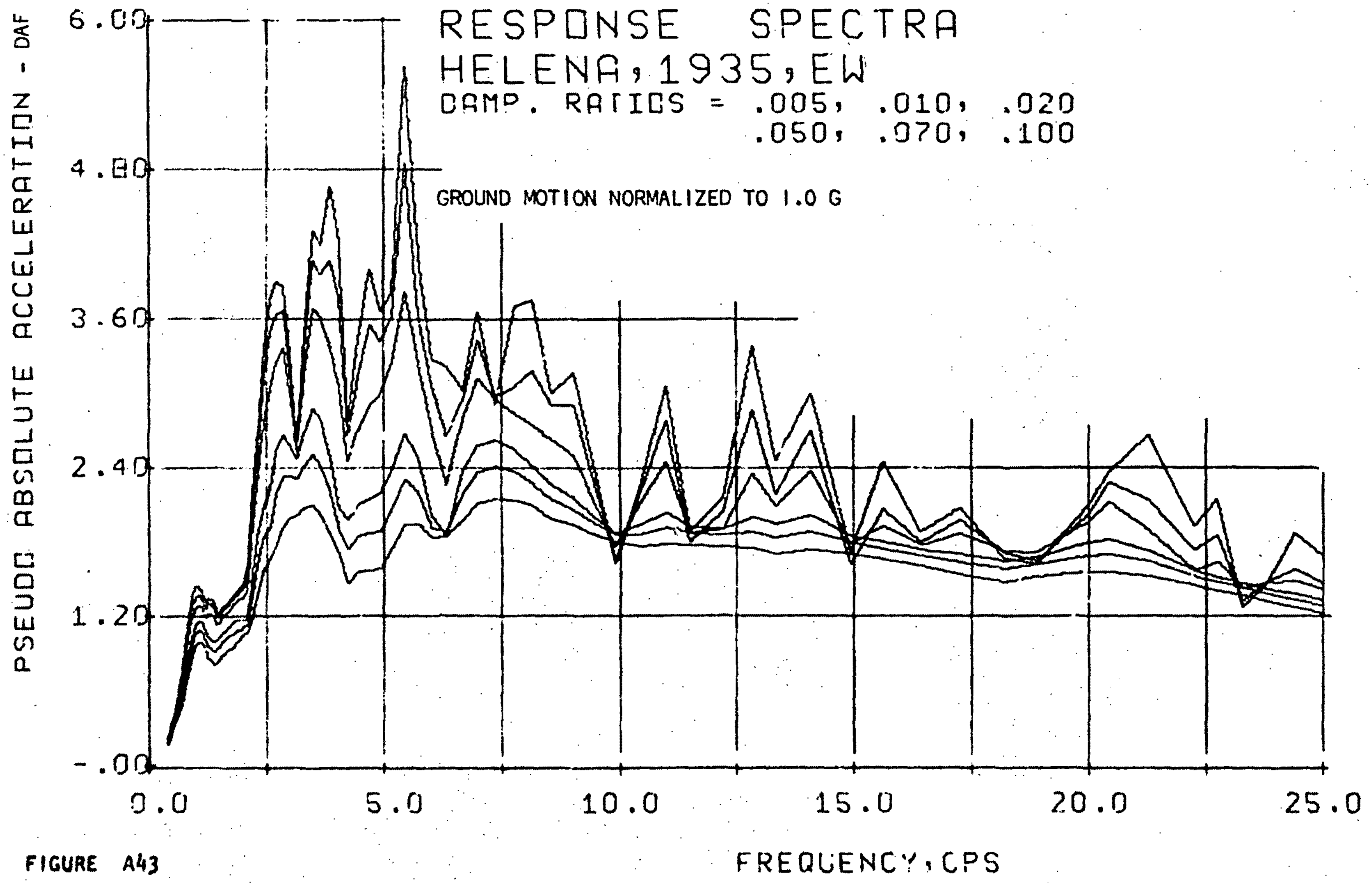

RESPONSE SPECTRA
HELENA,1935,EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
6.00
4.80
3.60
2.40
1.20
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A43

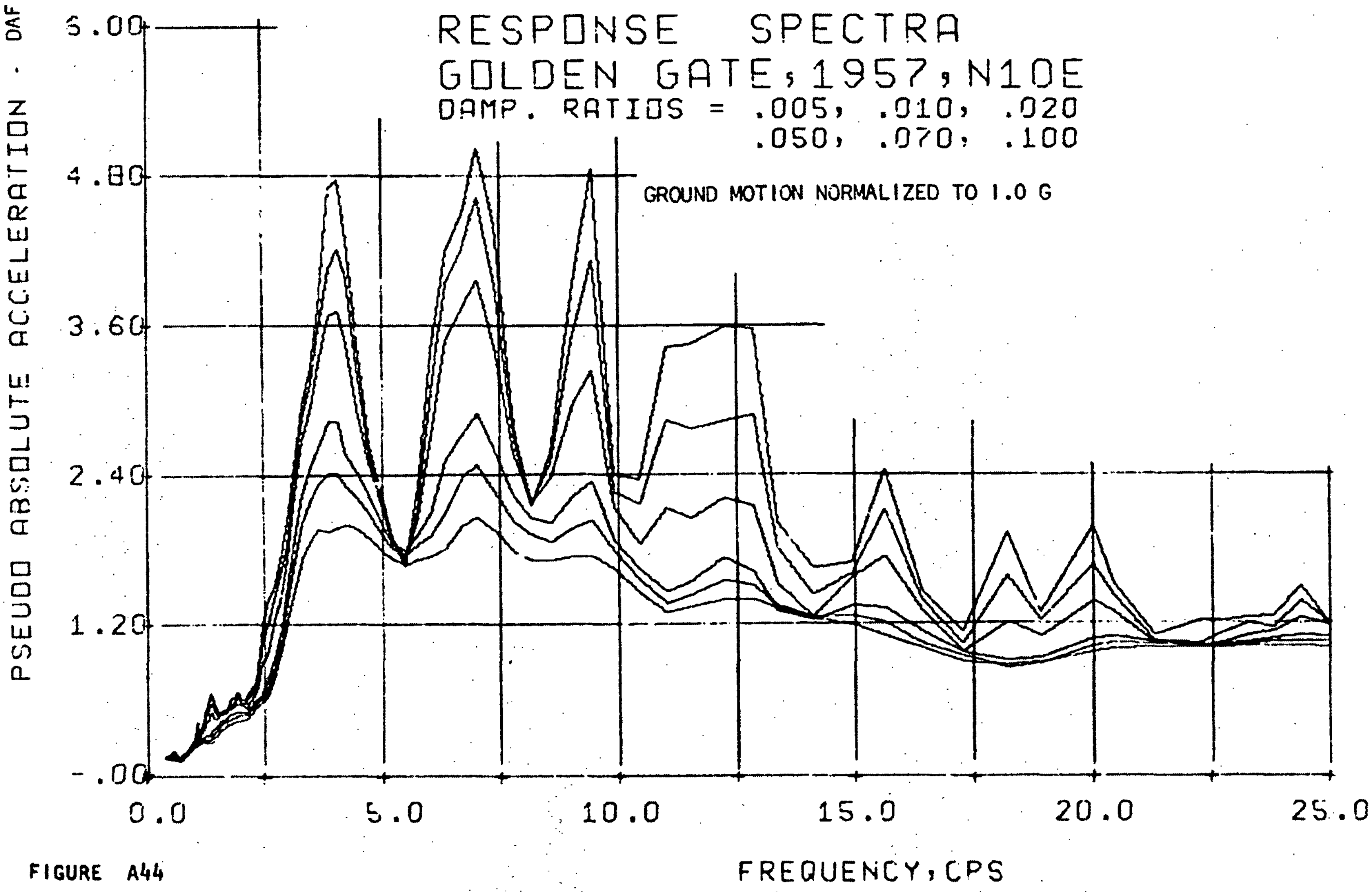

RESPONSE SPECTRA
GOLDEN GATE, 1957, N10E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
6.00
4.80
3.60
2.40
1.20
.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A44

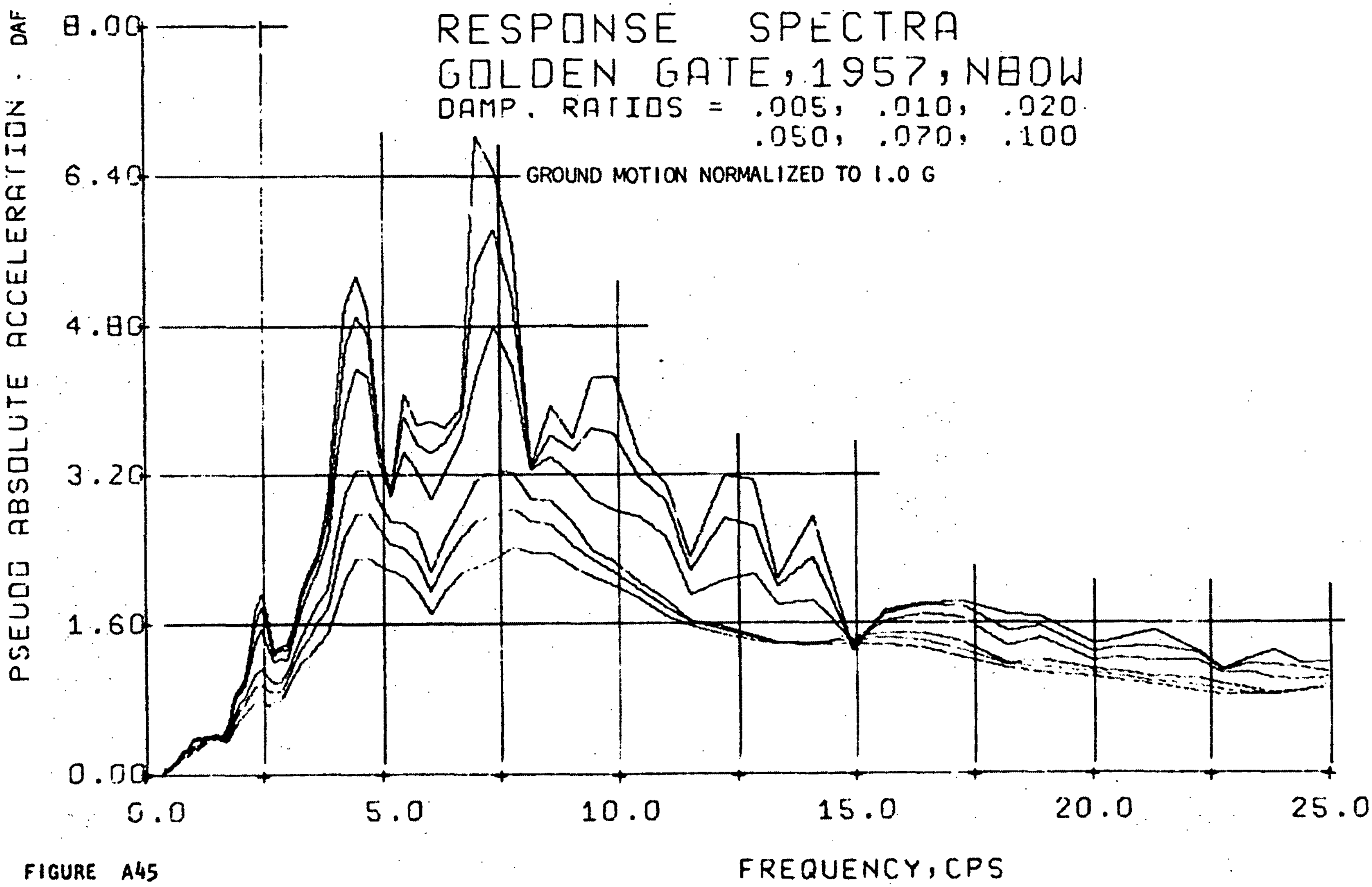

RESPONSE SPECTRA
GOLDEN GATE, 1957, N80W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION . DAF
8.00
6.40
4.80
3.20
1.60
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A45

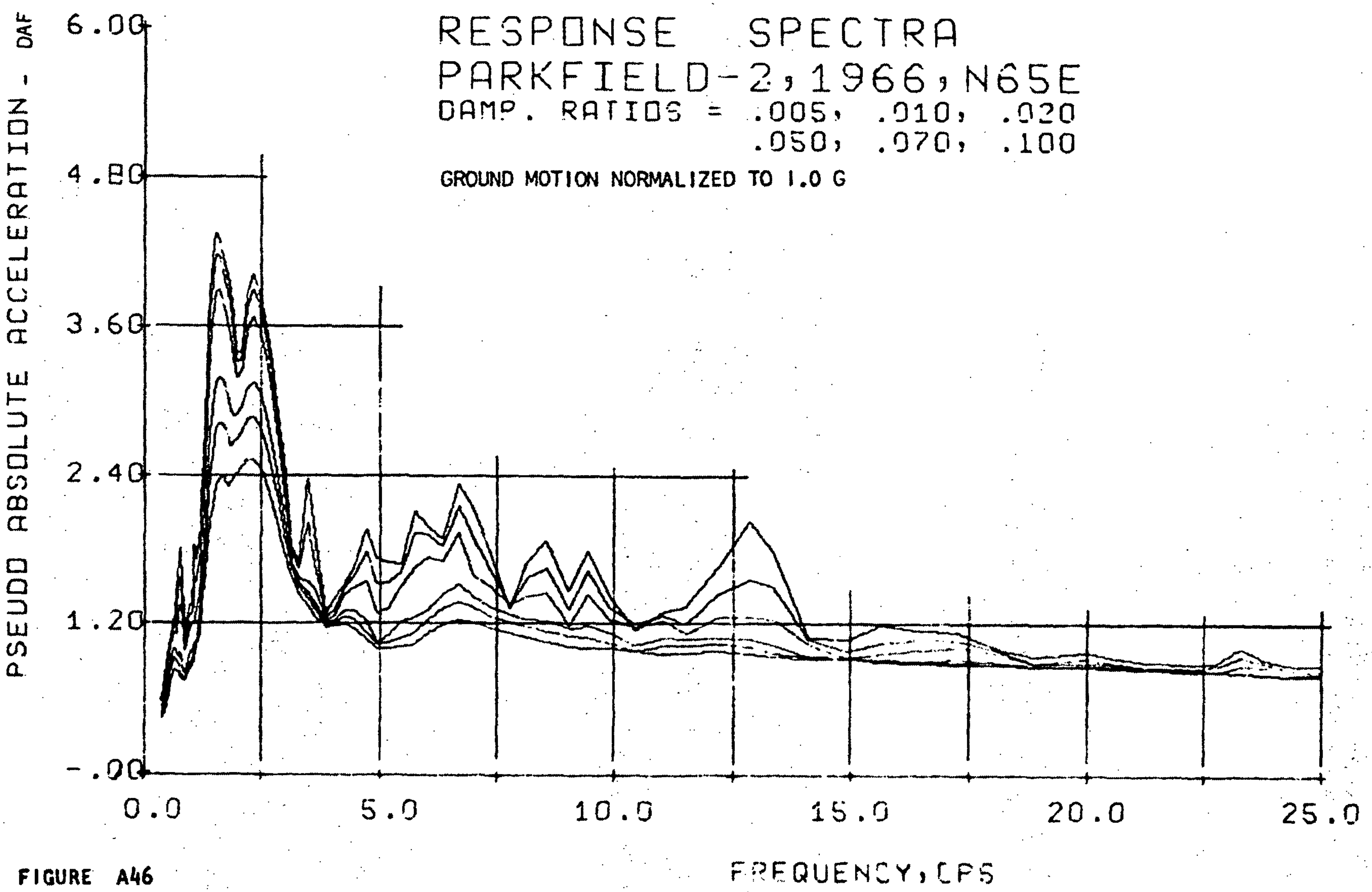

RESPONSE SPECTRA
PARKFIELD-2,1966,N65E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
6.00
4.80
3.60
2.40
1.20
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A46

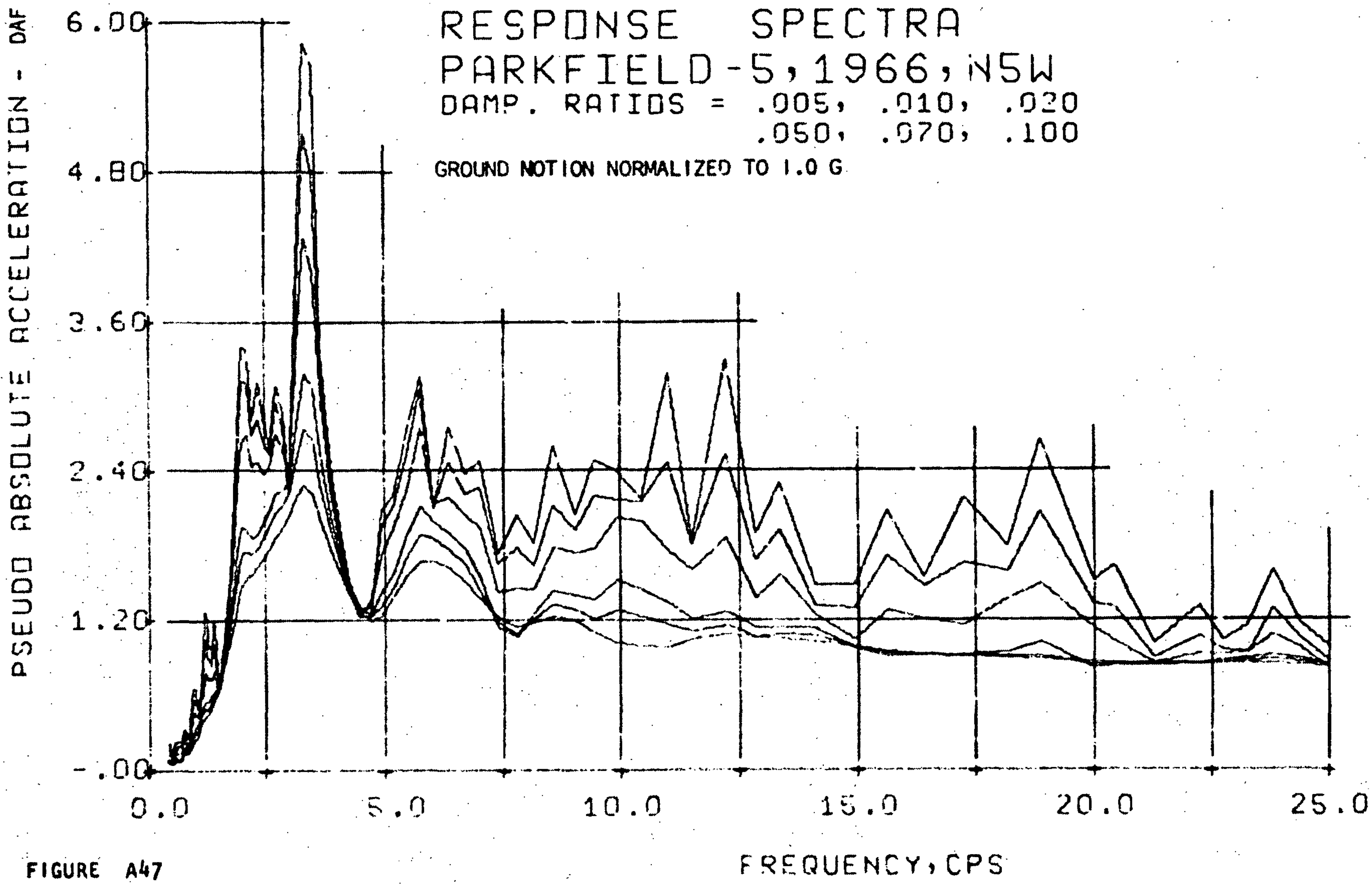
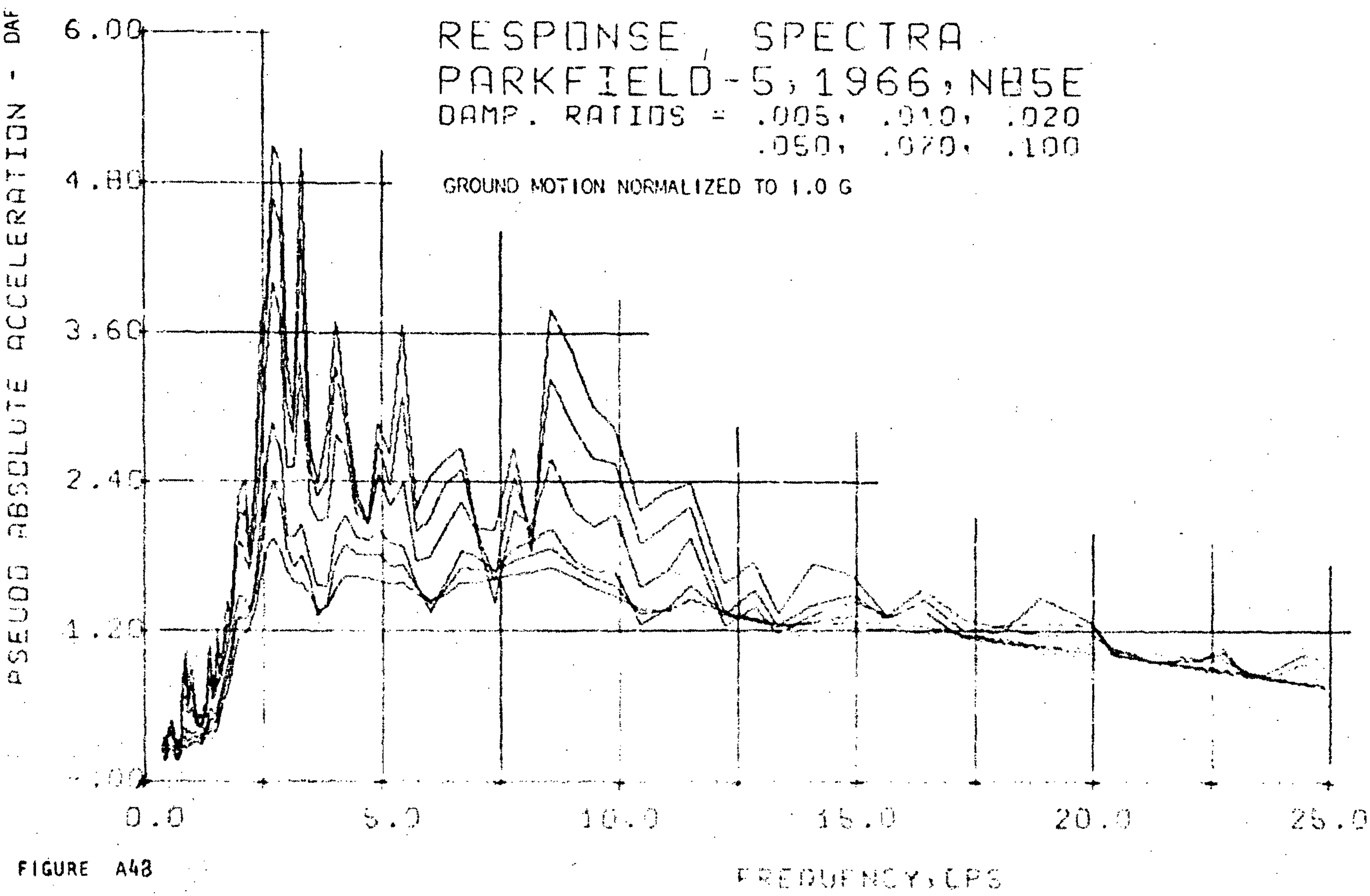

RESPONSE SPECTRA
PARKFIELD-5, 1966, N5W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
6.00
4.80
3.60
2.40
1.20
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A47



RESPONSE, SPECTRA
PARKFIELD-5,1966,N85E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
6.00
4.80
3.60
2.40
1.20
.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A48

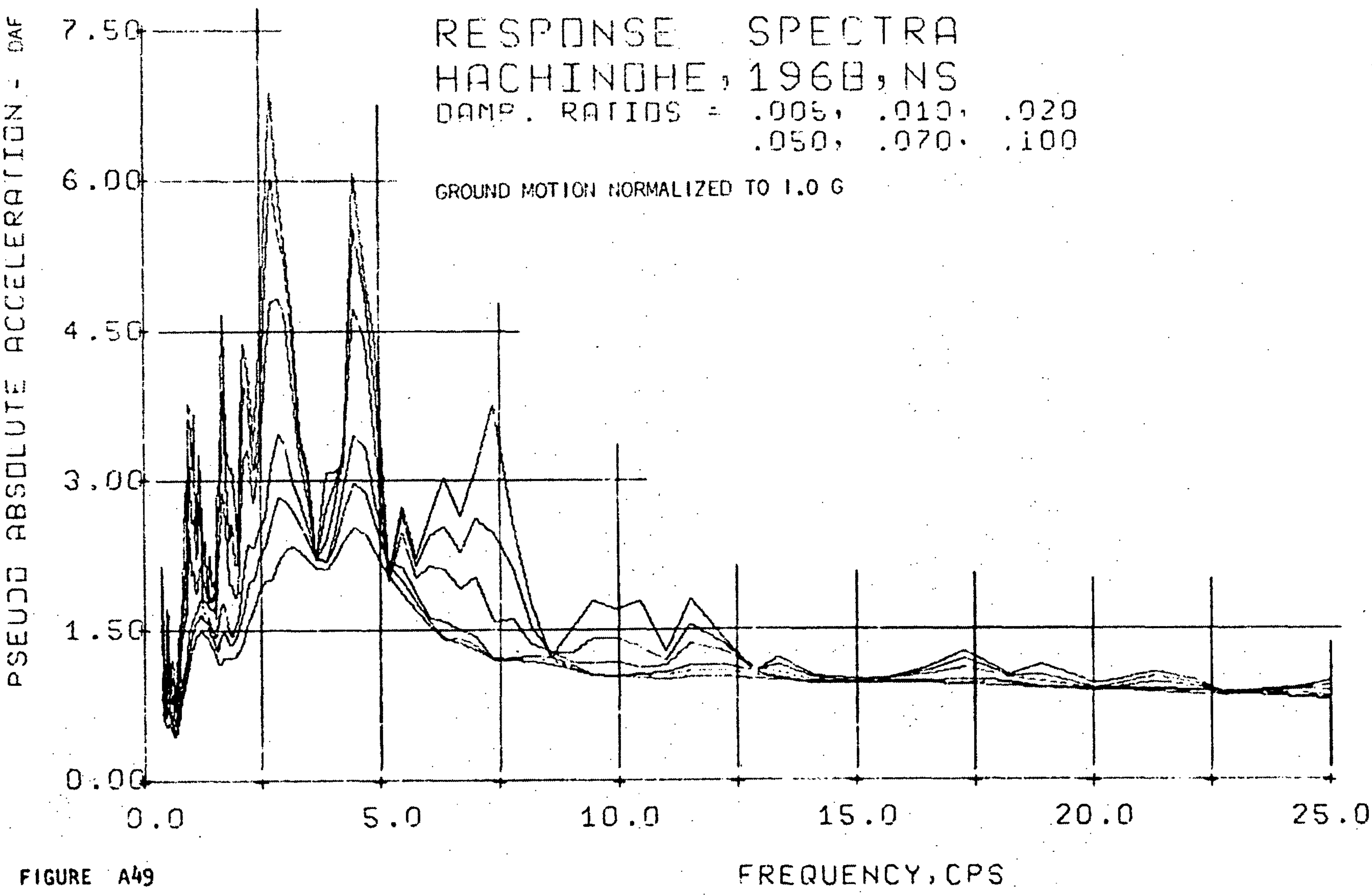
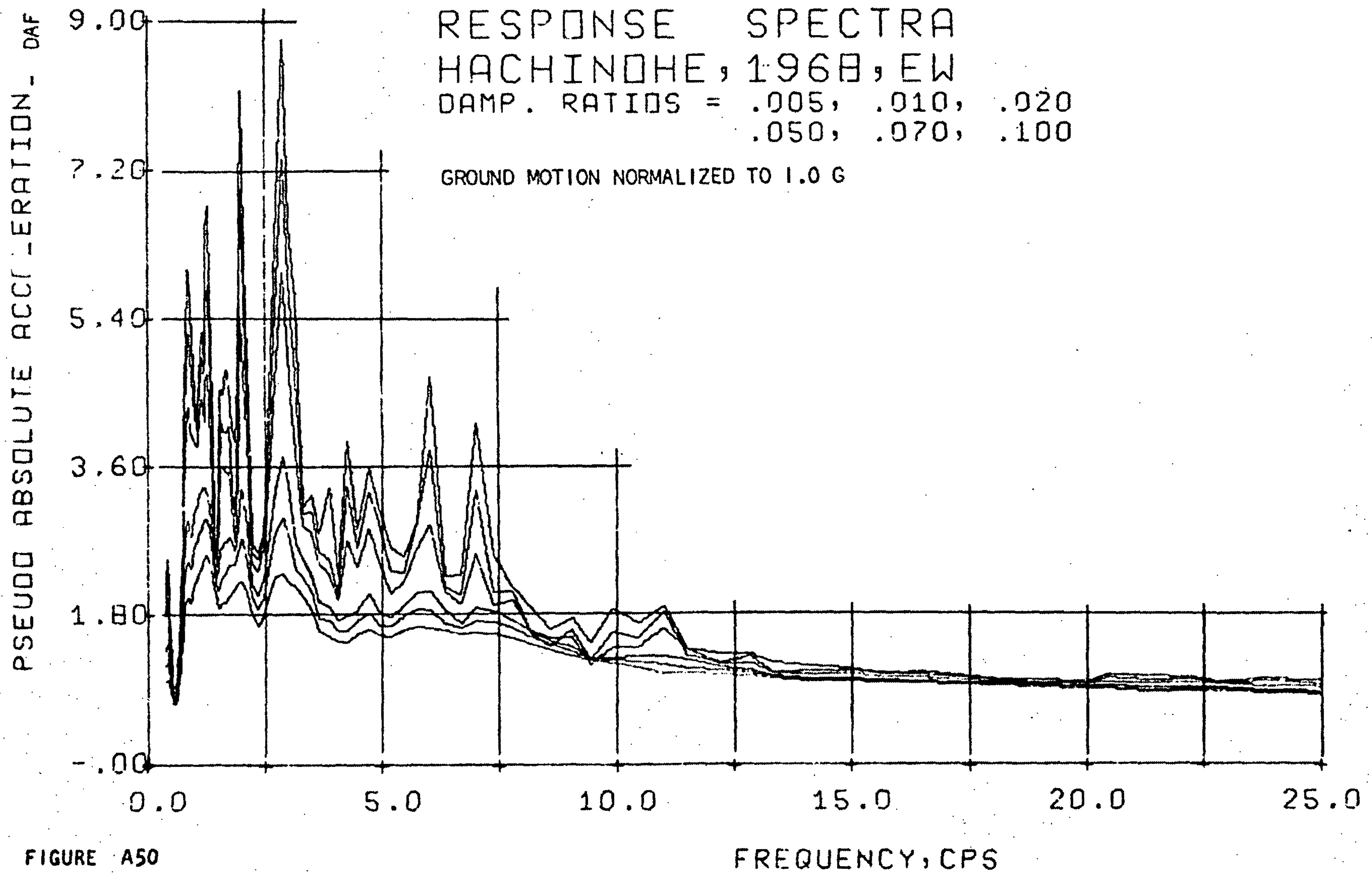
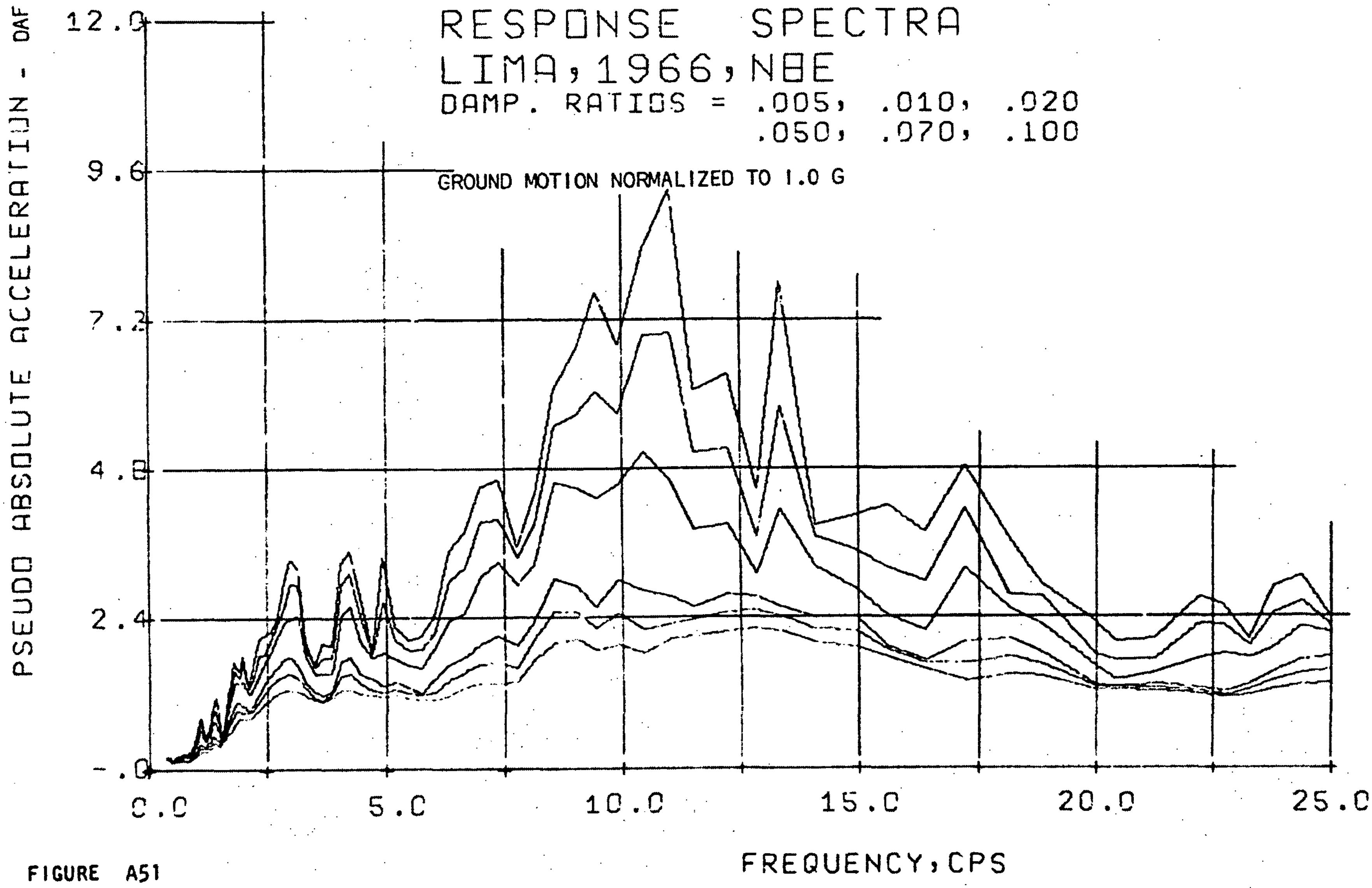

RESPONSE SPECTRA
HACHINOHE,1968,NS
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
7.50
6.00
4.50
3.00
1.50
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A49



RESPONSE SPECTRA
HACHINOHE, 1968, EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACC[illegible]ERATION - DAF
9.00
7.20
5.40
3.60
1.80
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A50



RESPONSE SPECTRA
LIMA,1966,N8E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
12.0
9.6
7.2
4.8
2.4
.0
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A51

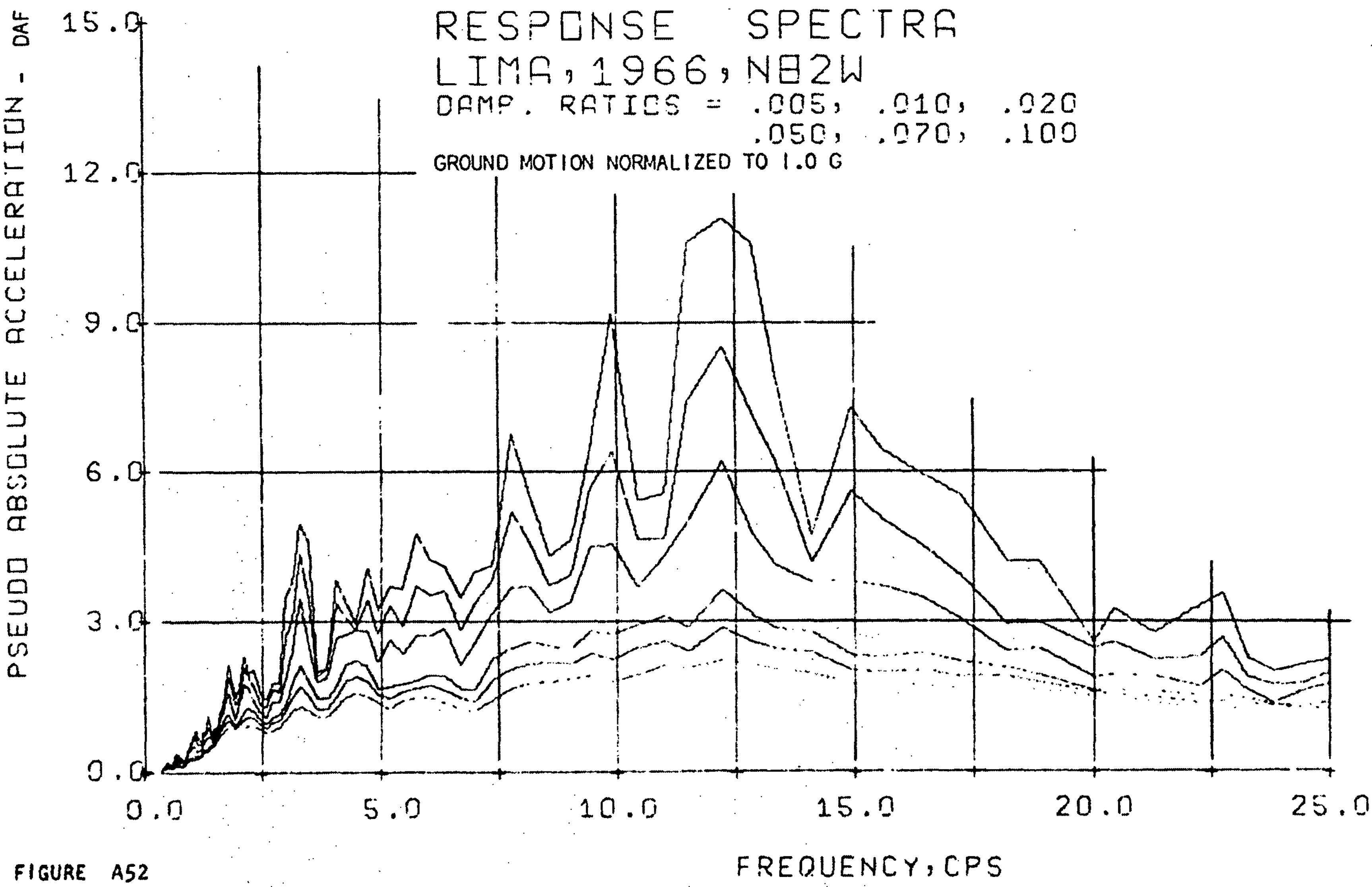

RESPONSE SPECTRA
LIMA,1966,N82W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A52

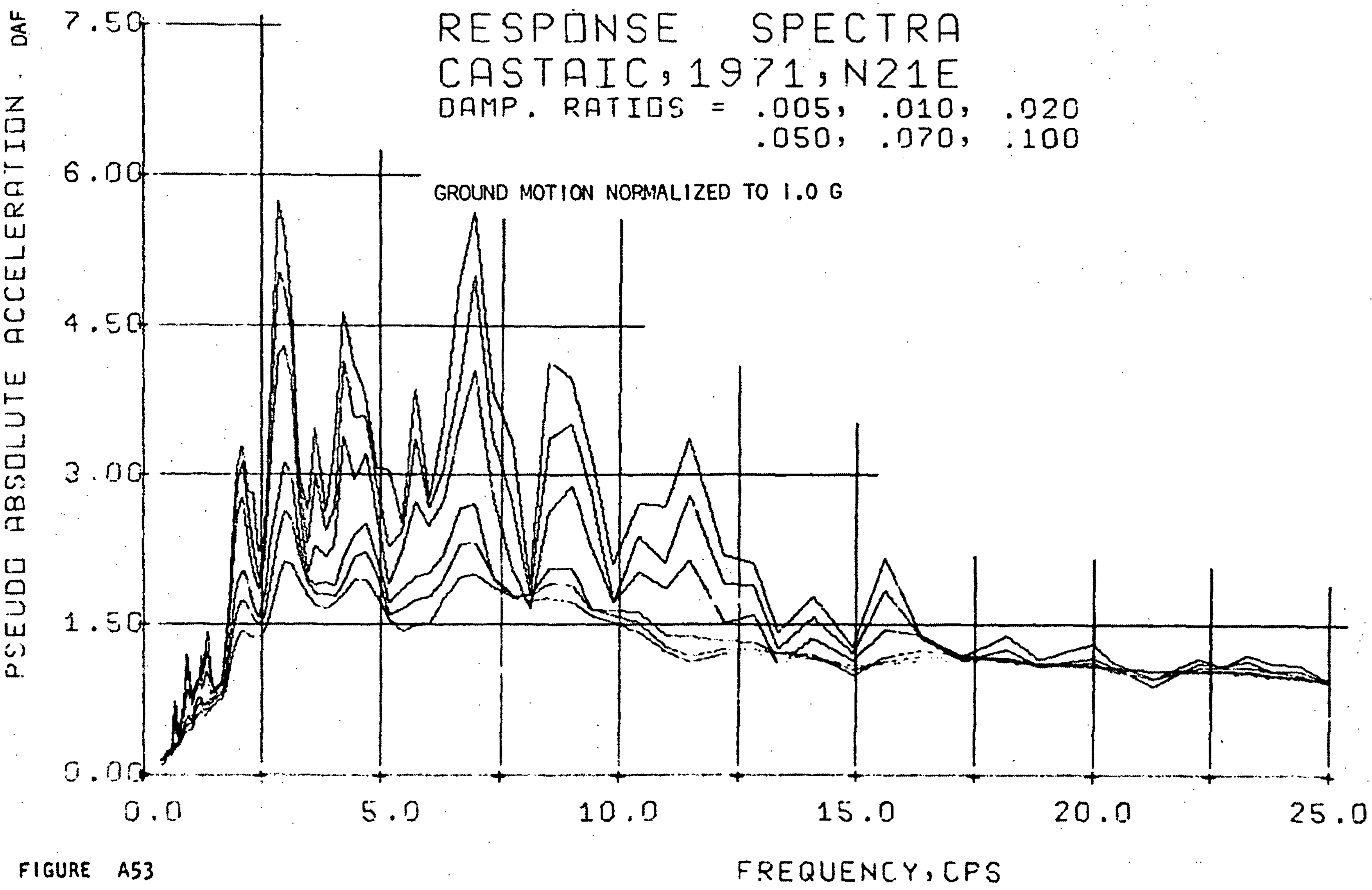
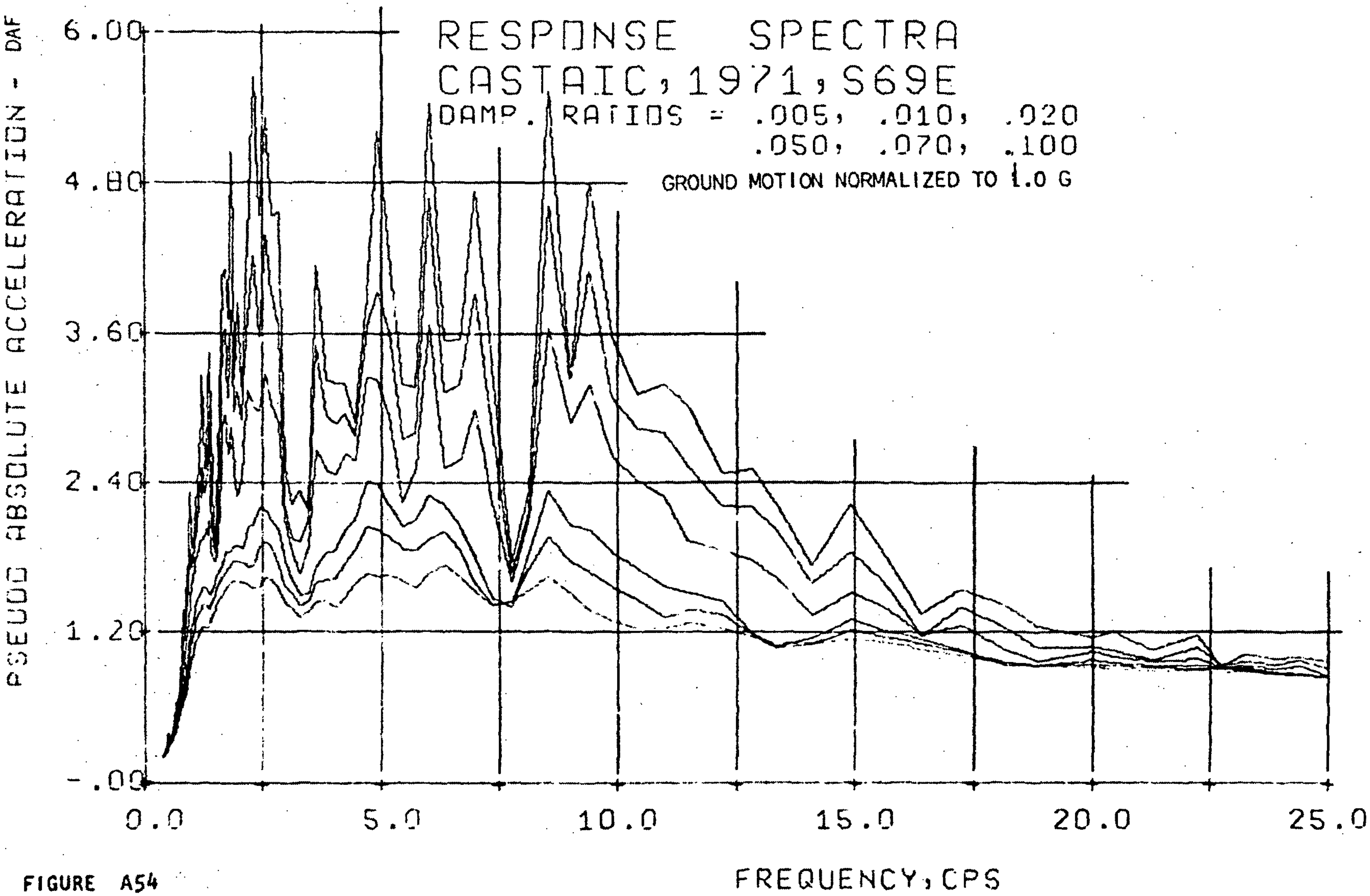
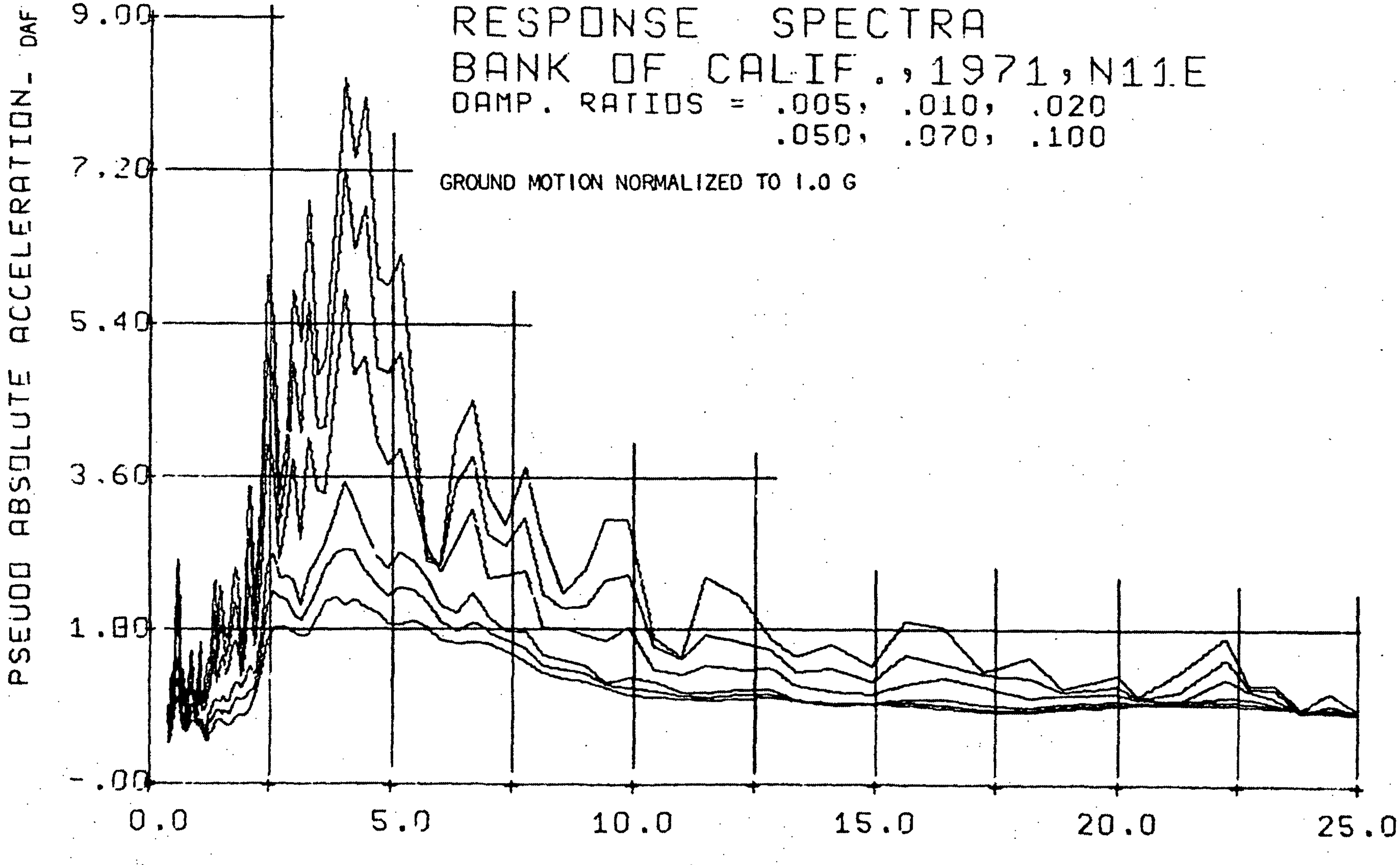

RESPONSE SPECTRA
CASTAIC,1971,N21E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION . DAF
7.50
6.00
4.50
3.00
1.50
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A53



RESPONSE SPECTRA
CASTAIC, 1971, S69E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
6.00
4.80
3.60
2.40
1.20
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A54



RESPONSE SPECTRA
BANK OF CALIF.,1971,N11E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION, DAF
9.00
7.20
5.40
3.60
1.80
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A55

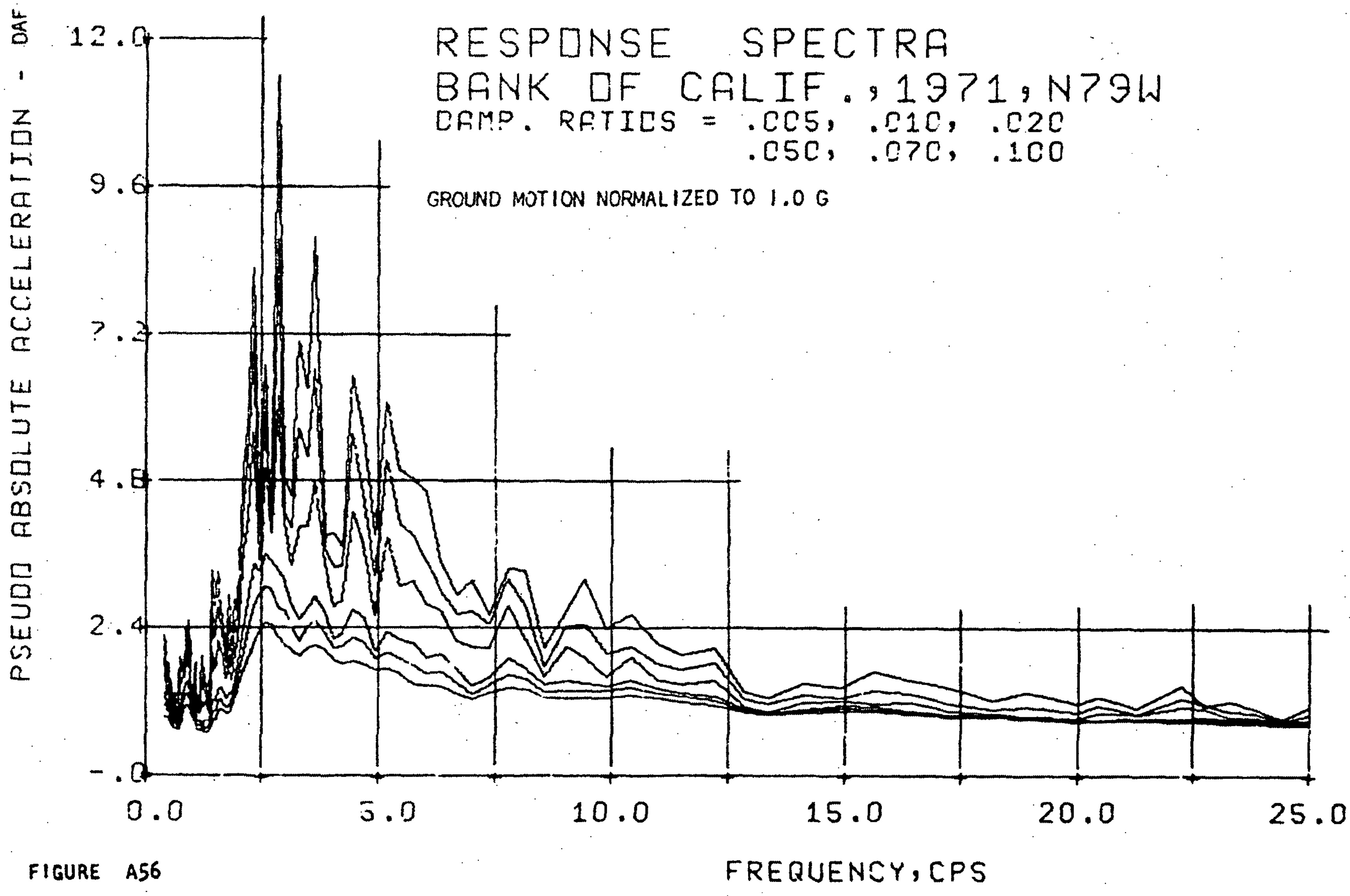

RESPONSE SPECTRA
BANK OF CALIF.,1971,N79W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
12.0
9.6
7.2
4.8
2.4
-.0
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A56

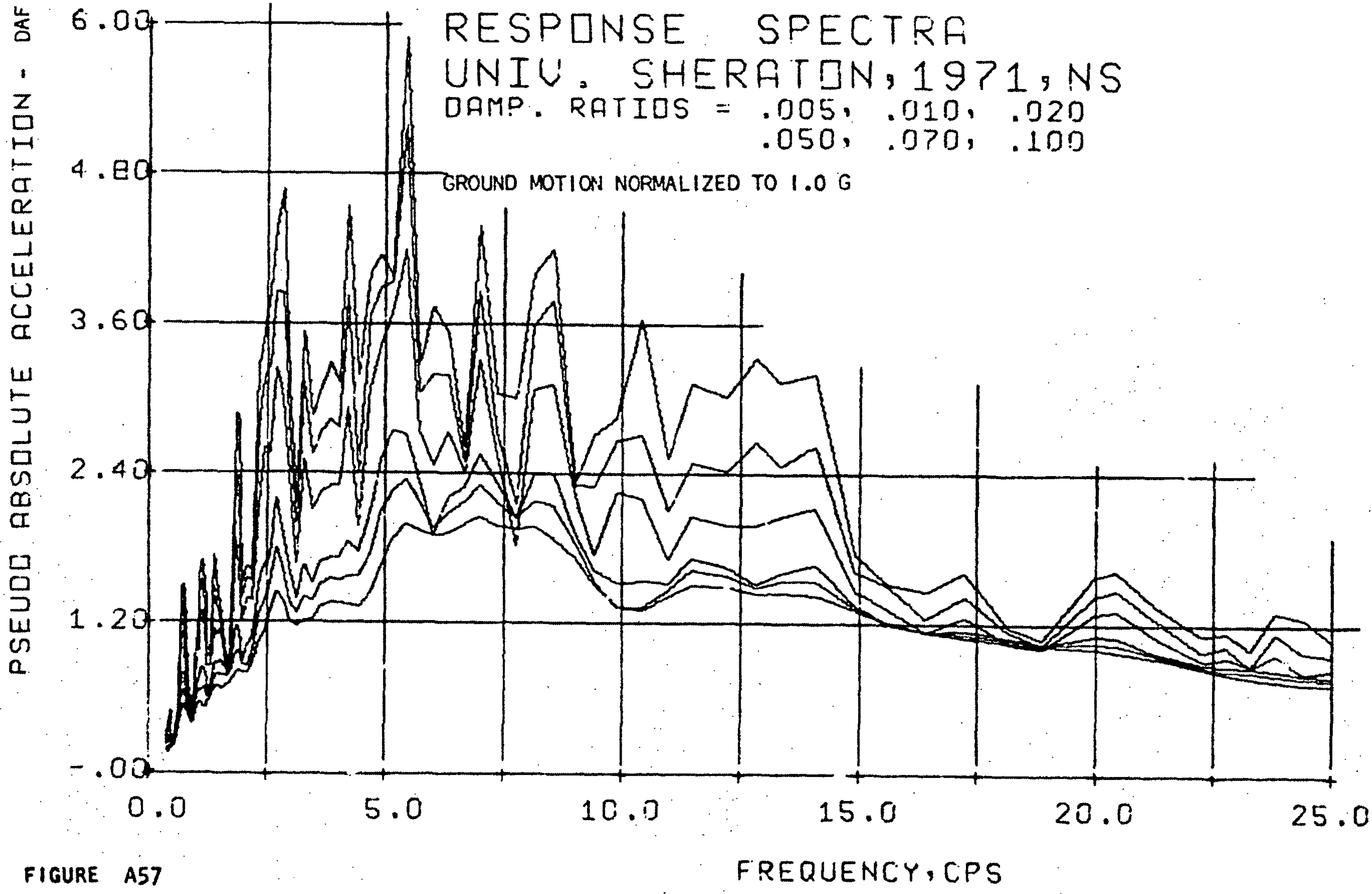

RESPONSE SPECTRA
UNIV. SHERATON, 1971, NS
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
6.00
4.80
3.60
2.40
1.20
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A57

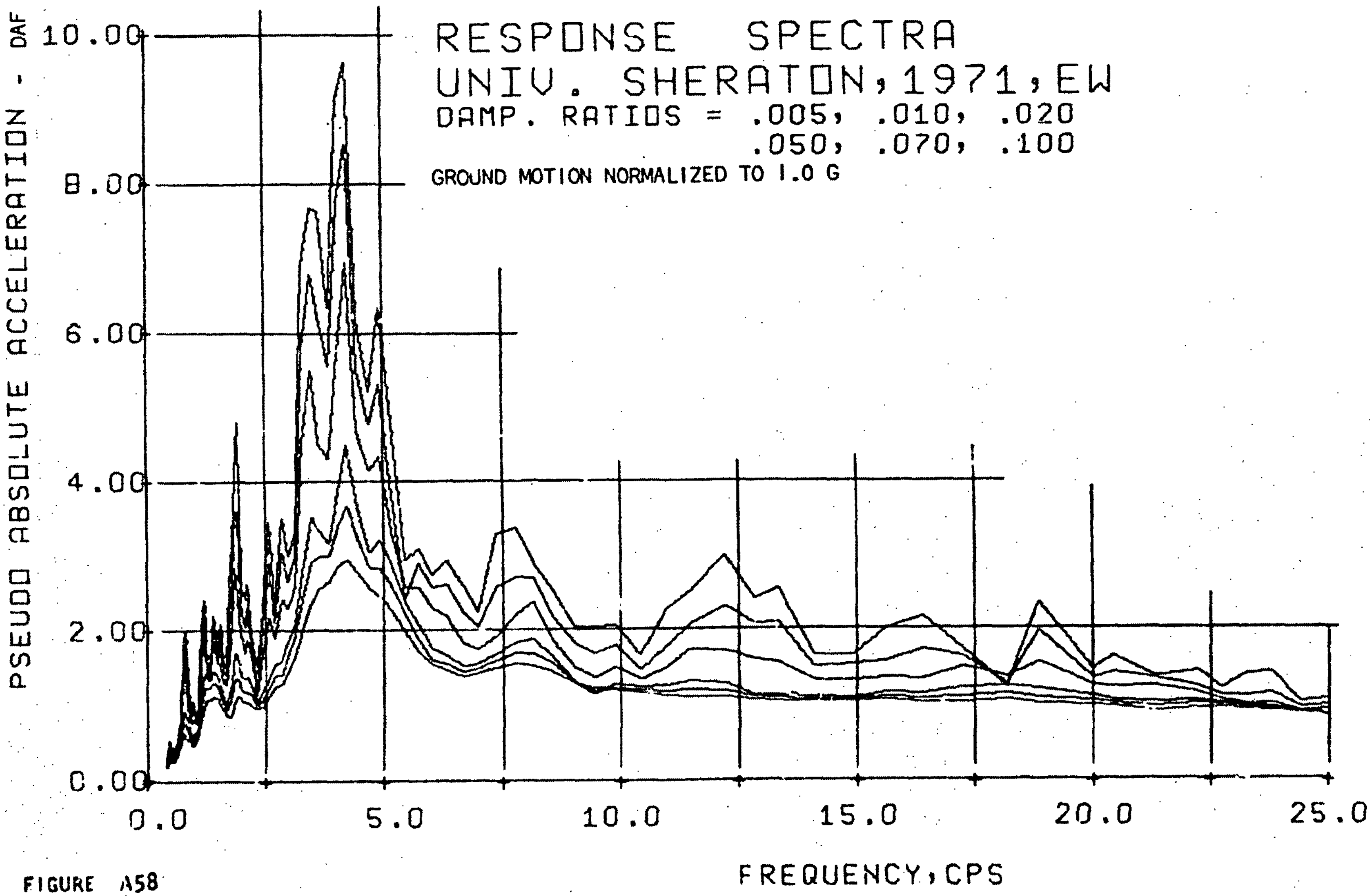
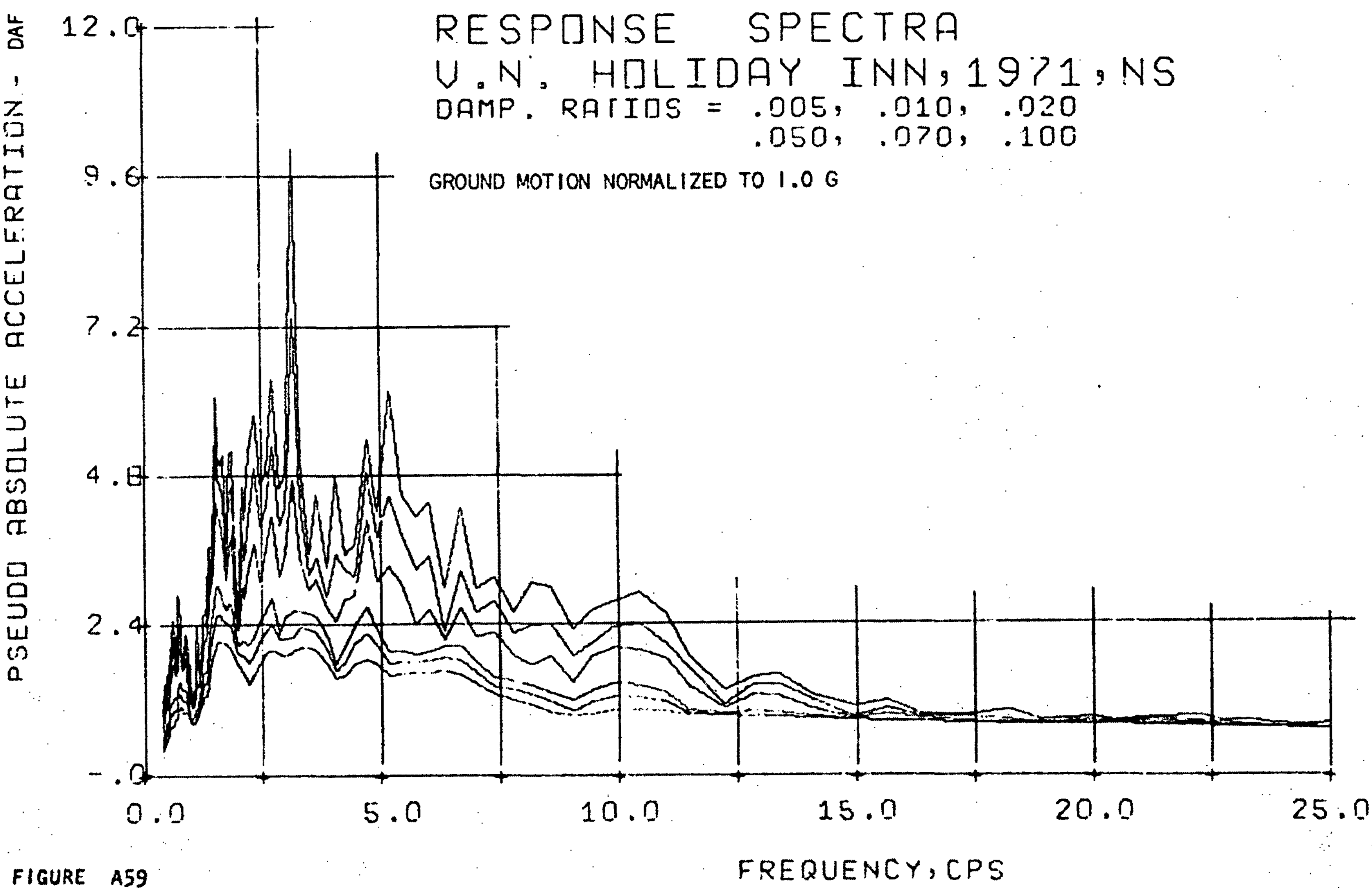
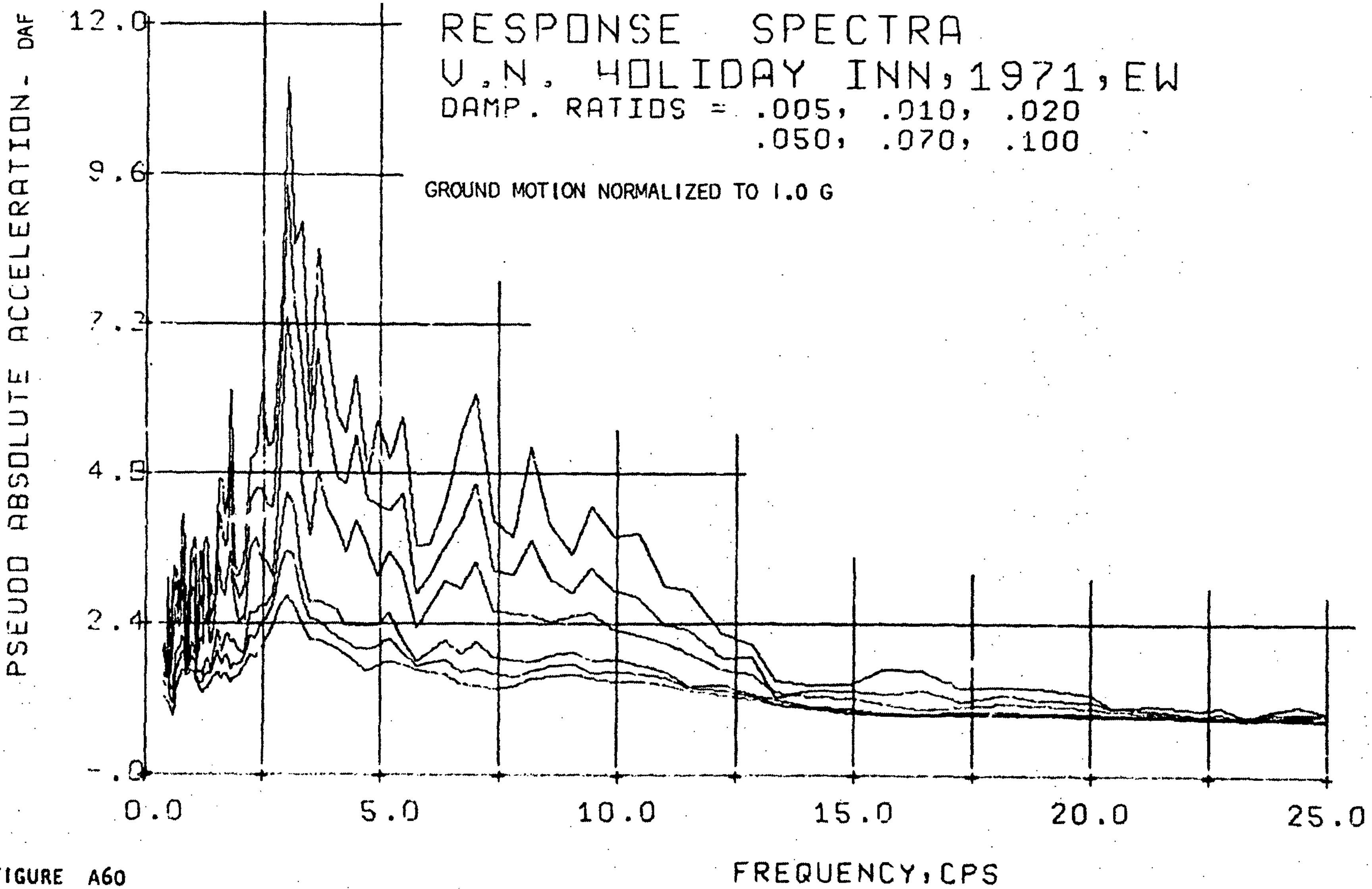

RESPONSE SPECTRA
UNIV. SHERATON,1971,EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
10.00
8.00
6.00
4.00
2.00
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A58



RESPONSE SPECTRA
V.N. HOLIDAY INN, 1971, NS
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
12.0
9.6
7.2
4.8
2.4
-.0
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A59



RESPONSE SPECTRA
V.N. HOLIDAY INN,1971,EW
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
12.0
9.6
7.2
4.8
2.4
.0
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A60

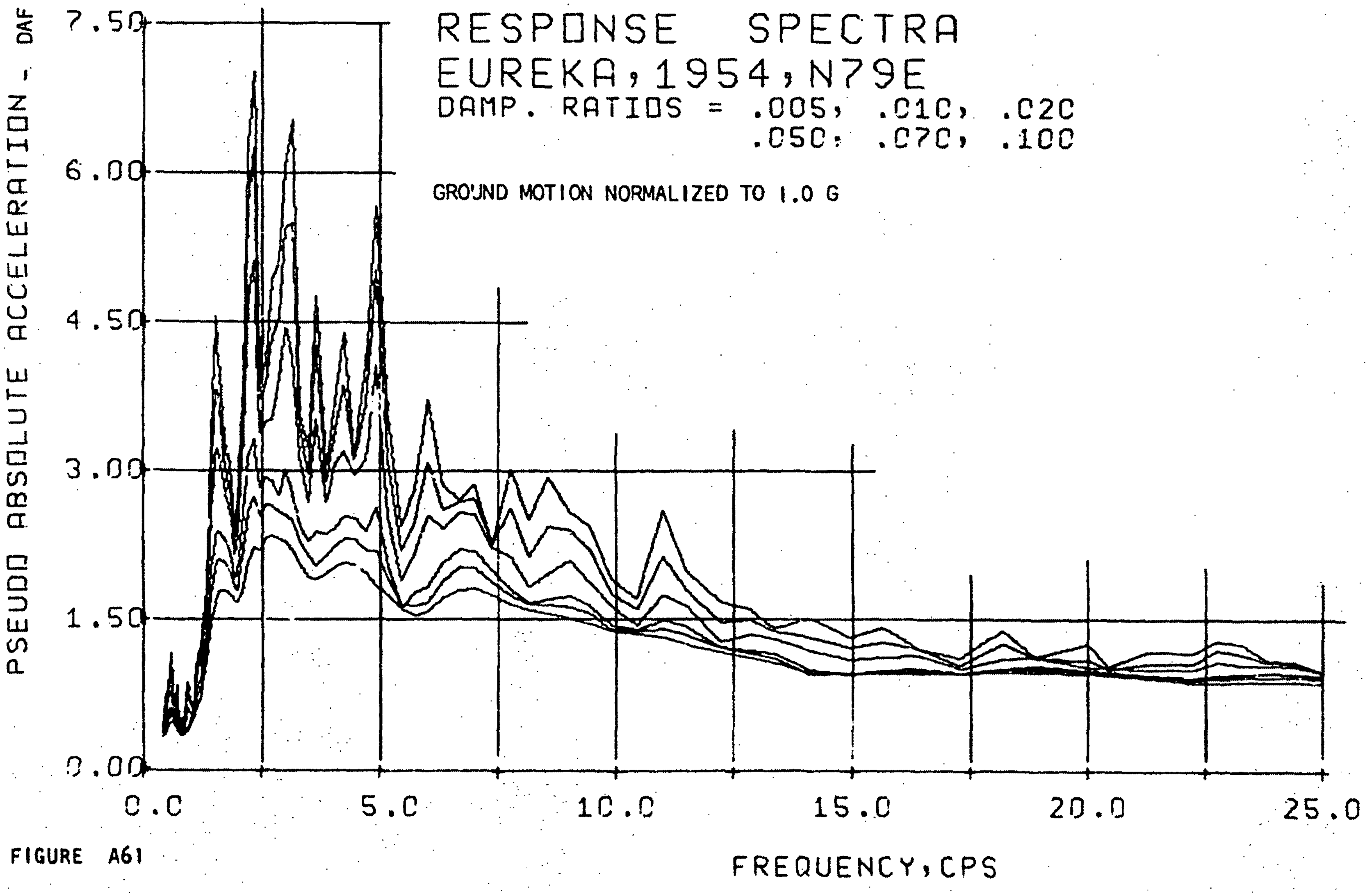

RESPONSE SPECTRA
EUREKA,1954,N79E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
7.50
6.00
4.50
3.00
1.50
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A61

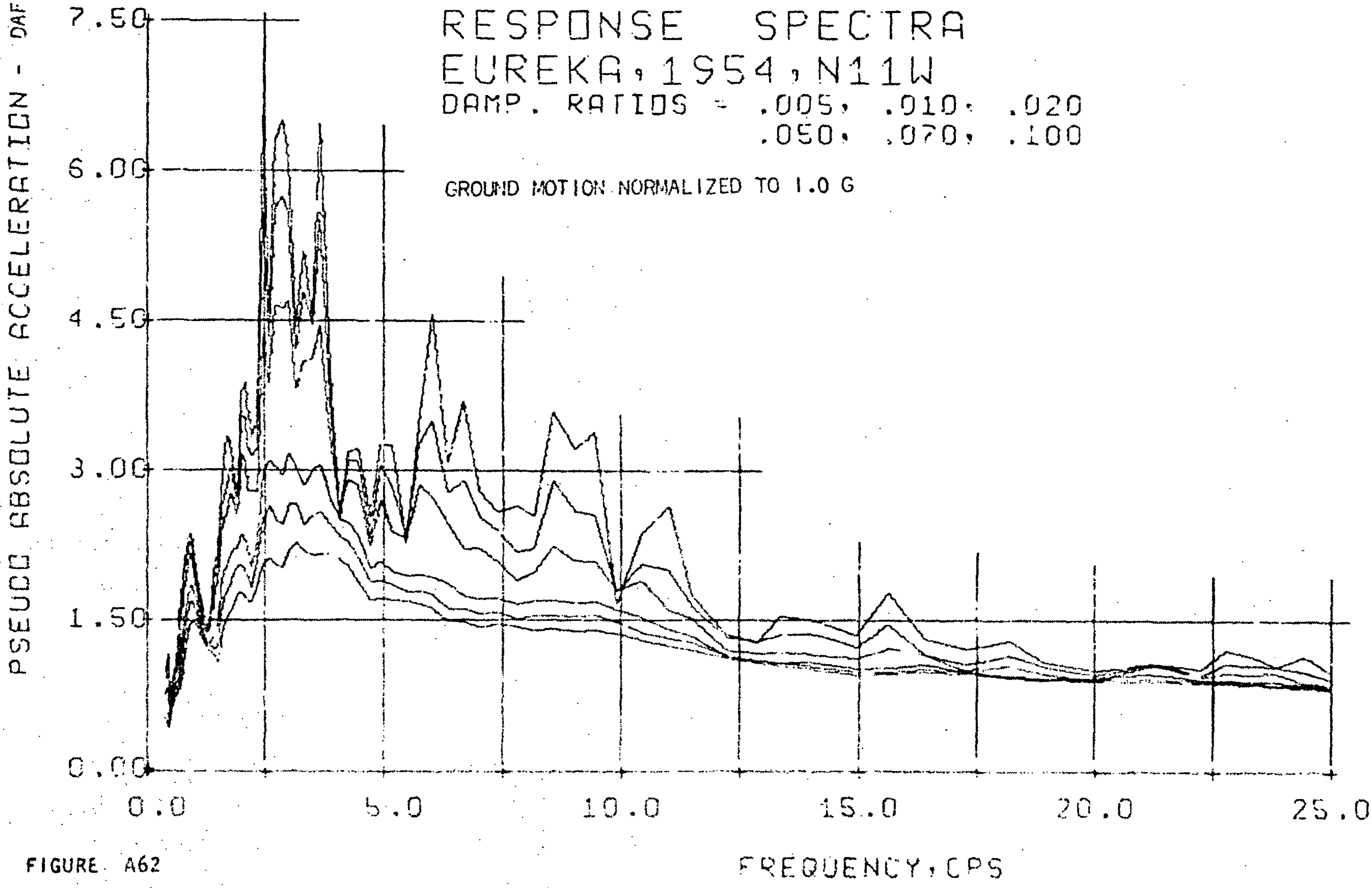

RESPONSE SPECTRA
EUREKA,1954,N11W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
7.50
6.00
4.50
3.00
1.50
0.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A62

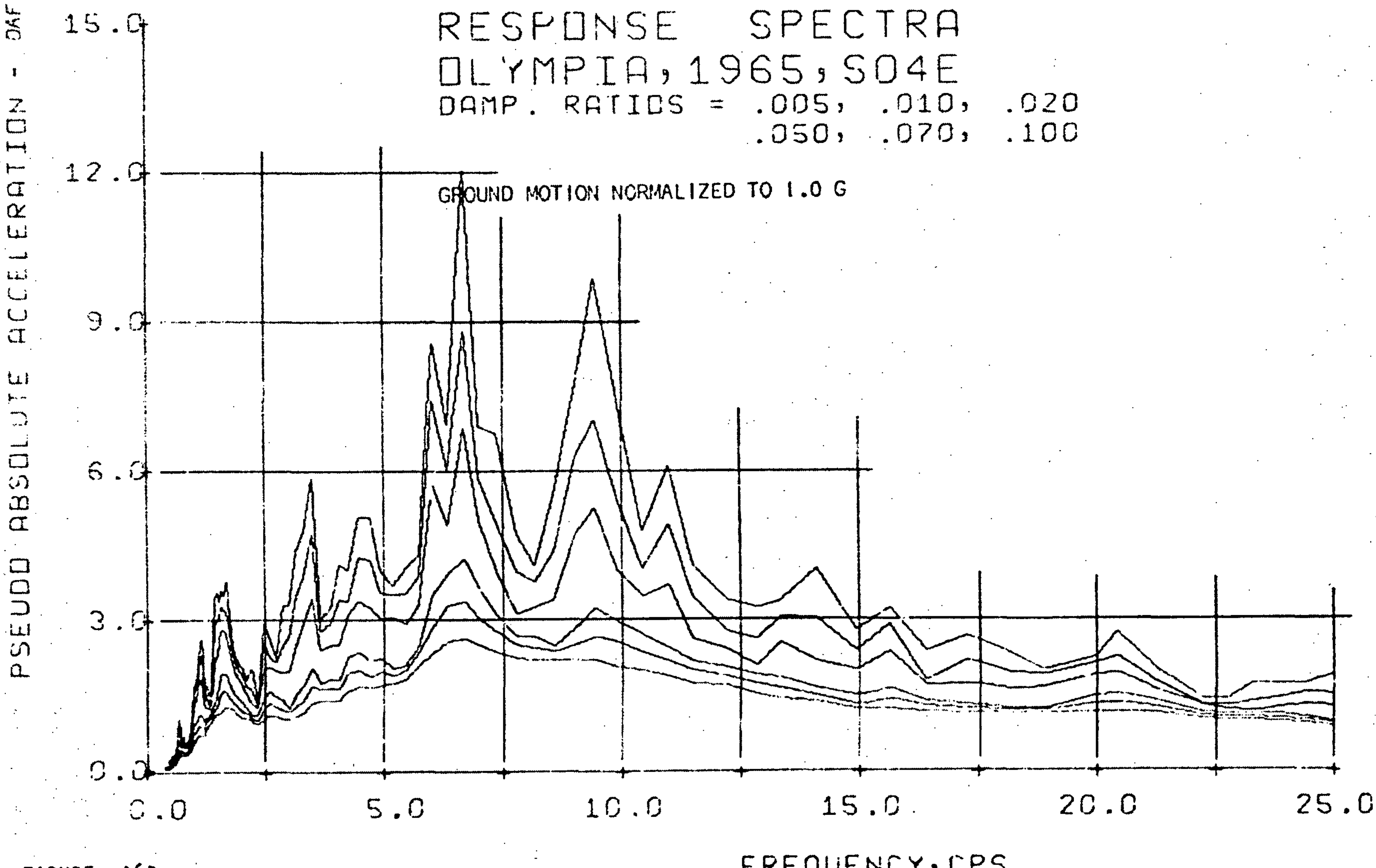

RESPONSE SPECTRA
OLYMPIA, 1965, S04E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A63

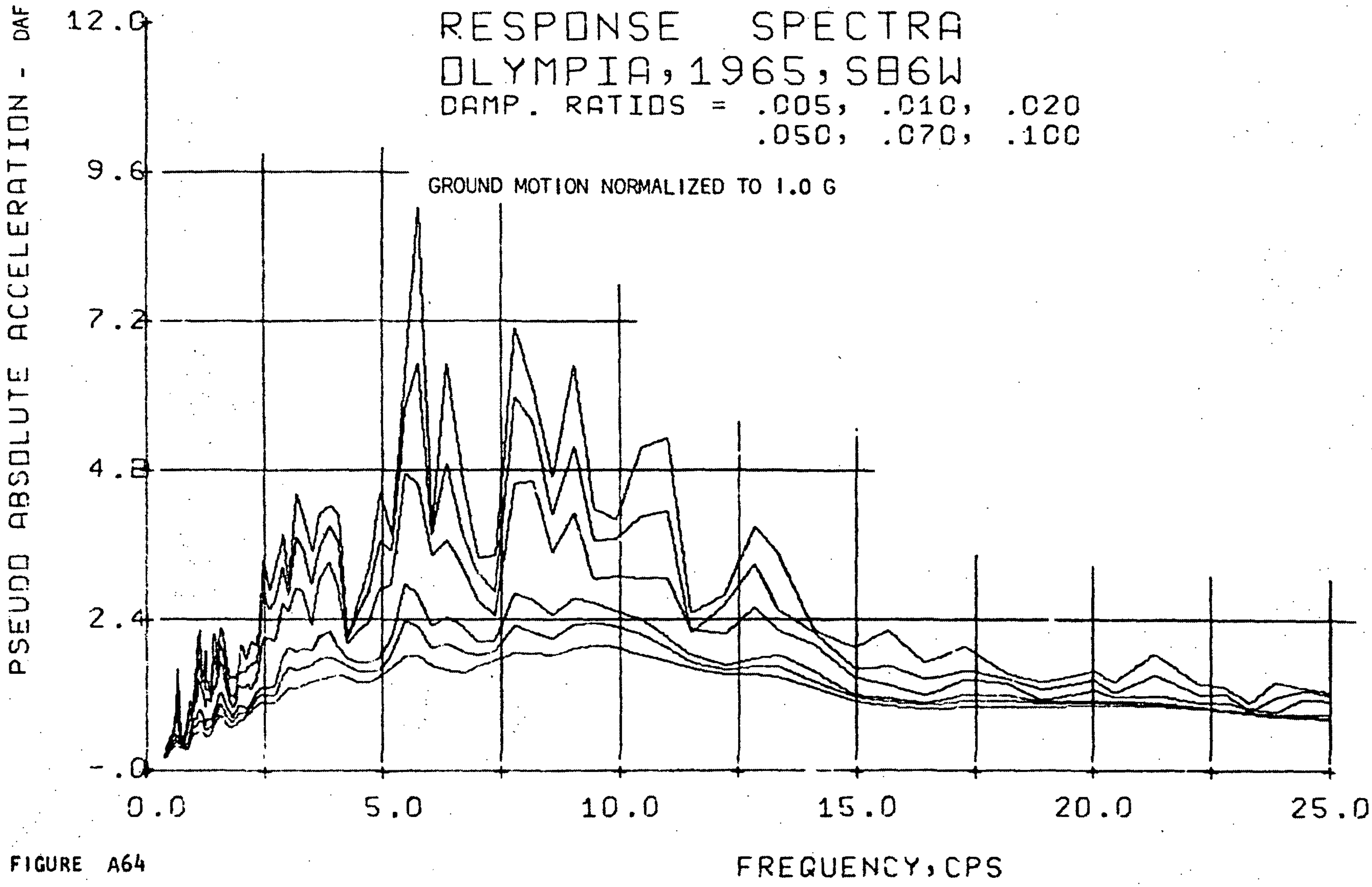

RESPONSE SPECTRA
OLYMPIA,1965,S86W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
12.0
9.6
7.2
4.8
2.4
-.0
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A64

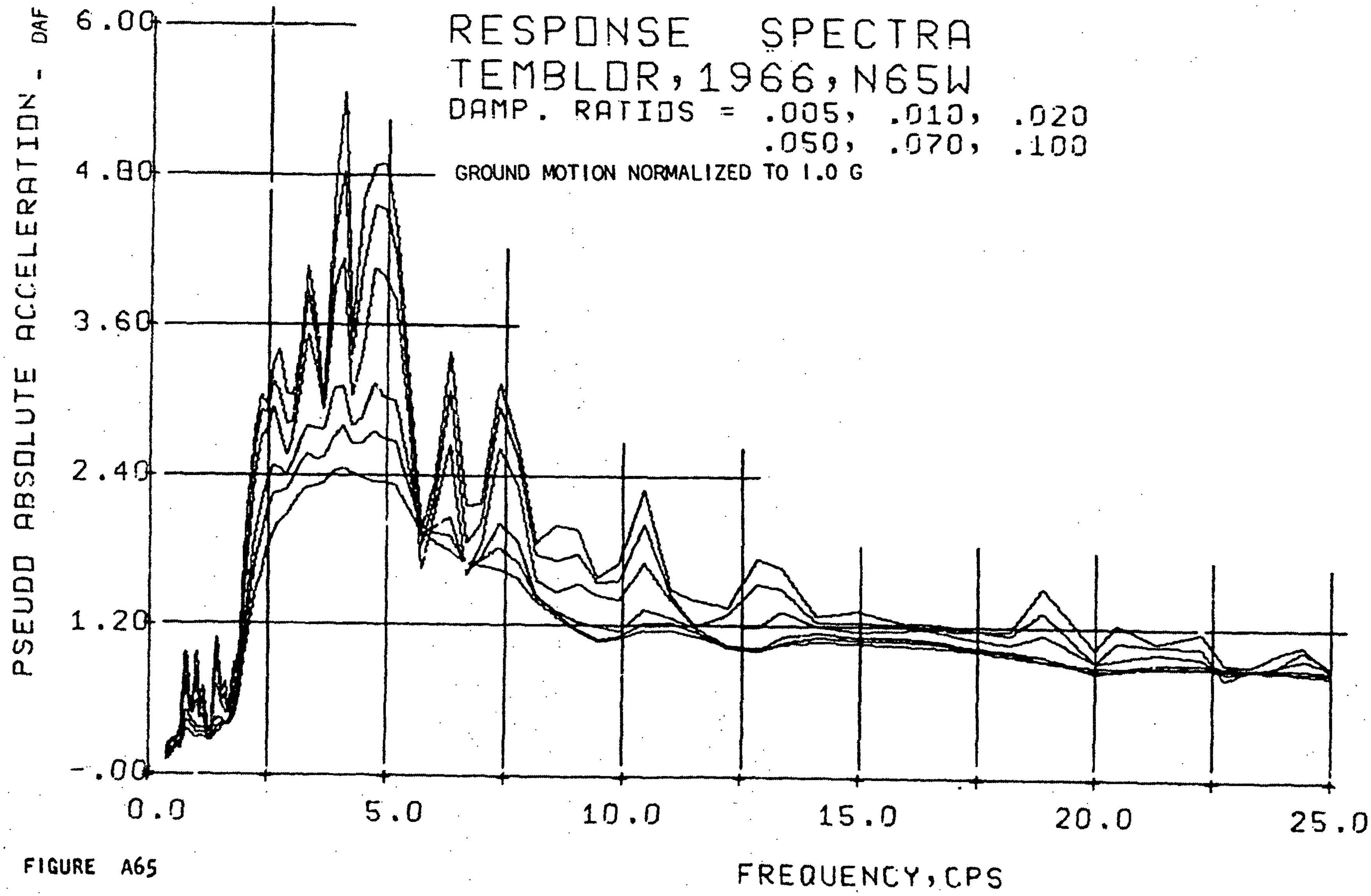

RESPONSE SPECTRA
TEMBLOR, 1966, N65W
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
6.00
4.80
3.60
2.40
1.20
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY, CPS

FIGURE A65

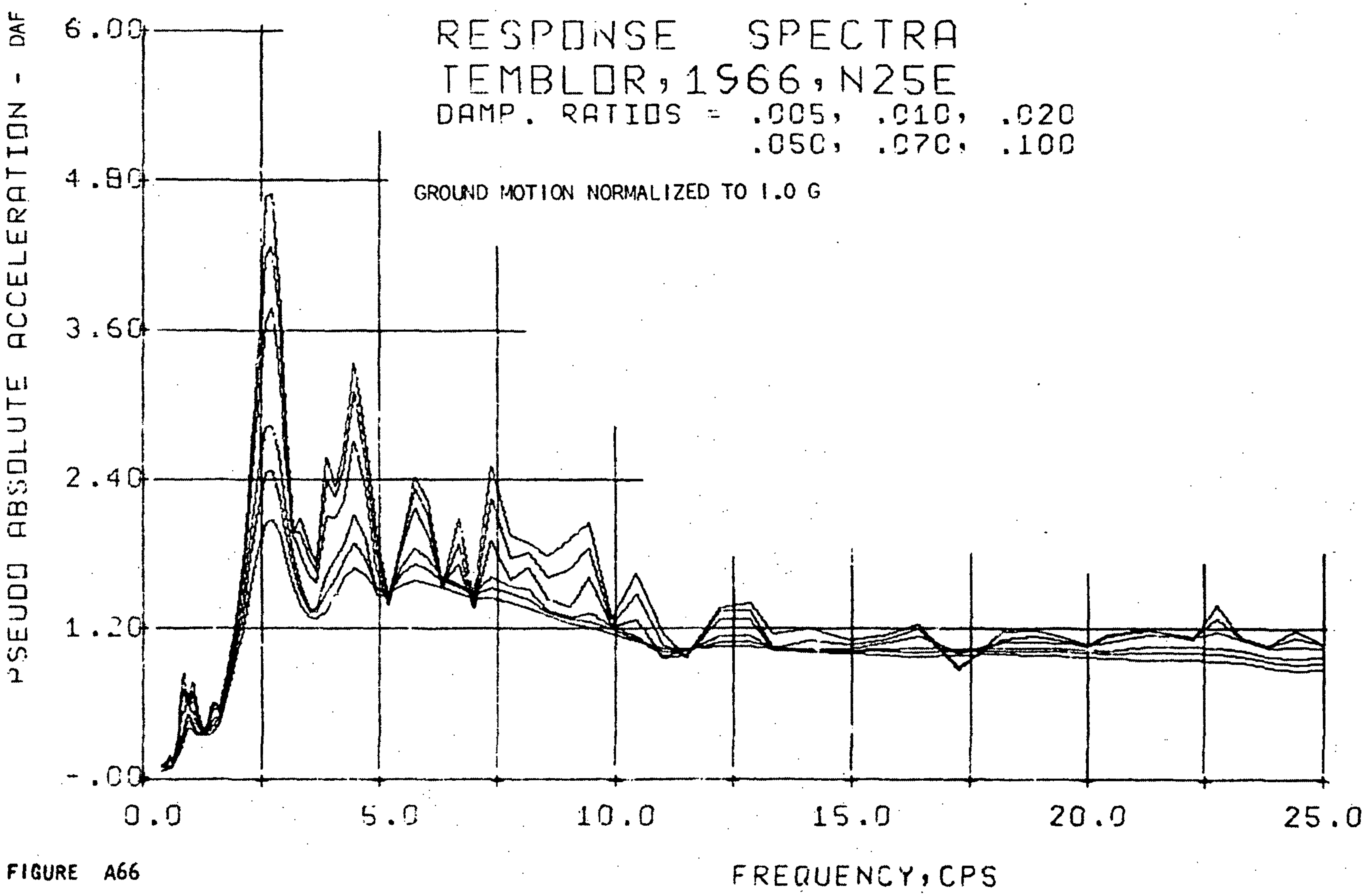

RESPONSE SPECTRA
TEMBLOR,1966,N25E
DAMP. RATIOS = .005, .010, .020
.050, .070, .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
6.00
4.80
3.60
2.40
1.20
-.00
0.0
5.0
10.0
15.0
20.0
25.0
FREQUENCY,CPS

FIGURE A66

APPENDIX B

Ensemble Spectrum Statistics

Figures B1 through B18

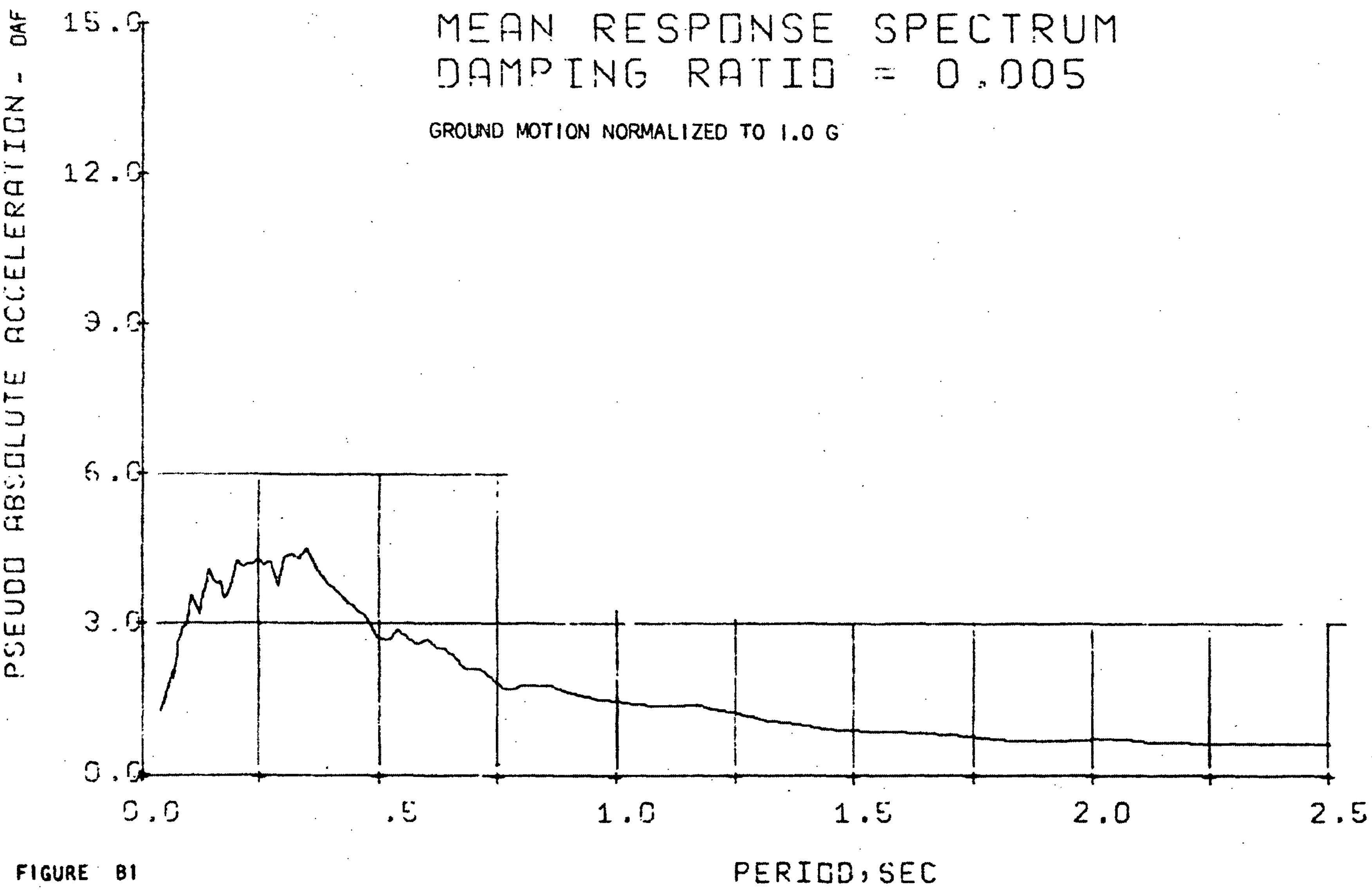
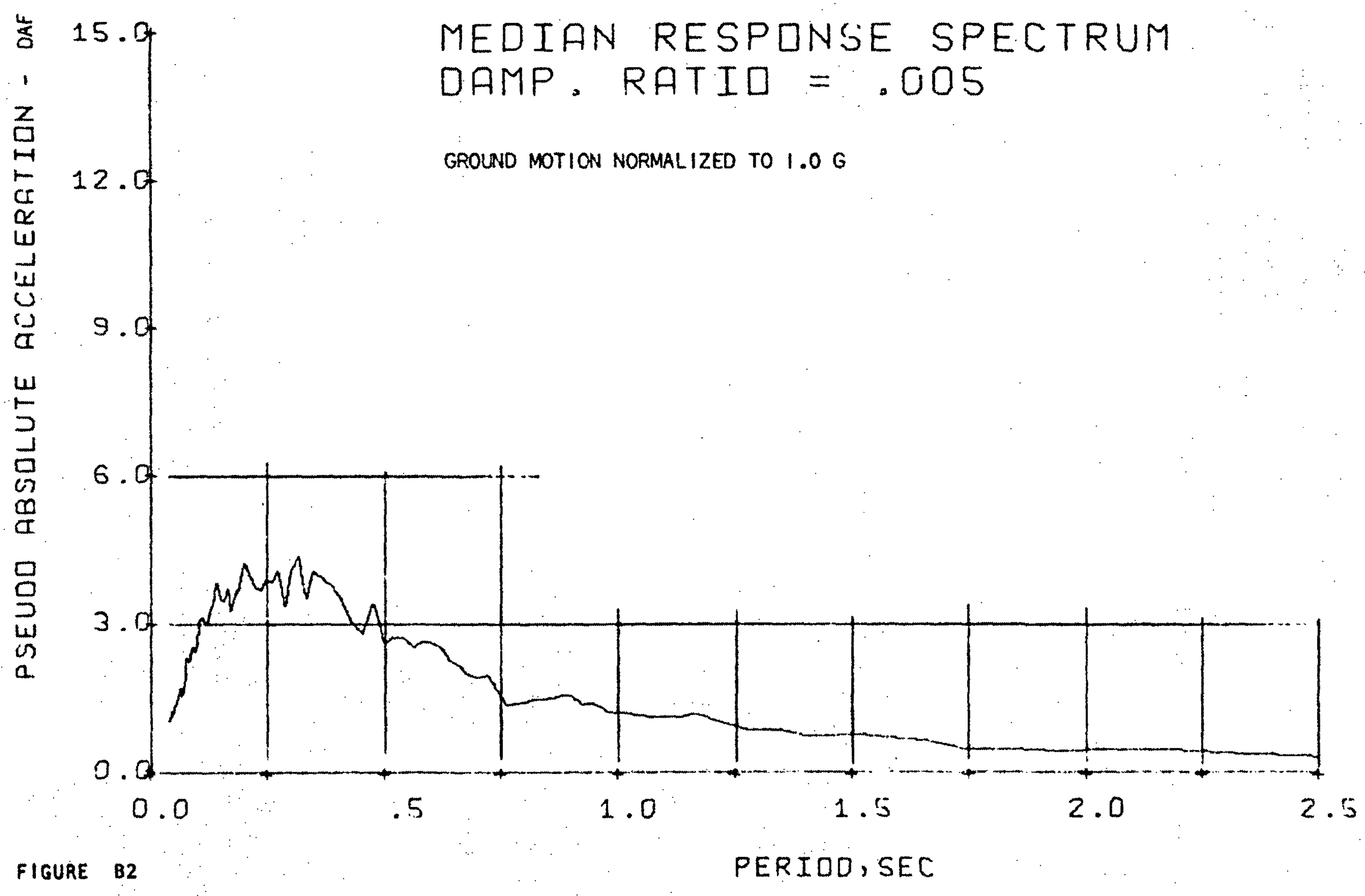

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.005
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B1



MEDIAN RESPONSE SPECTRUM
DAMP. RATIO = .005
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B2

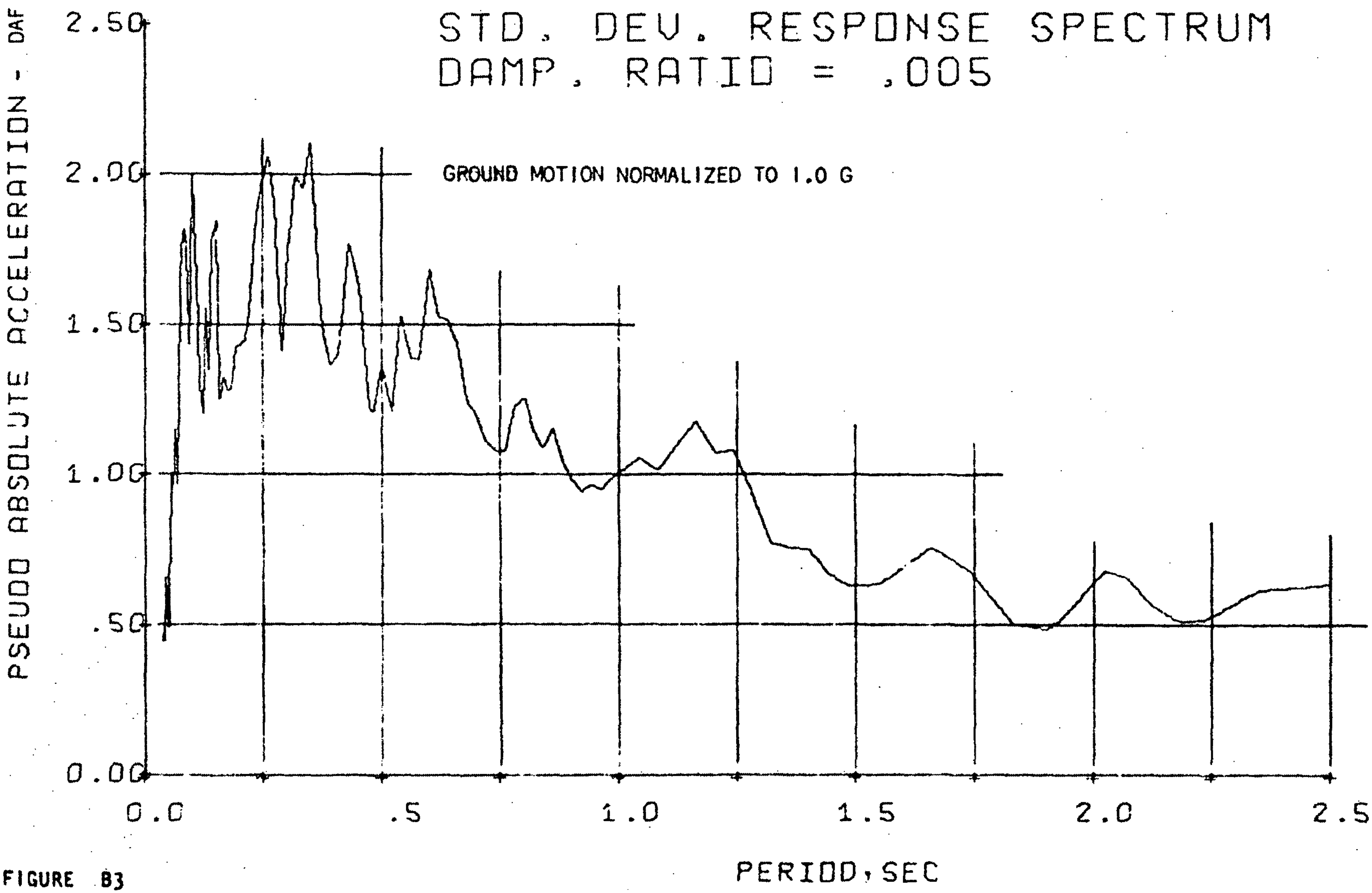

STD. DEV. RESPONSE SPECTRUM
DAMP. RATIO = .005
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B3

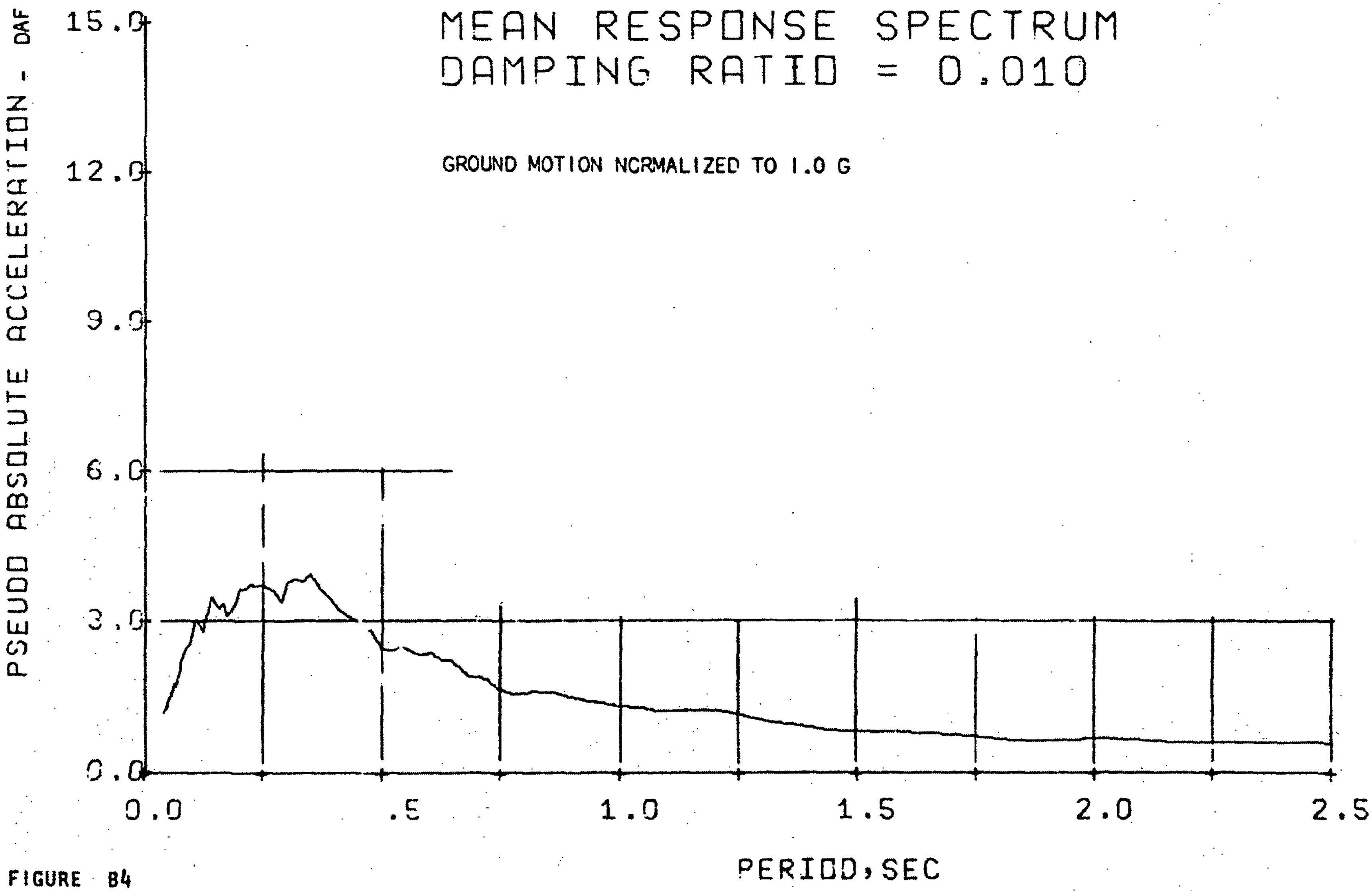

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.010
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B4

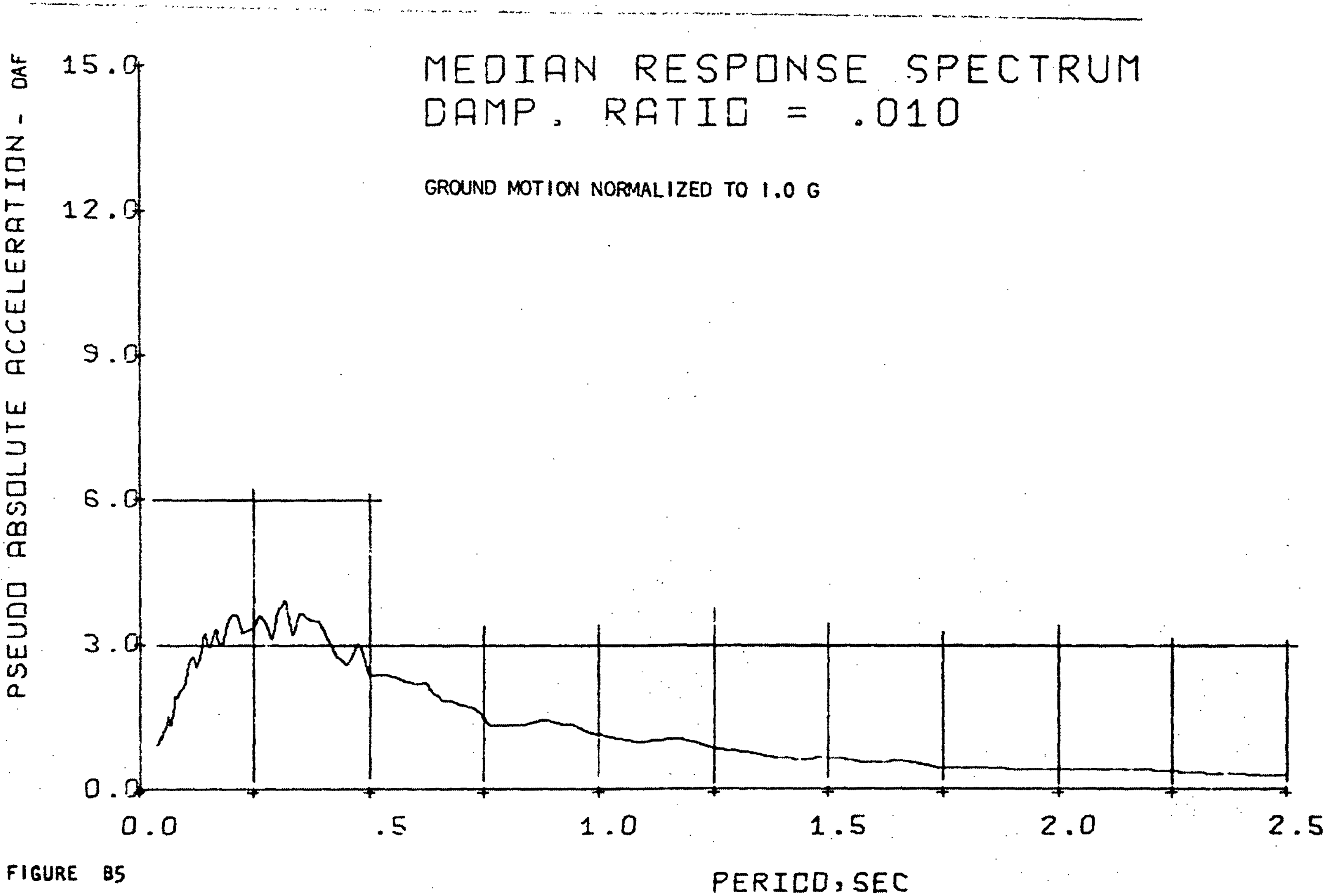

MEDIAN RESPONSE SPECTRUM
DAMP. RATIO = .010
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B5

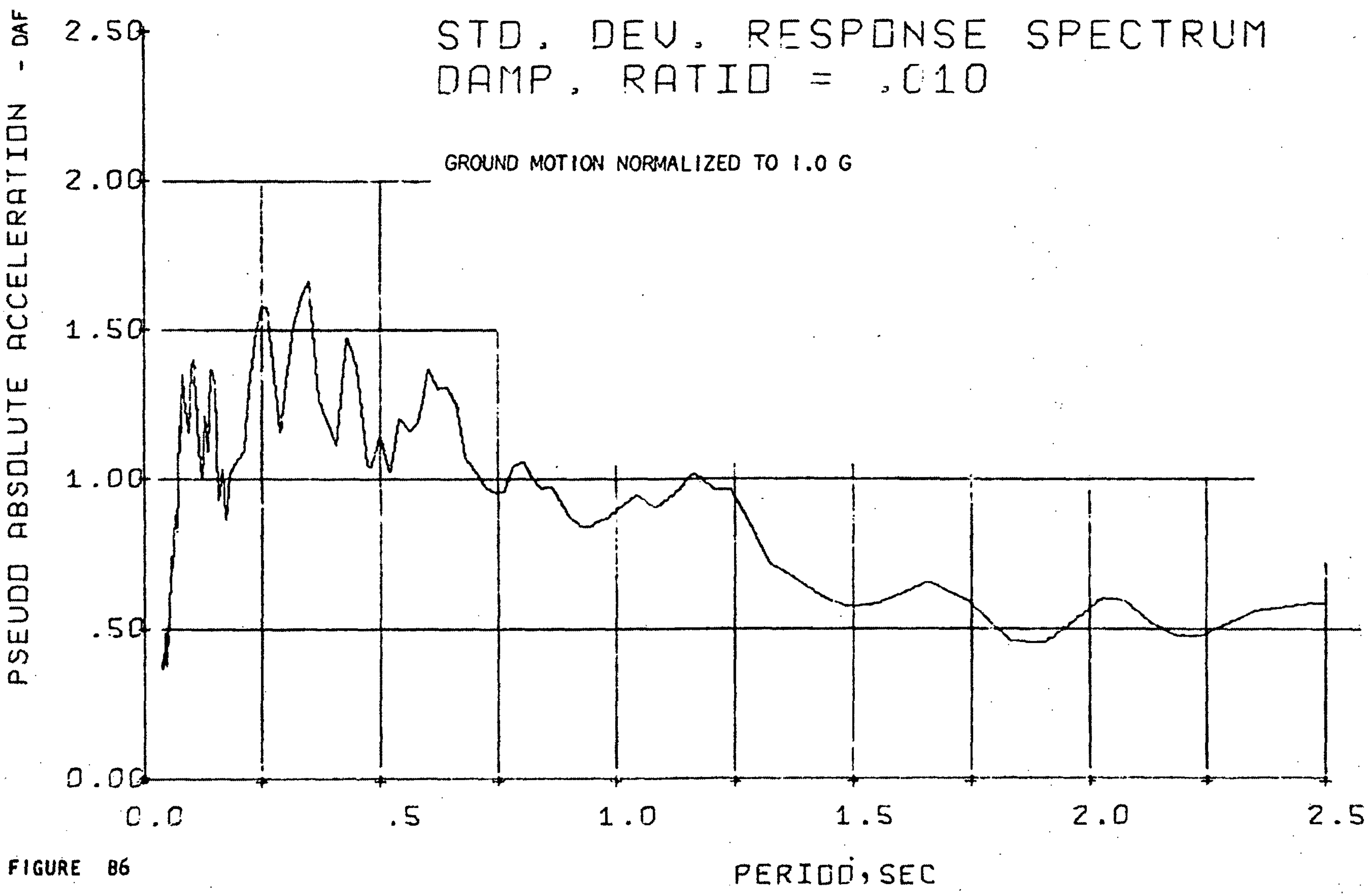

STD. DEV. RESPONSE SPECTRUM
DAMP. RATIO = .010
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B6

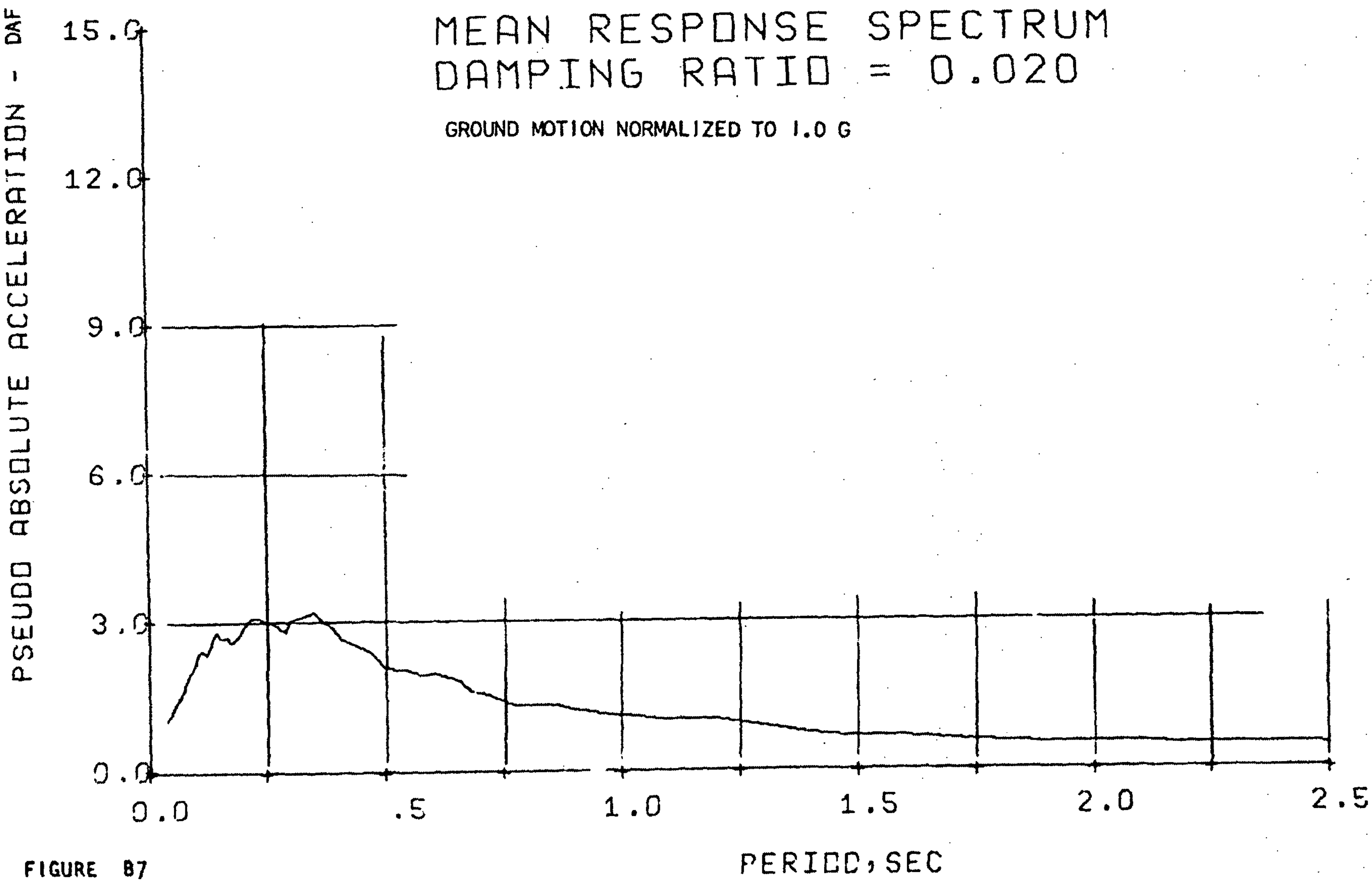

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B7

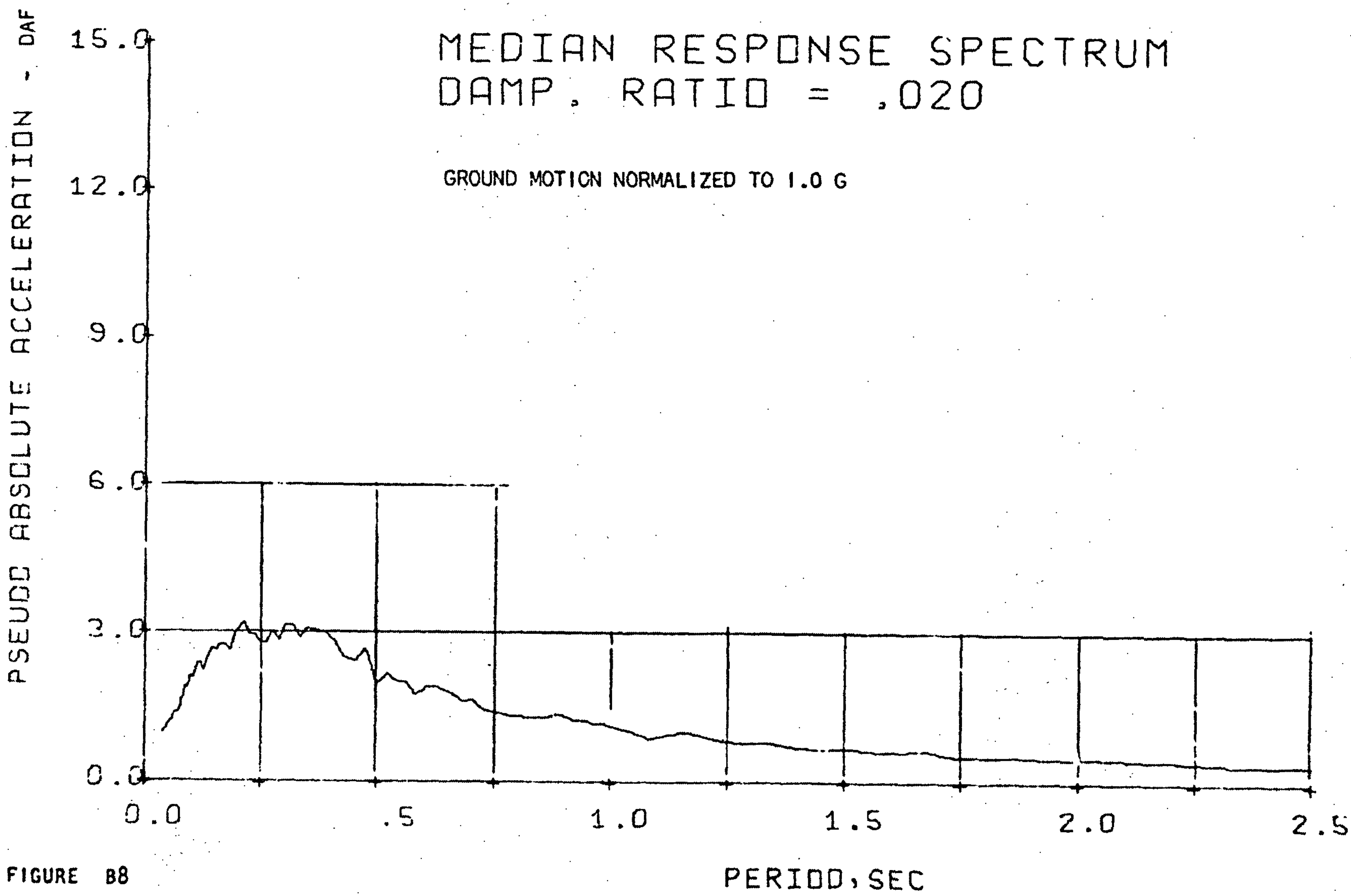
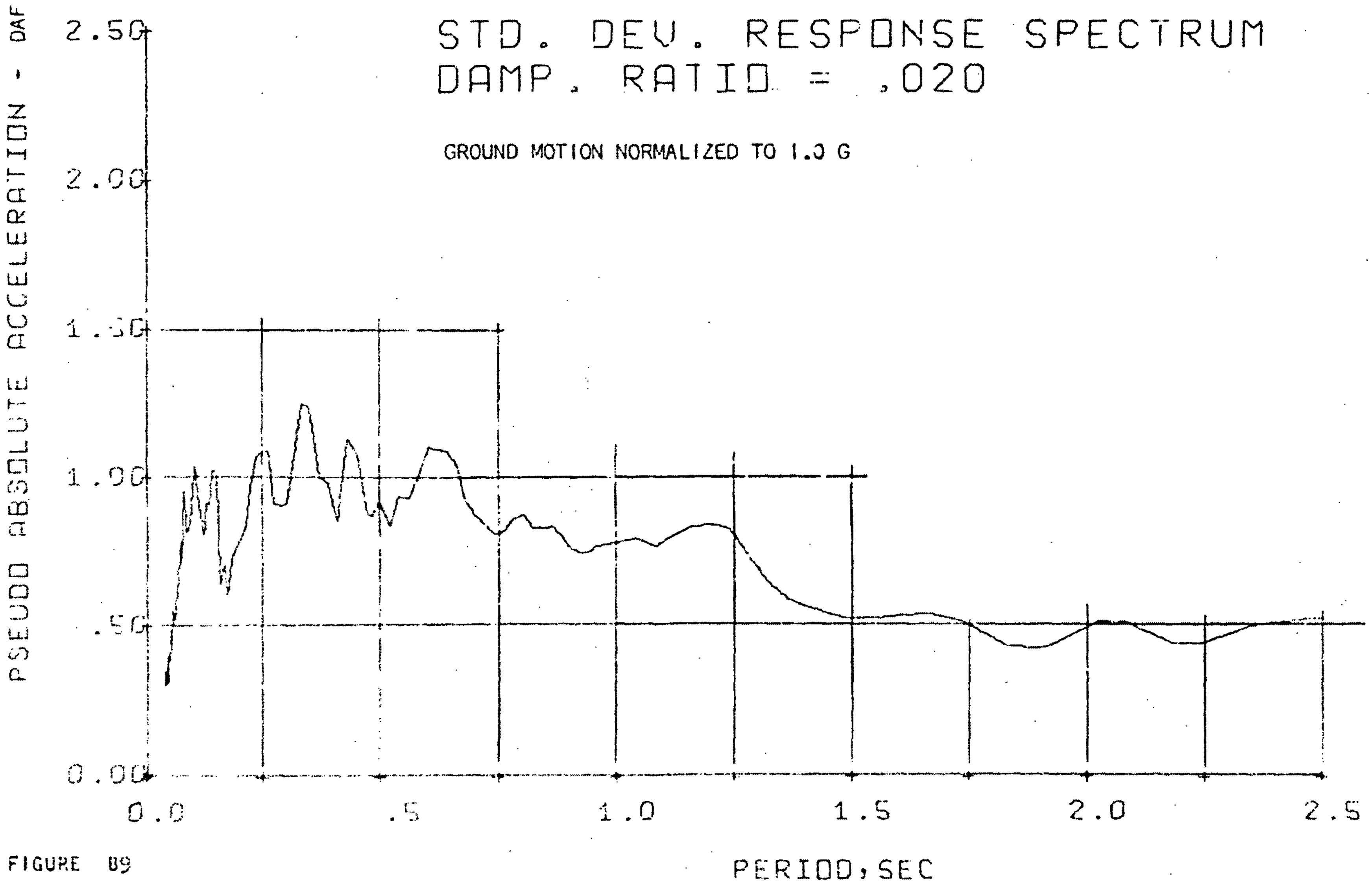

MEDIAN RESPONSE SPECTRUM
DAMP. RATIO = .020
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B8



STD. DEV. RESPONSE SPECTRUM
DAMP. RATIO = .020
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B9

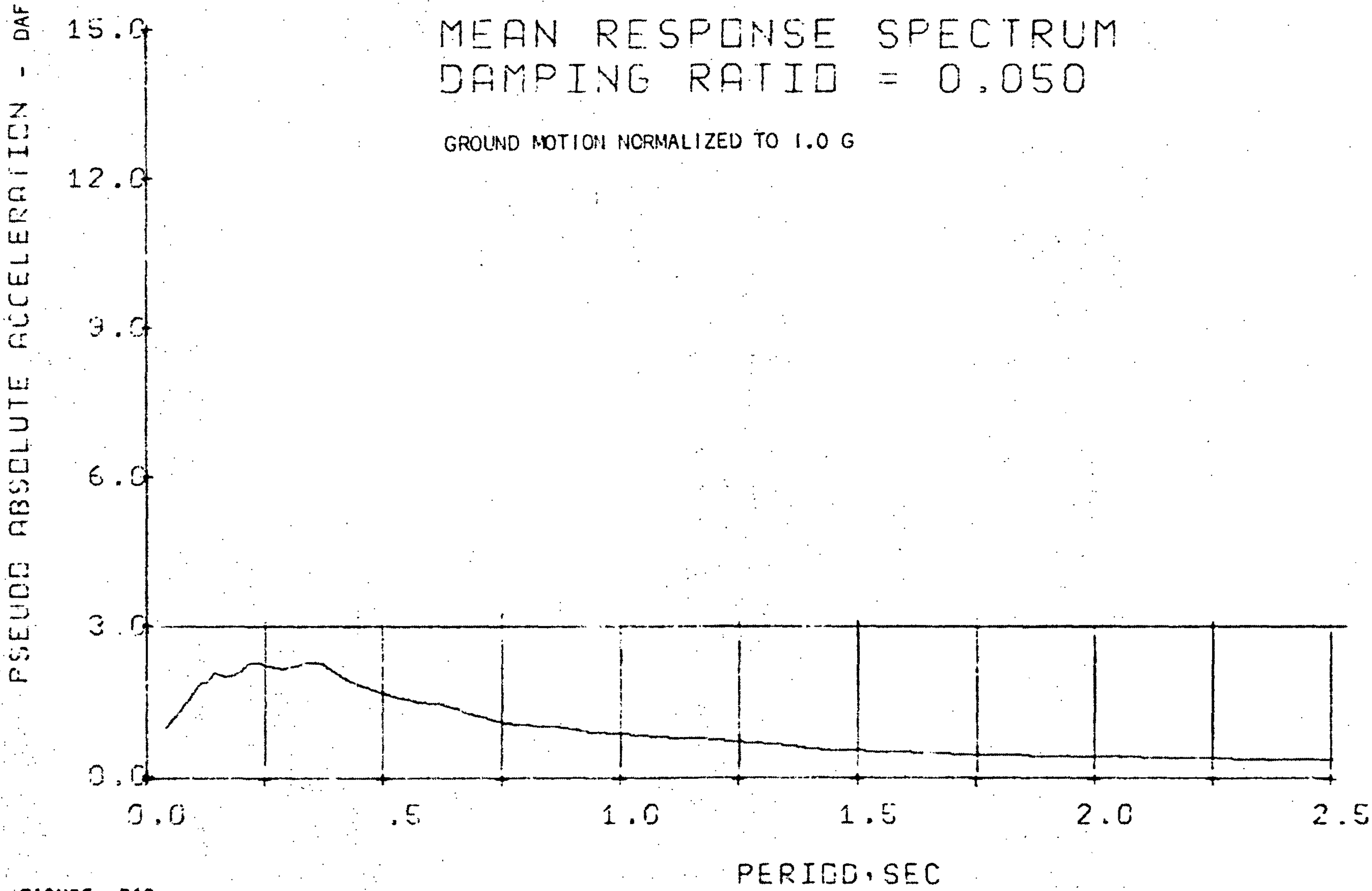

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.050
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B10

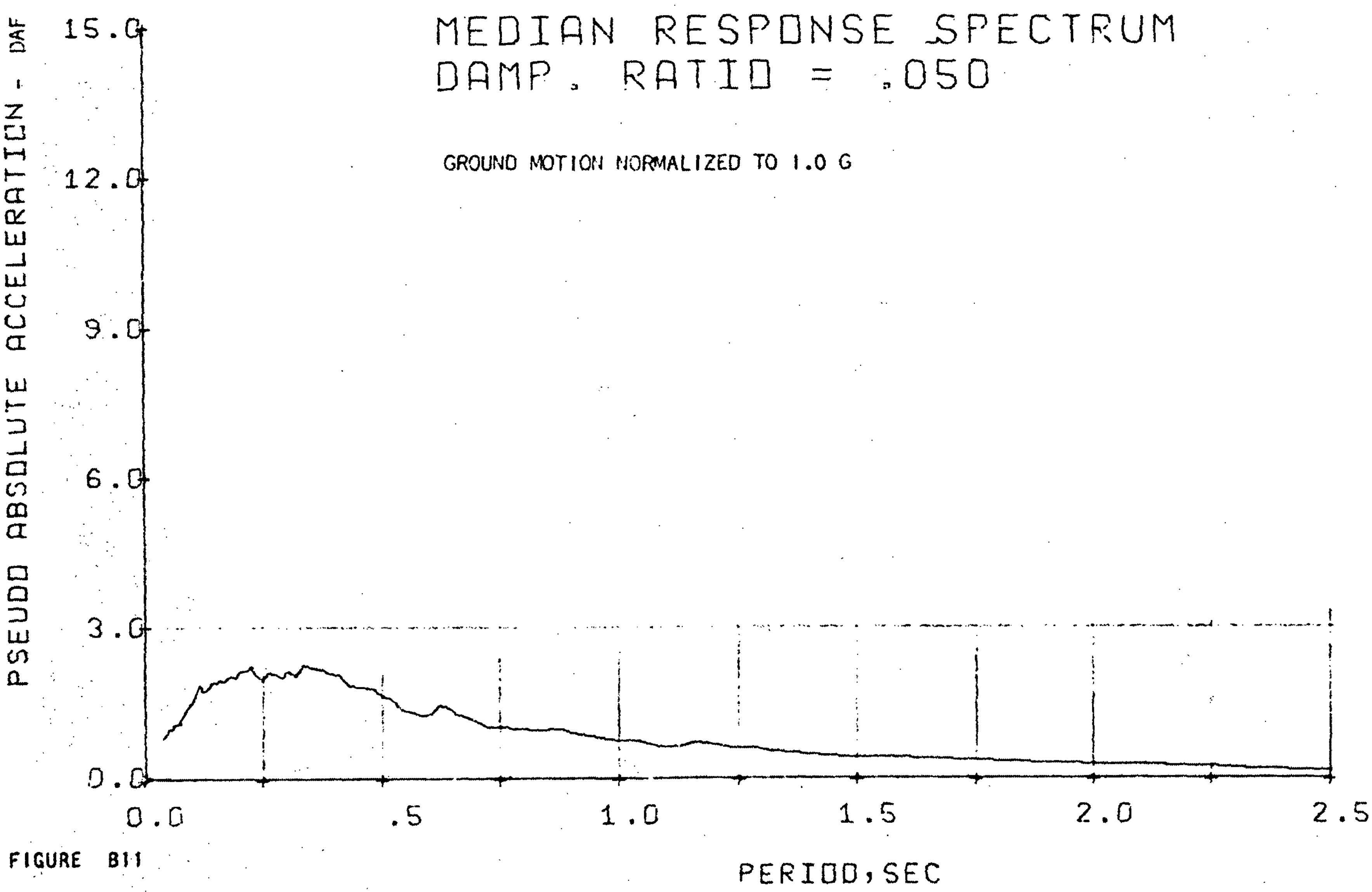
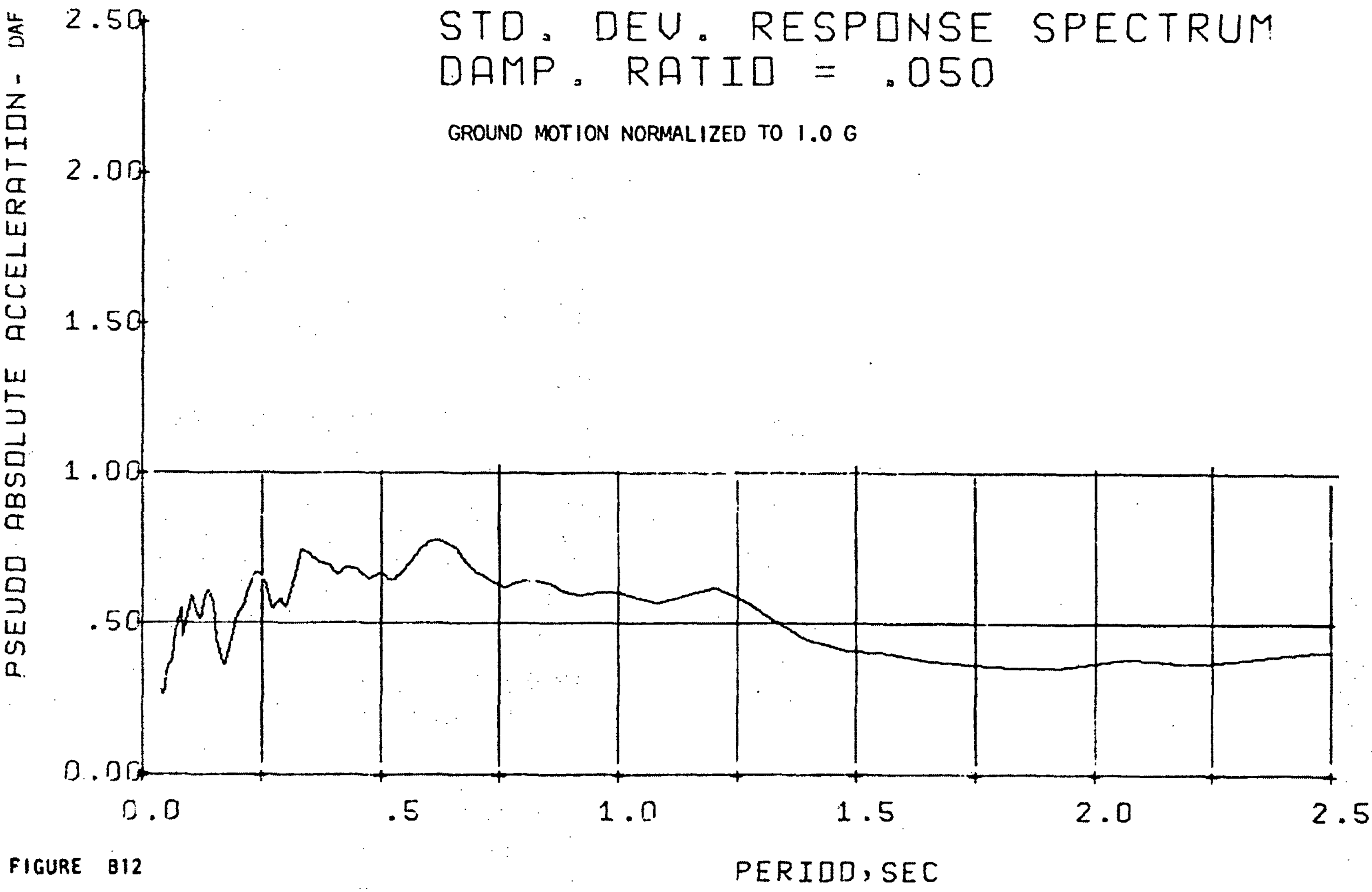

MEDIAN RESPONSE SPECTRUM
DAMP. RATIO = .050
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B11



STD. DEV. RESPONSE SPECTRUM
DAMP. RATIO = .050
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION- DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B12

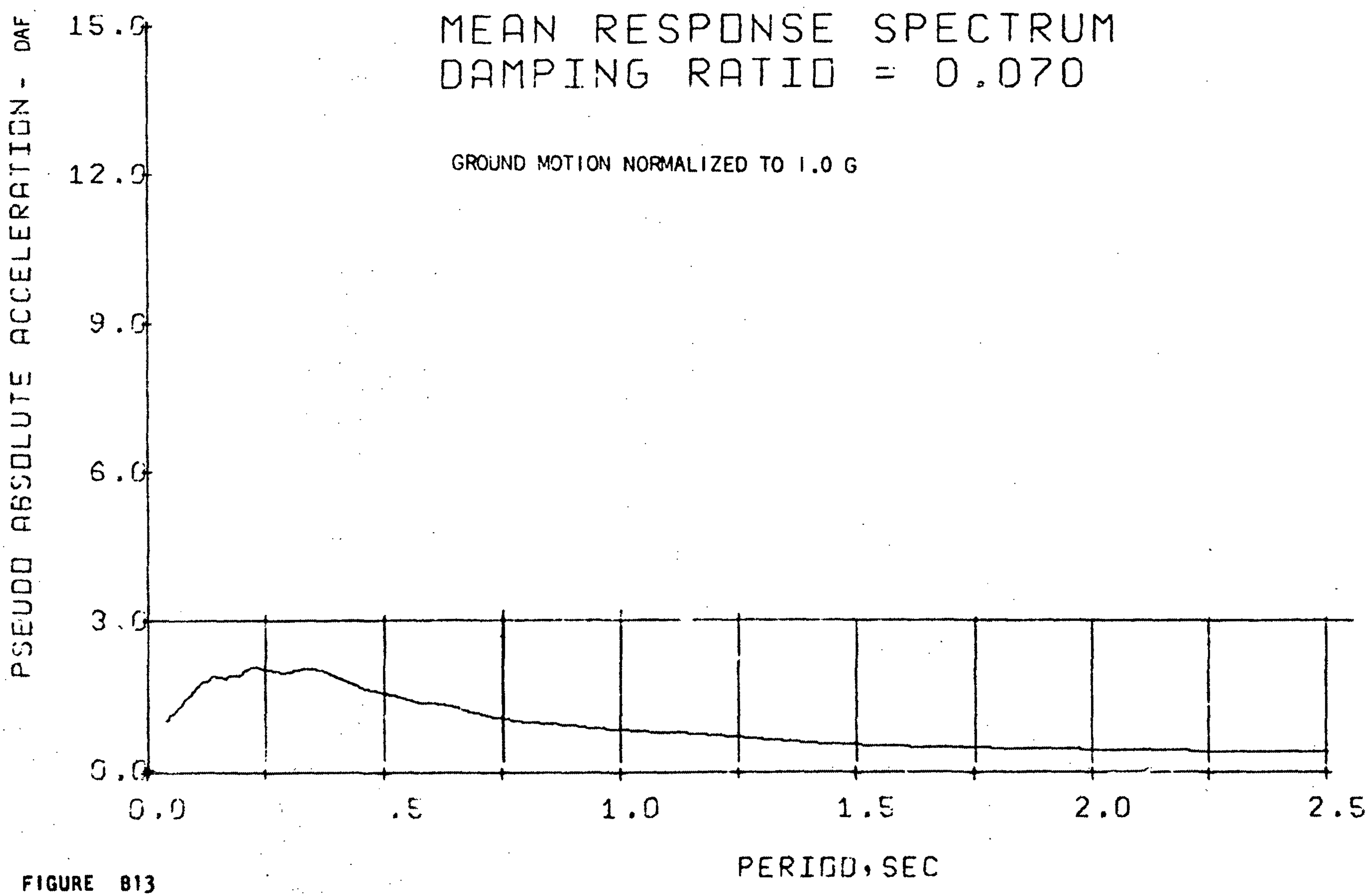

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.070
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B13

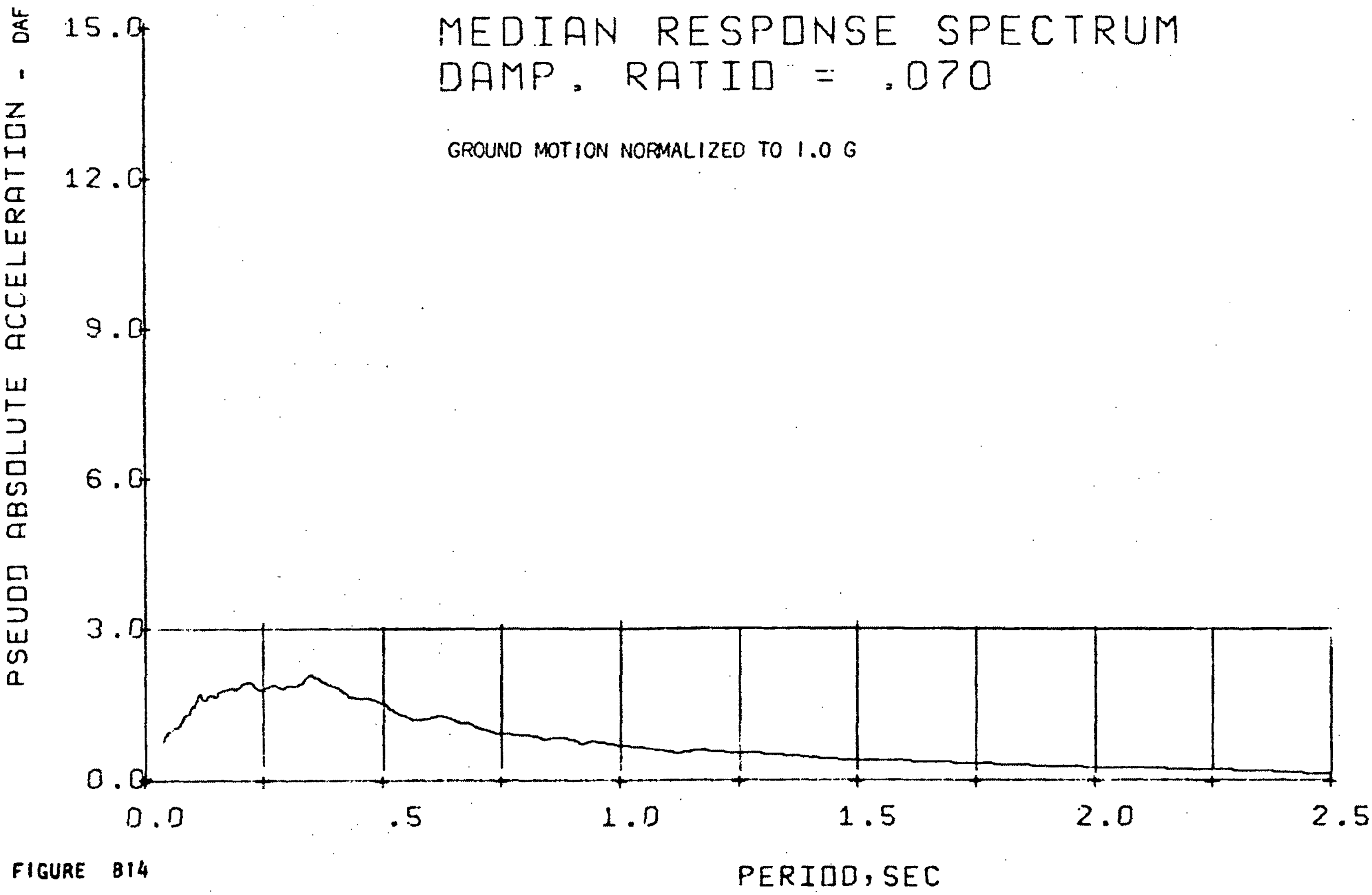

MEDIAN RESPONSE SPECTRUM
DAMP. RATIO = .070
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B14

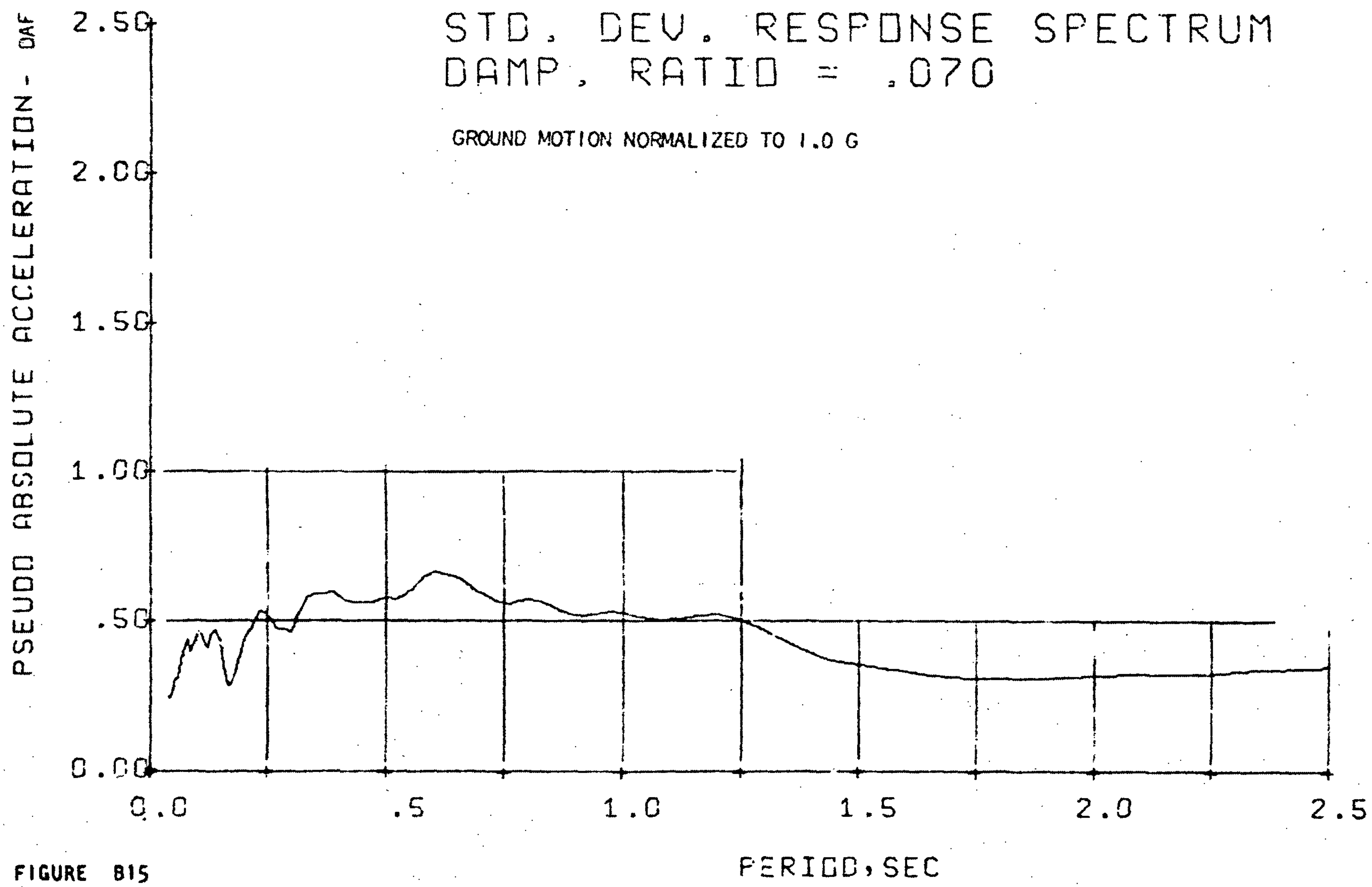

STD. DEV. RESPONSE SPECTRUM
DAMP. RATIO = .070
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B15

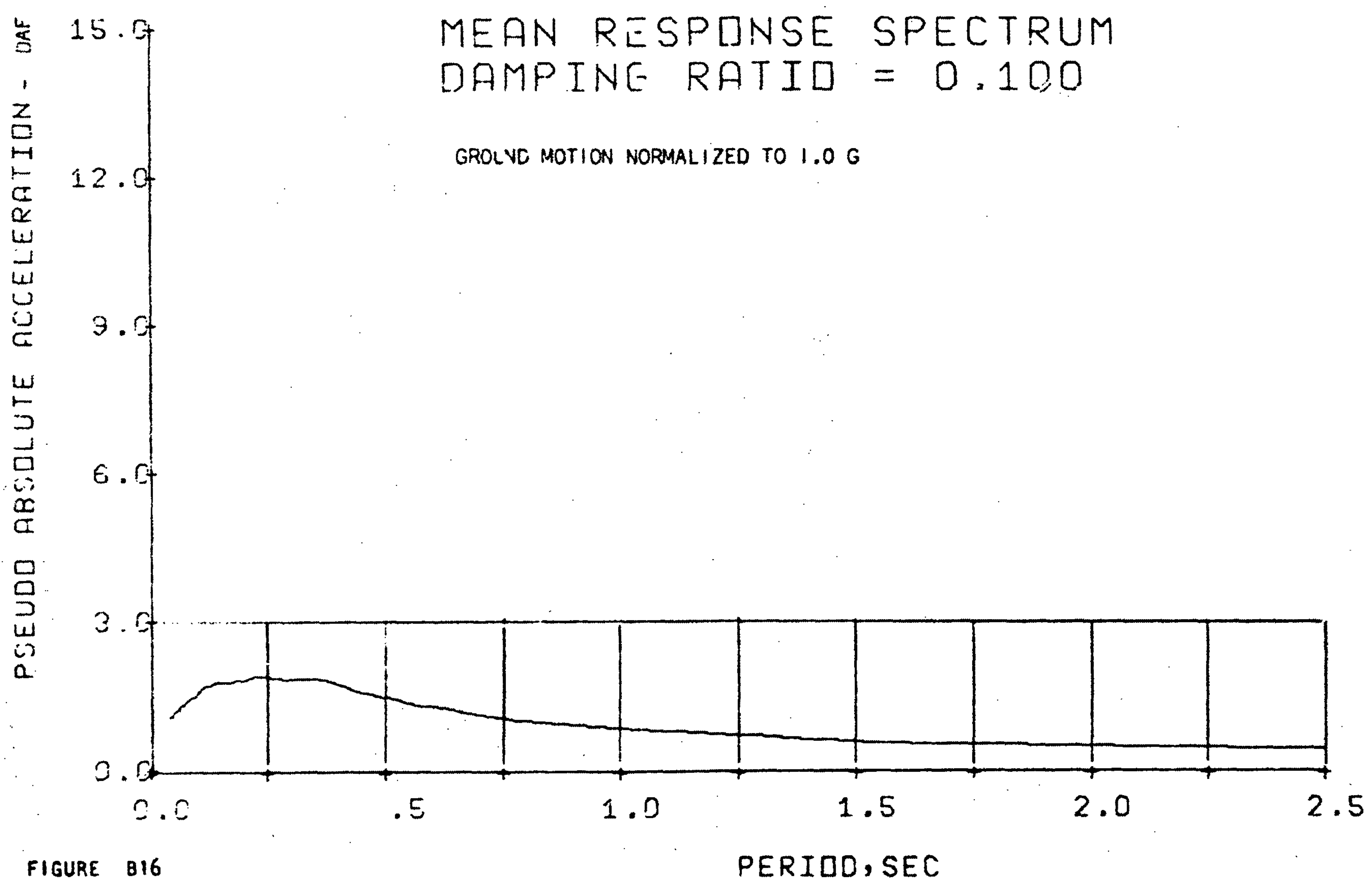

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B16

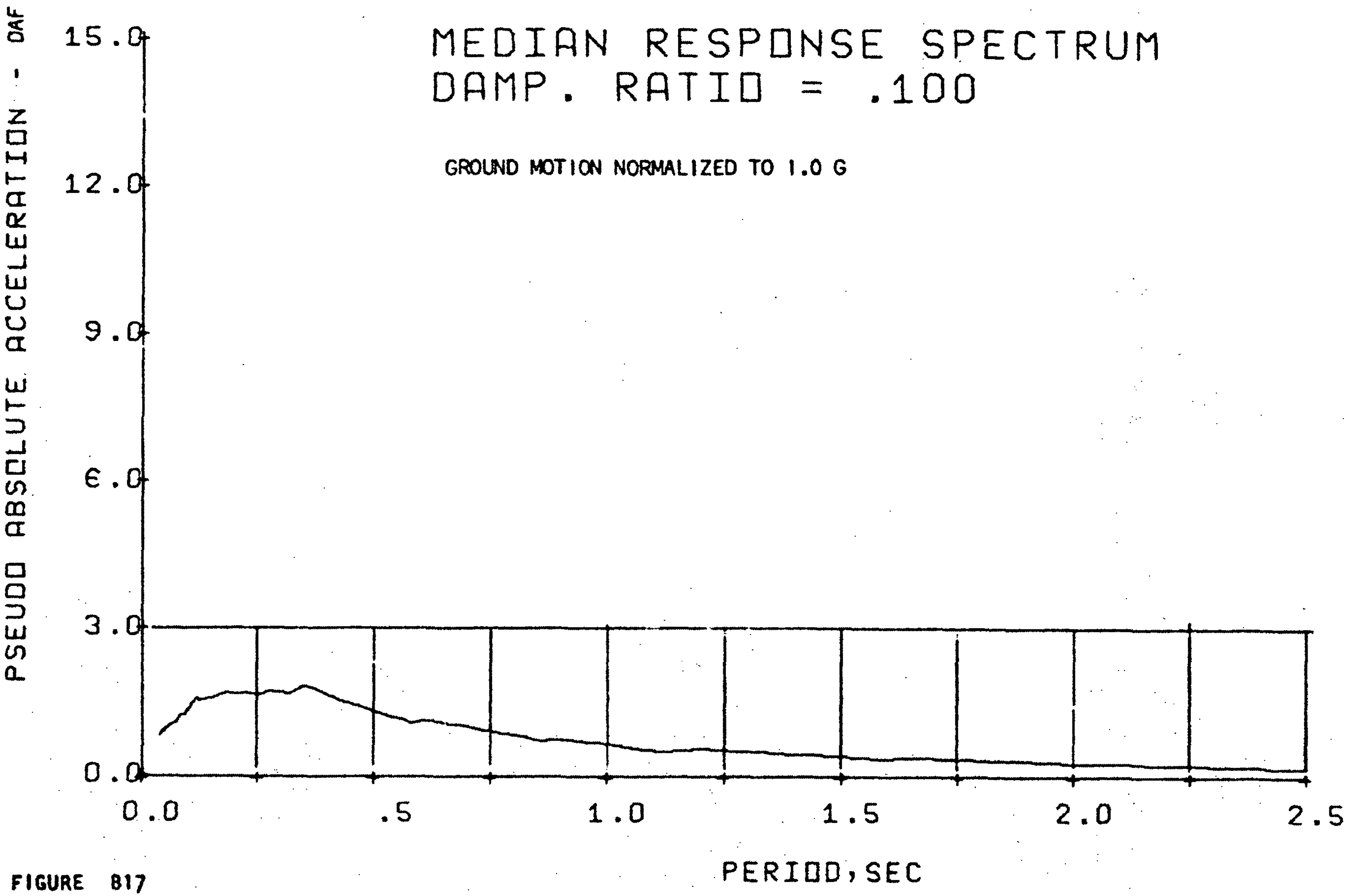

MEDIAN RESPONSE SPECTRUM
DAMP. RATIO = .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B17

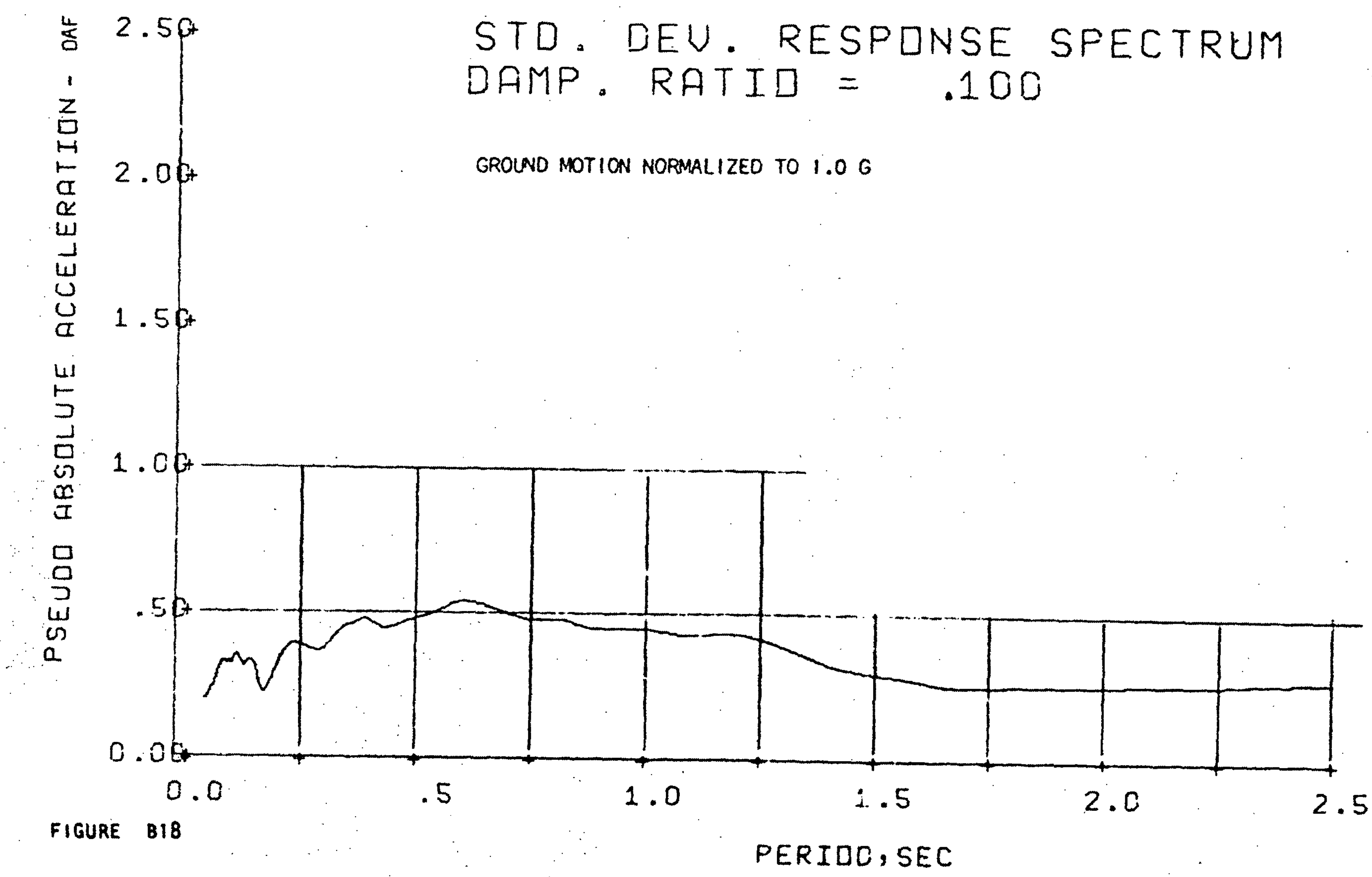
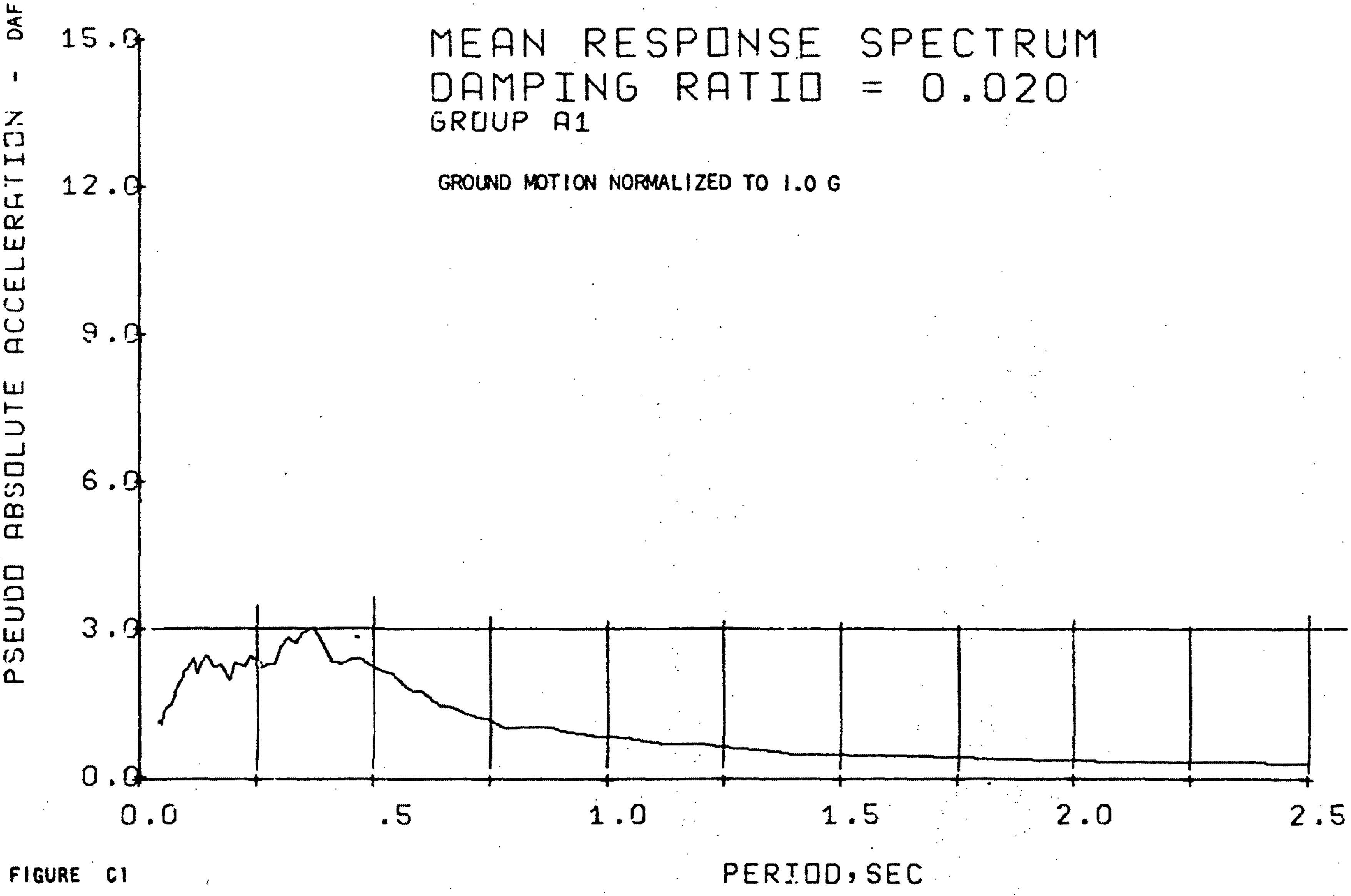

STD. DEV. RESPONSE SPECTRUM
DAMP. RATIO = .100
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE B18

APPENDIX C

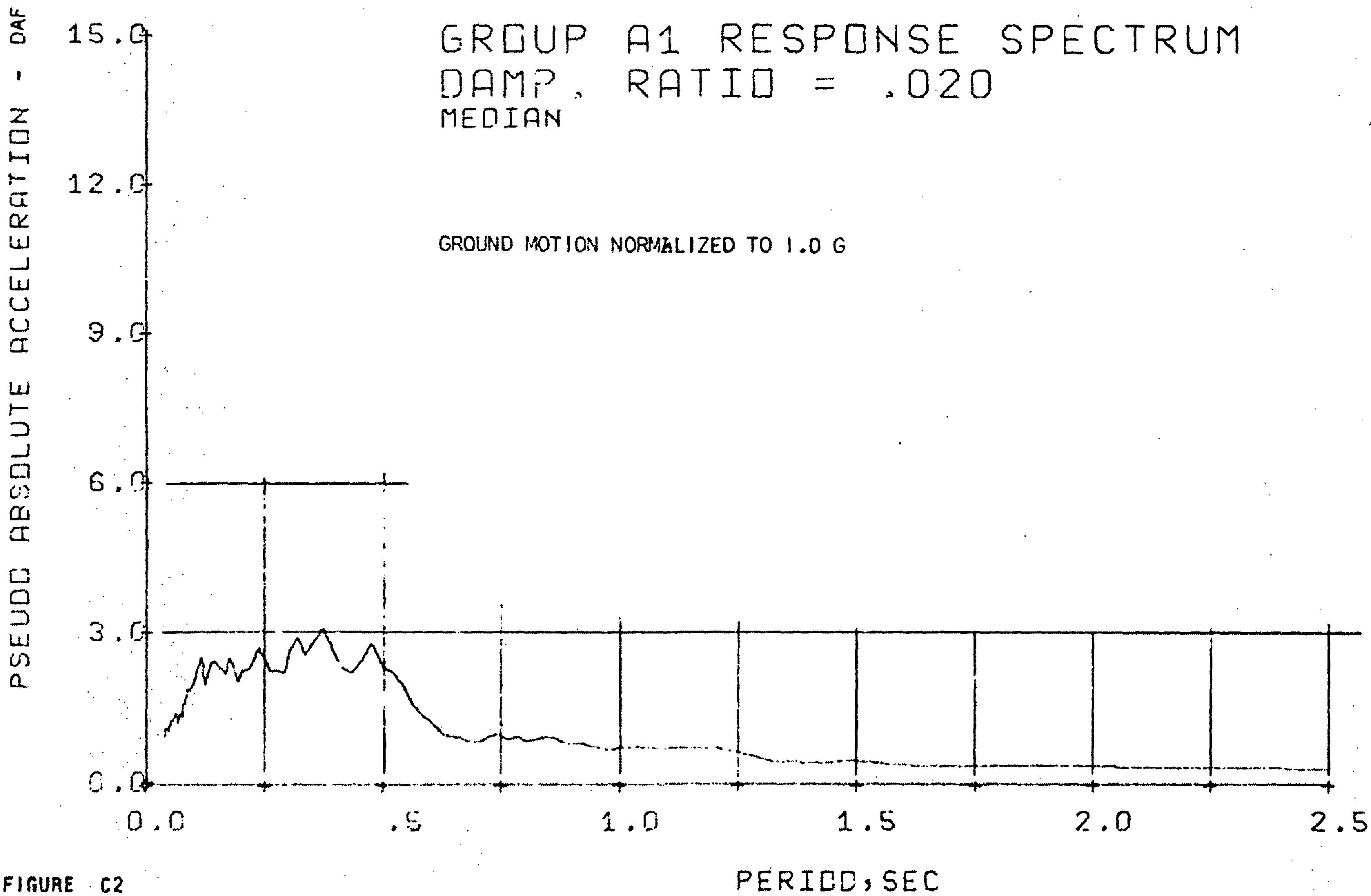
Group Spectrum Statistics

Figures C1 through C33



MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP A1
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C1



GROUP A1 RESPONSE SPECTRUM
DAMP. RATIO = .020
MEDIAN
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C2

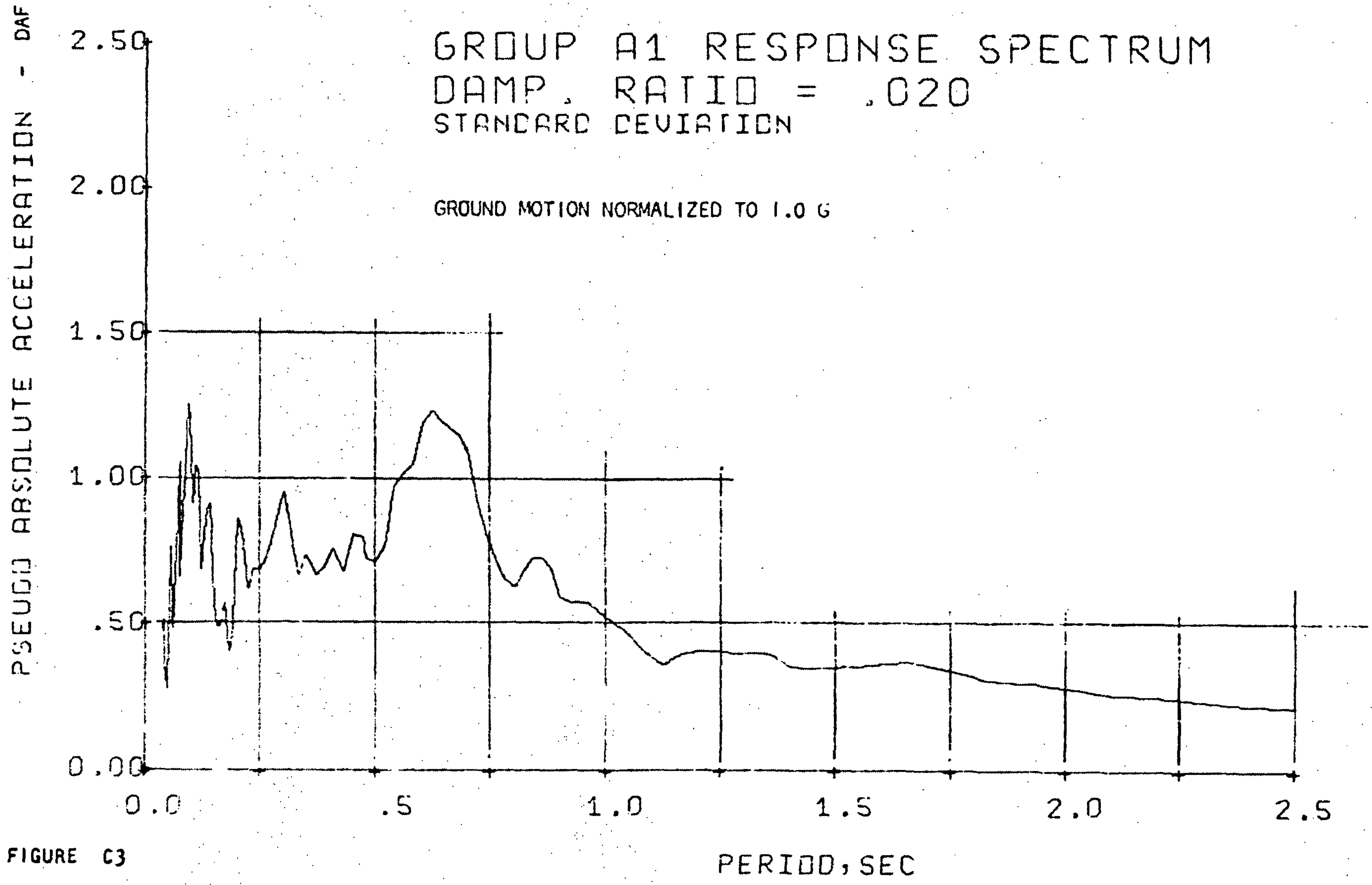

GROUP A1 RESPONSE SPECTRUM
DAMP. RATIO = .020
STANDARD DEVIATION
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C3

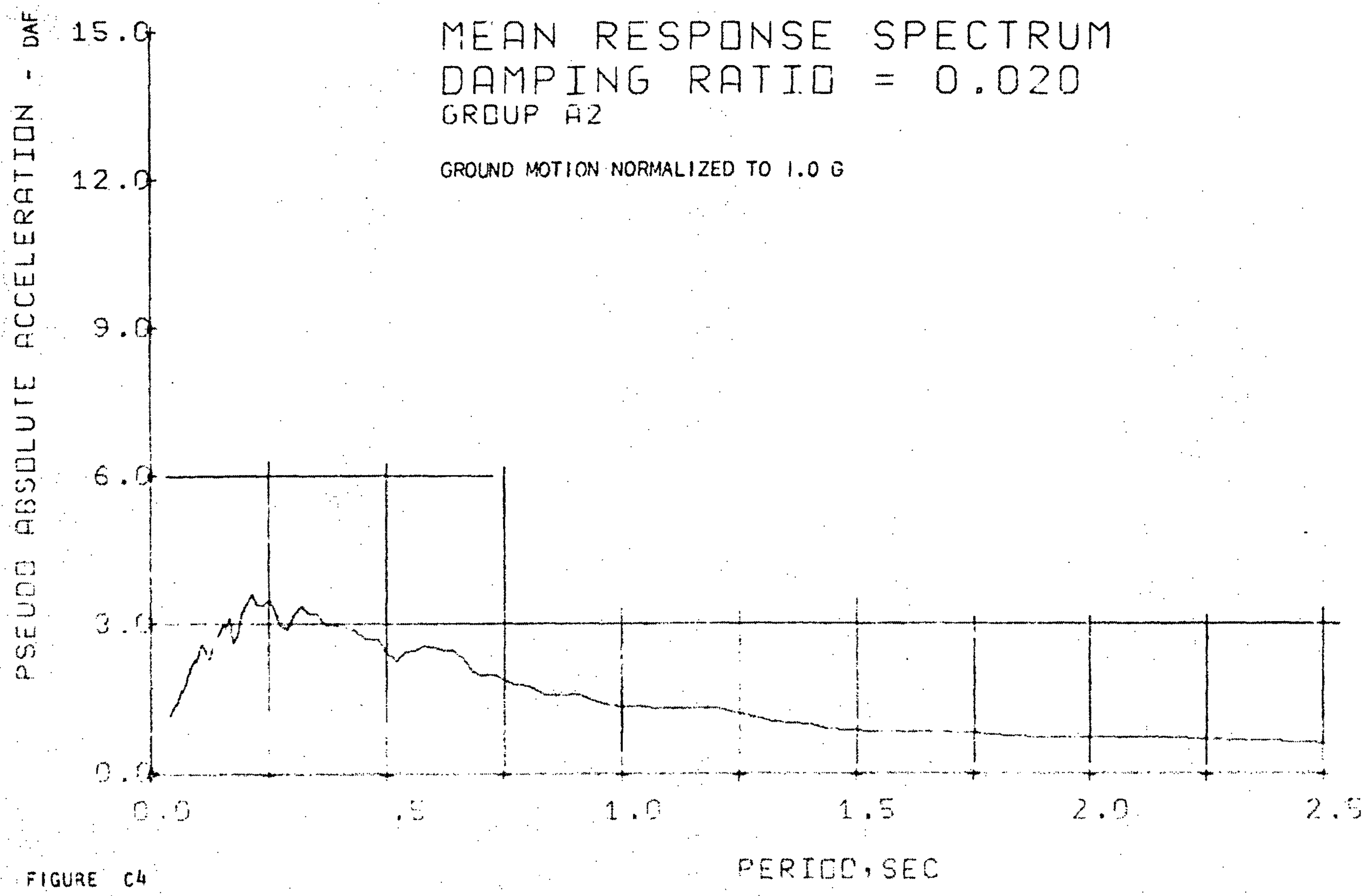

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP A2
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD,SEC

FIGURE C4

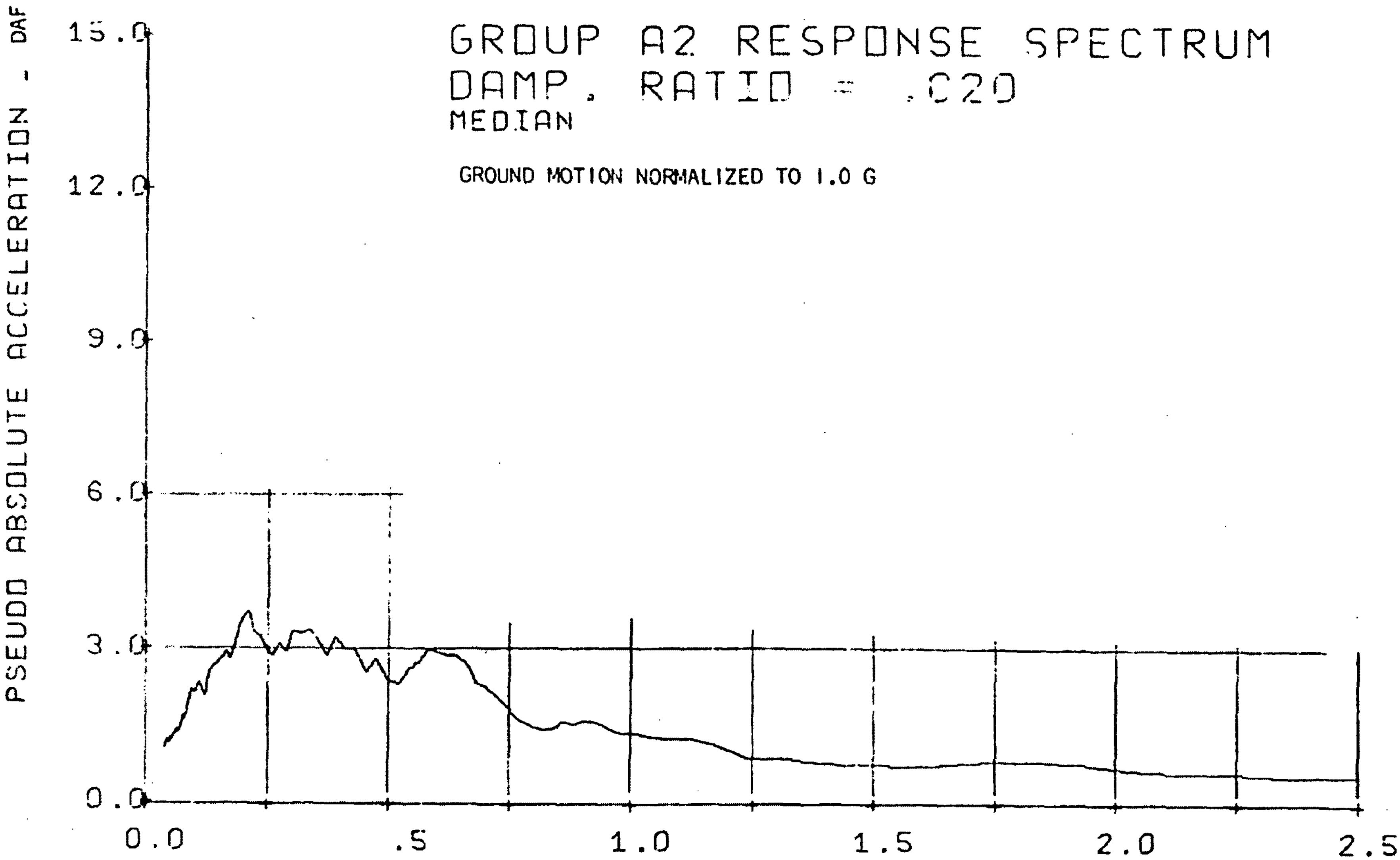

GROUP A2 RESPONSE SPECTRUM
DAMP. RATIO = .020
MEDIAN
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5

FIGURE C5

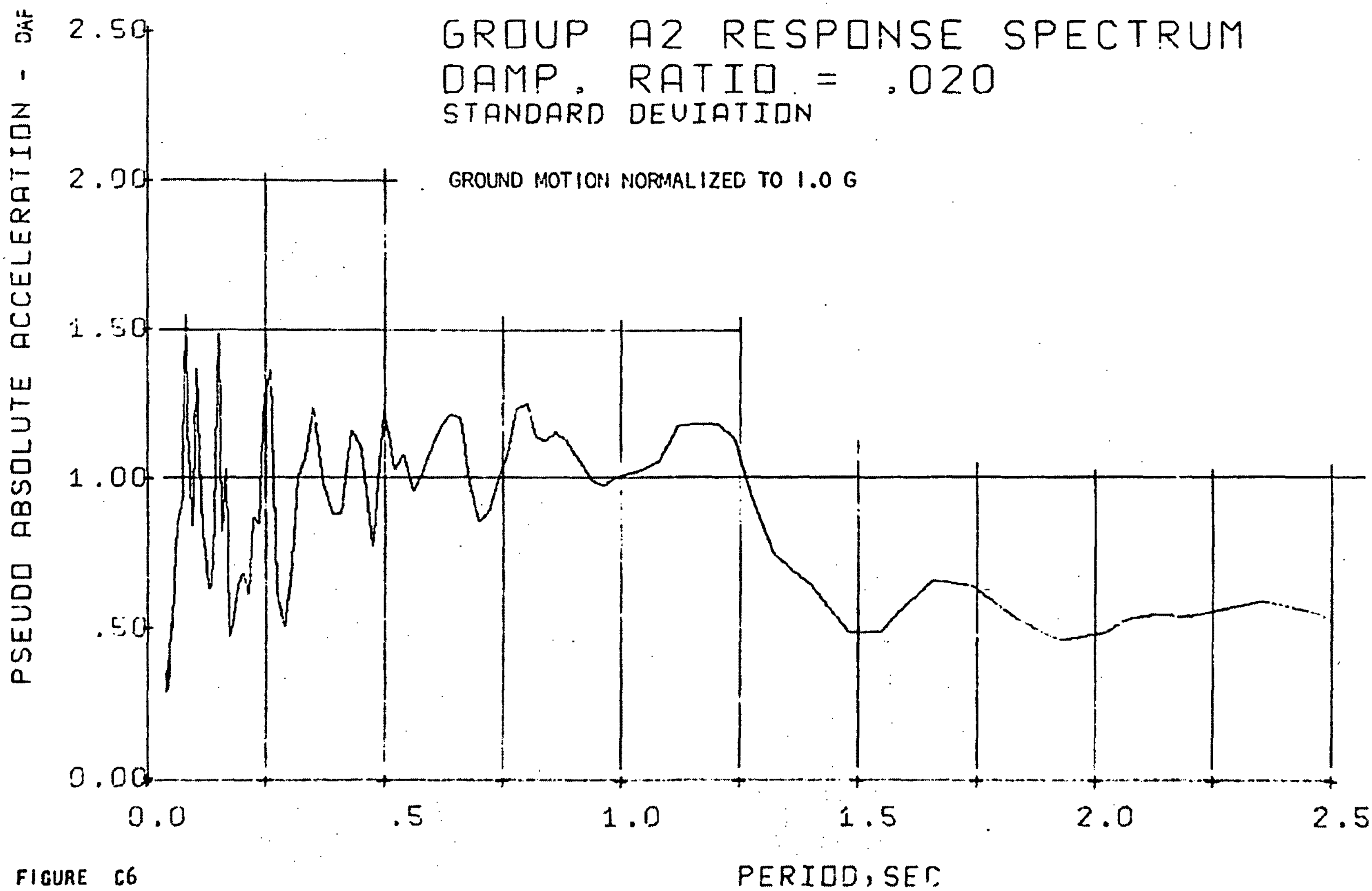

GROUP A2 RESPONSE SPECTRUM
DAMP. RATIO = .020
STANDARD DEVIATION
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C6

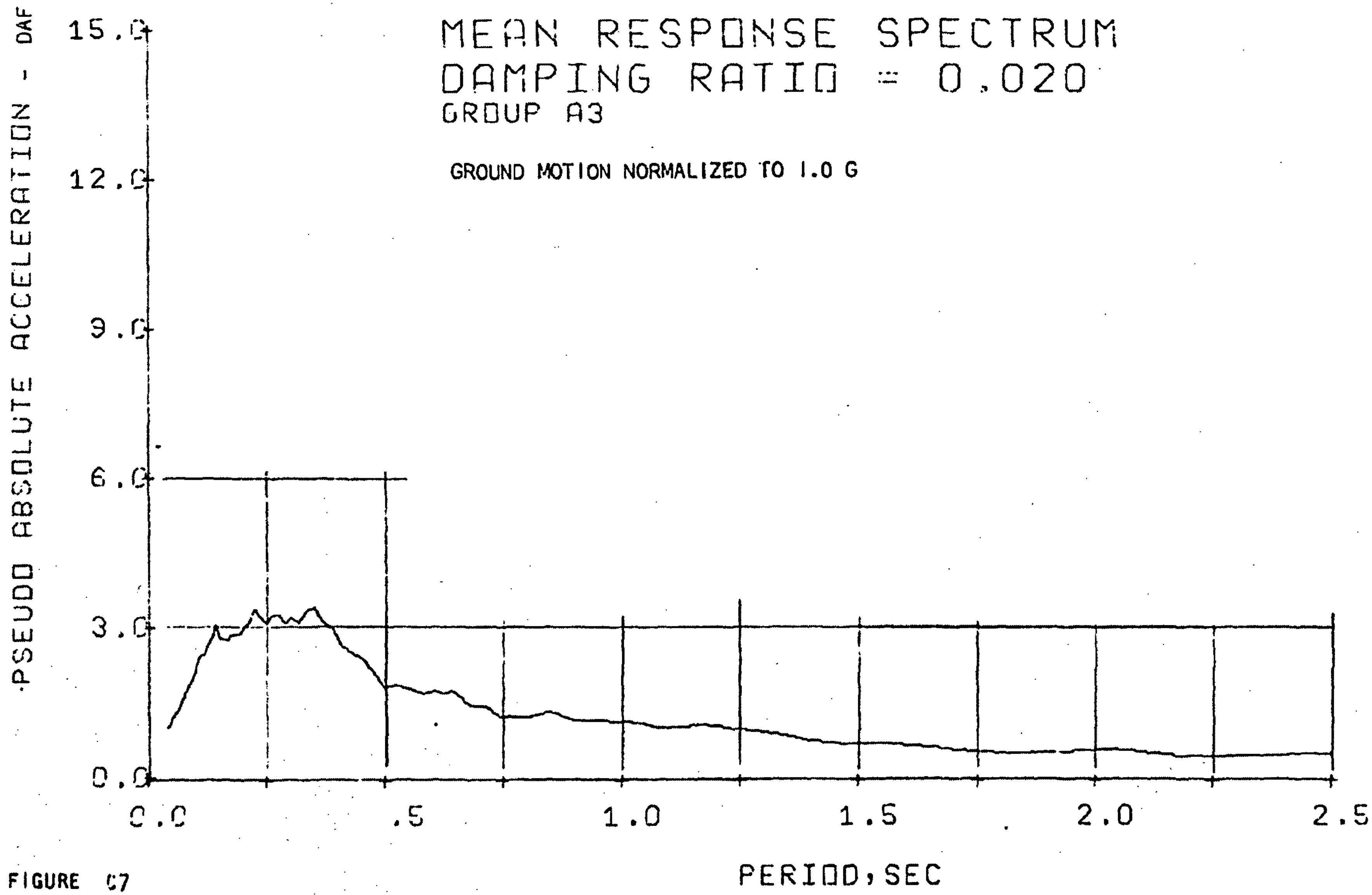

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP A3
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C7

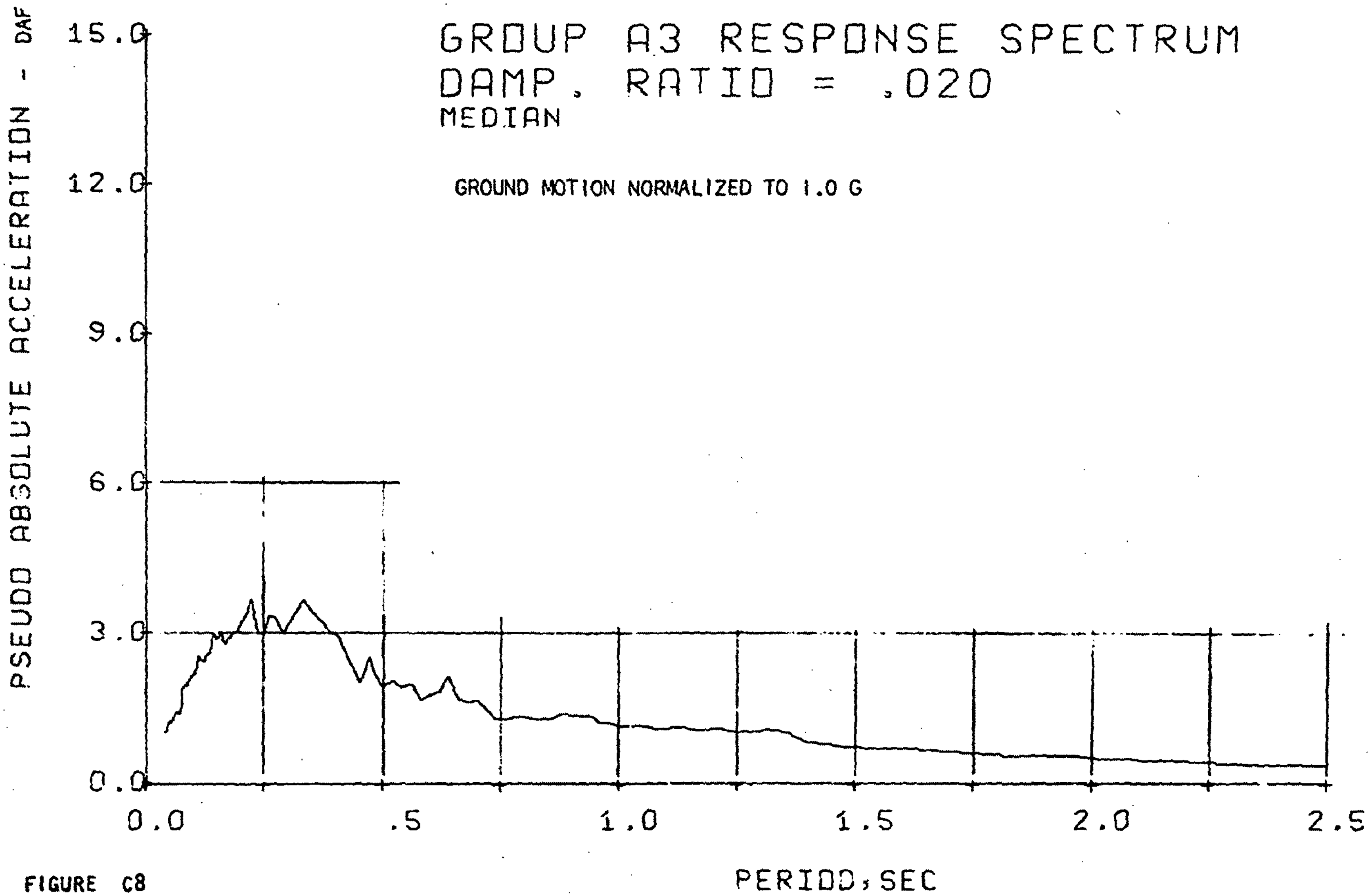

GROUP A3 RESPONSE SPECTRUM
DAMP. RATIO = .020
MEDIAN
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C8

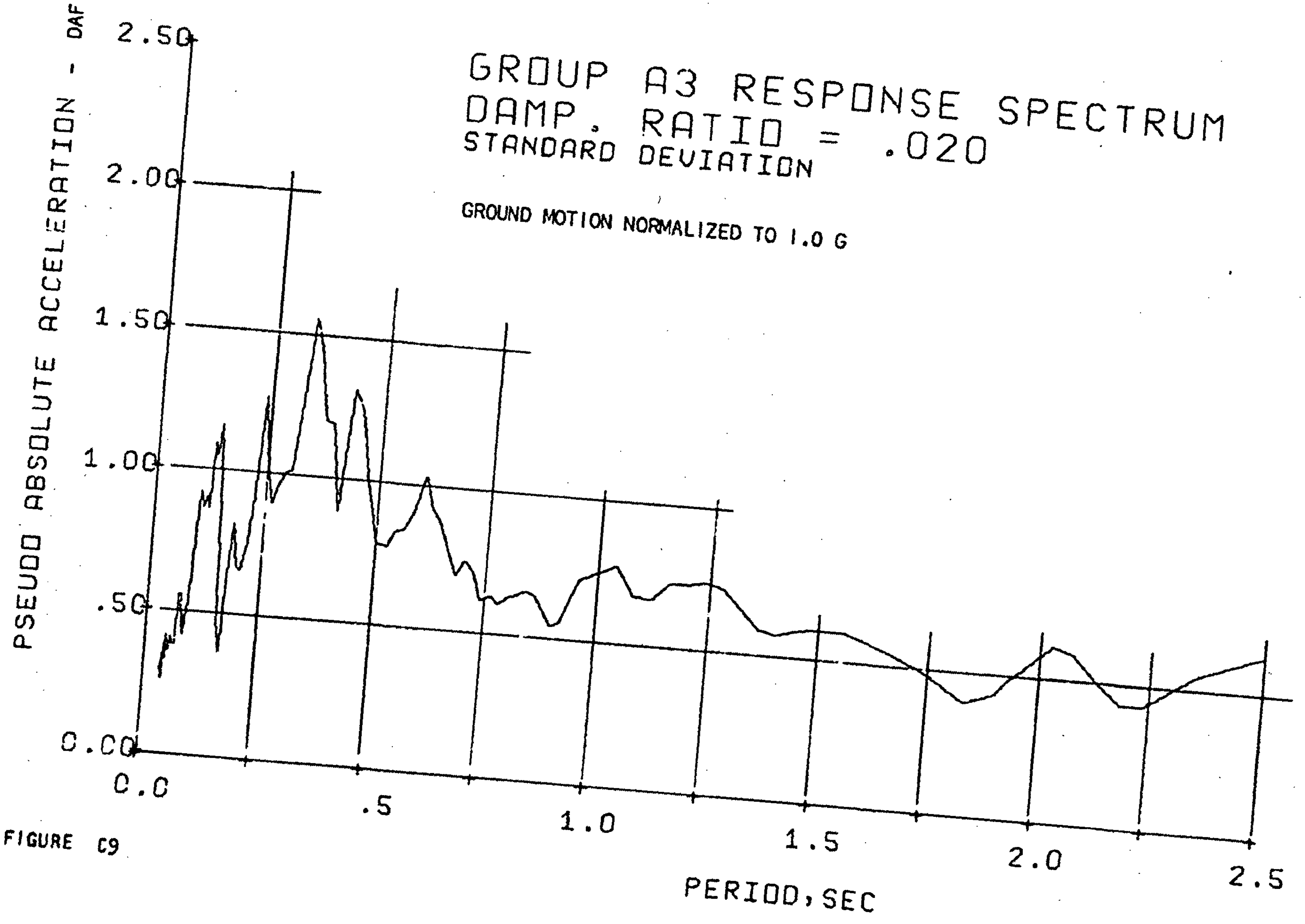

GROUP A3 RESPONSE SPECTRUM
DAMP. RATIO = .020
STANDARD DEVIATION
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C9

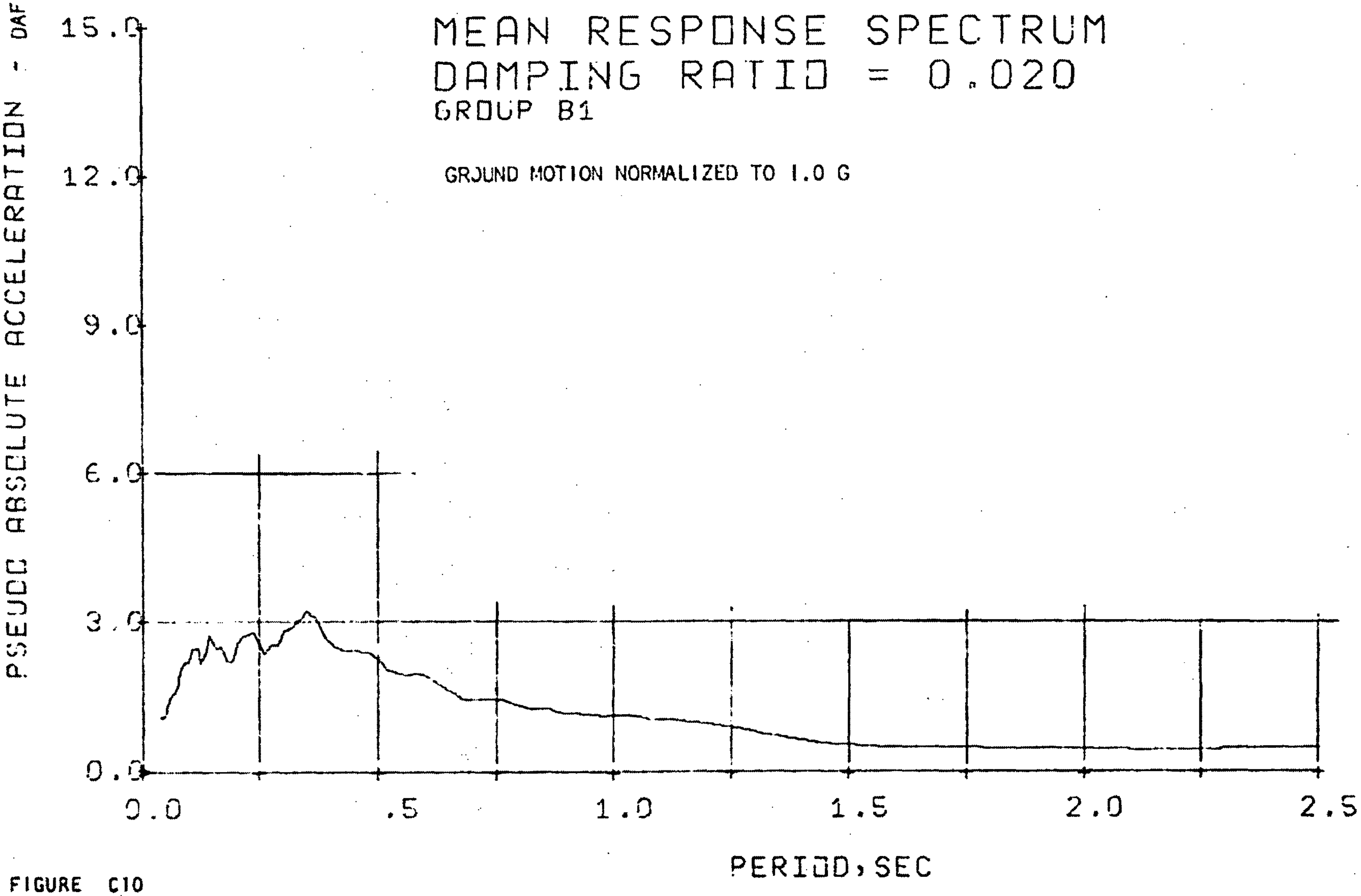

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP B1
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C10

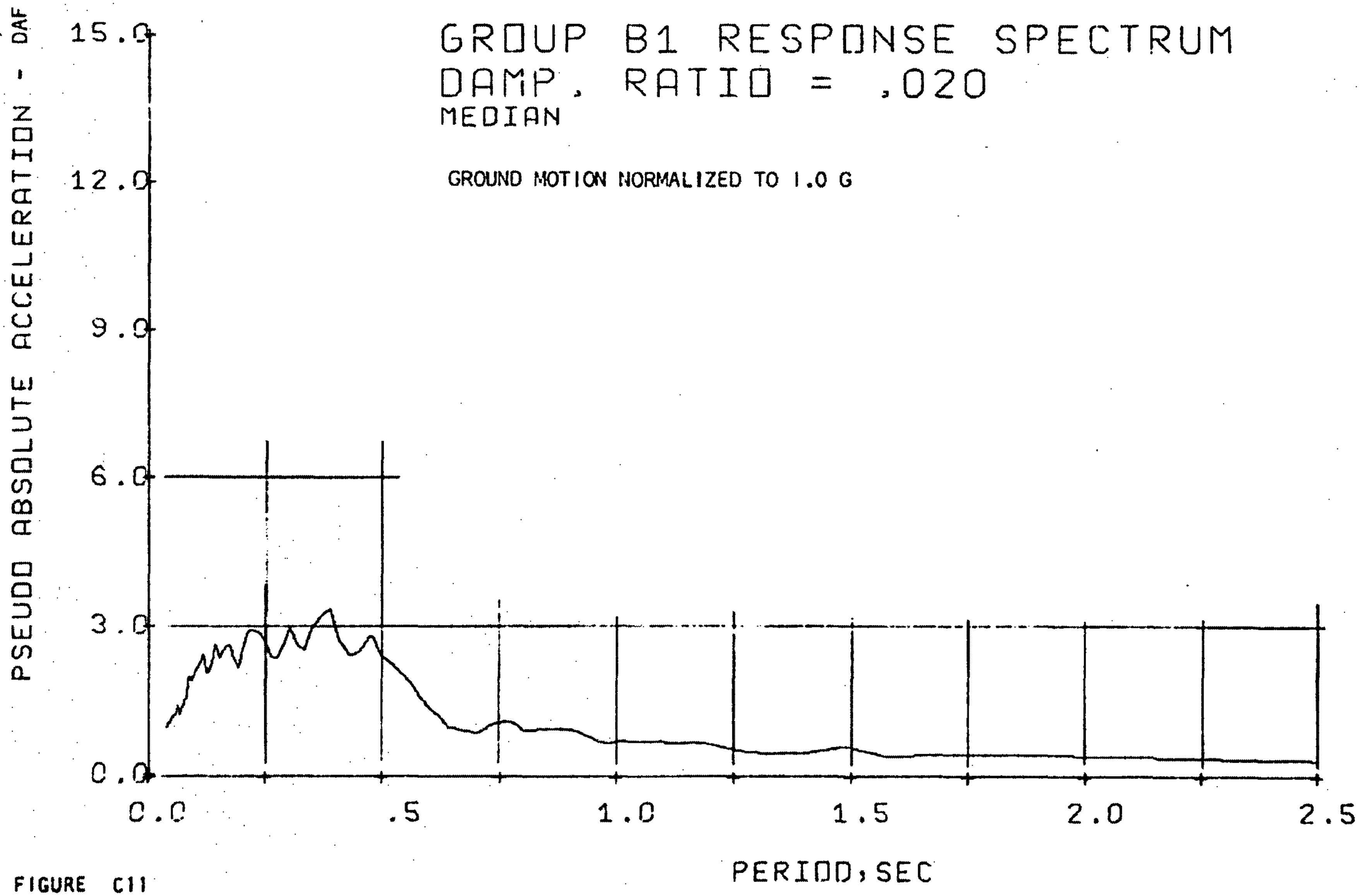

GROUP B1 RESPONSE SPECTRUM
DAMP. RATIO = .020
MEDIAN
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C11

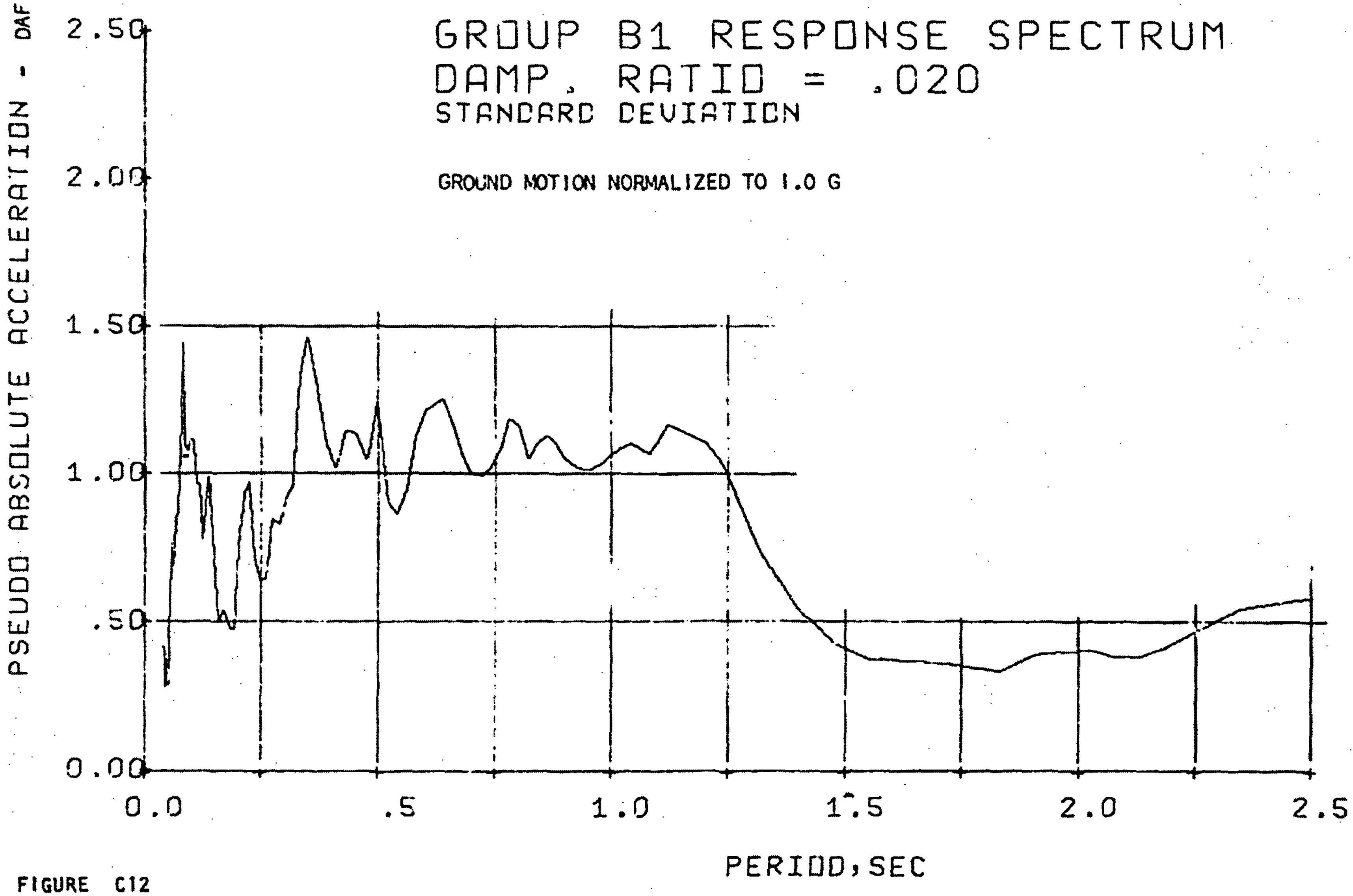
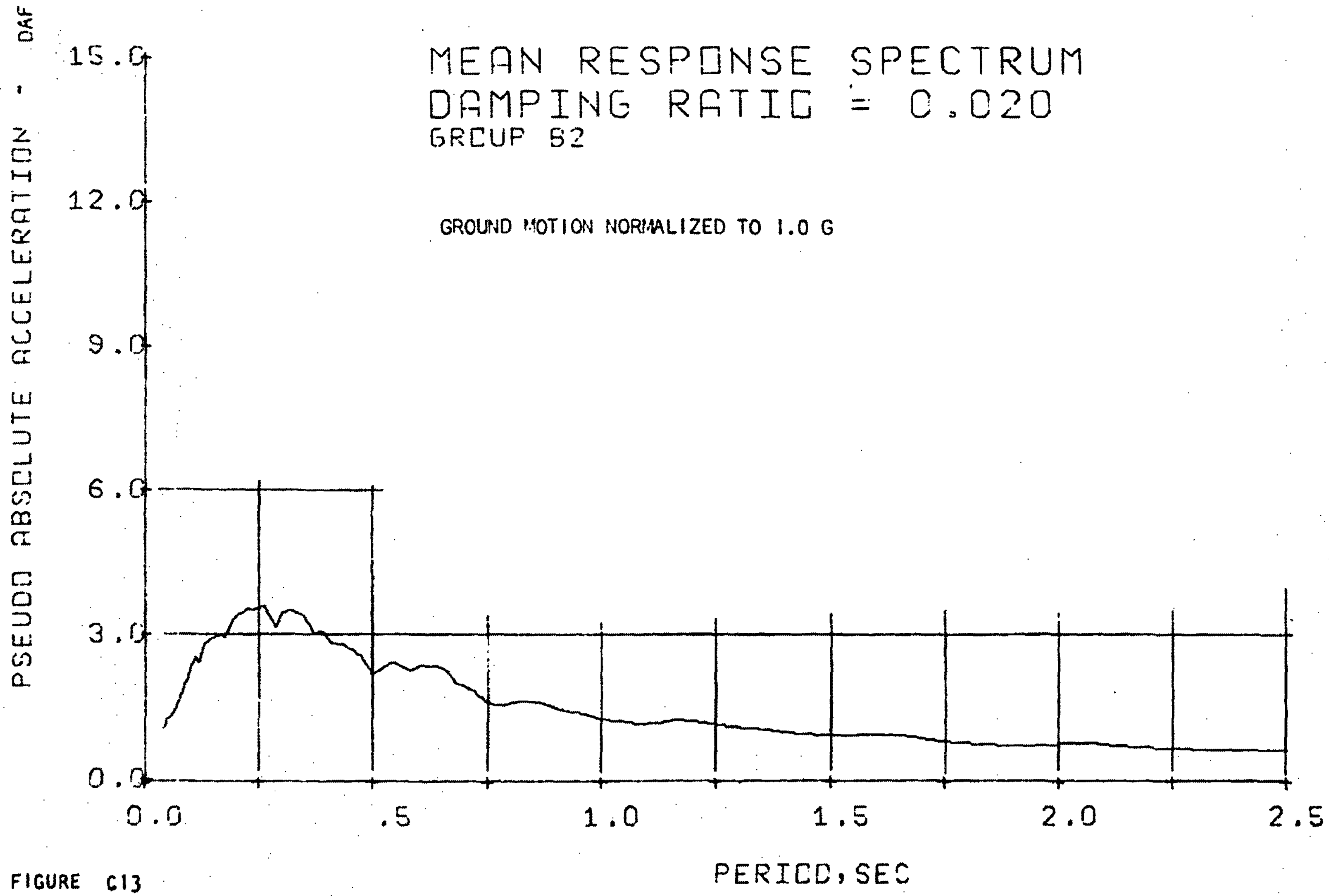

GROUP B1 RESPONSE SPECTRUM
DAMP. RATIO = .020
STANDARD DEVIATION
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C12



MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP 62
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C13

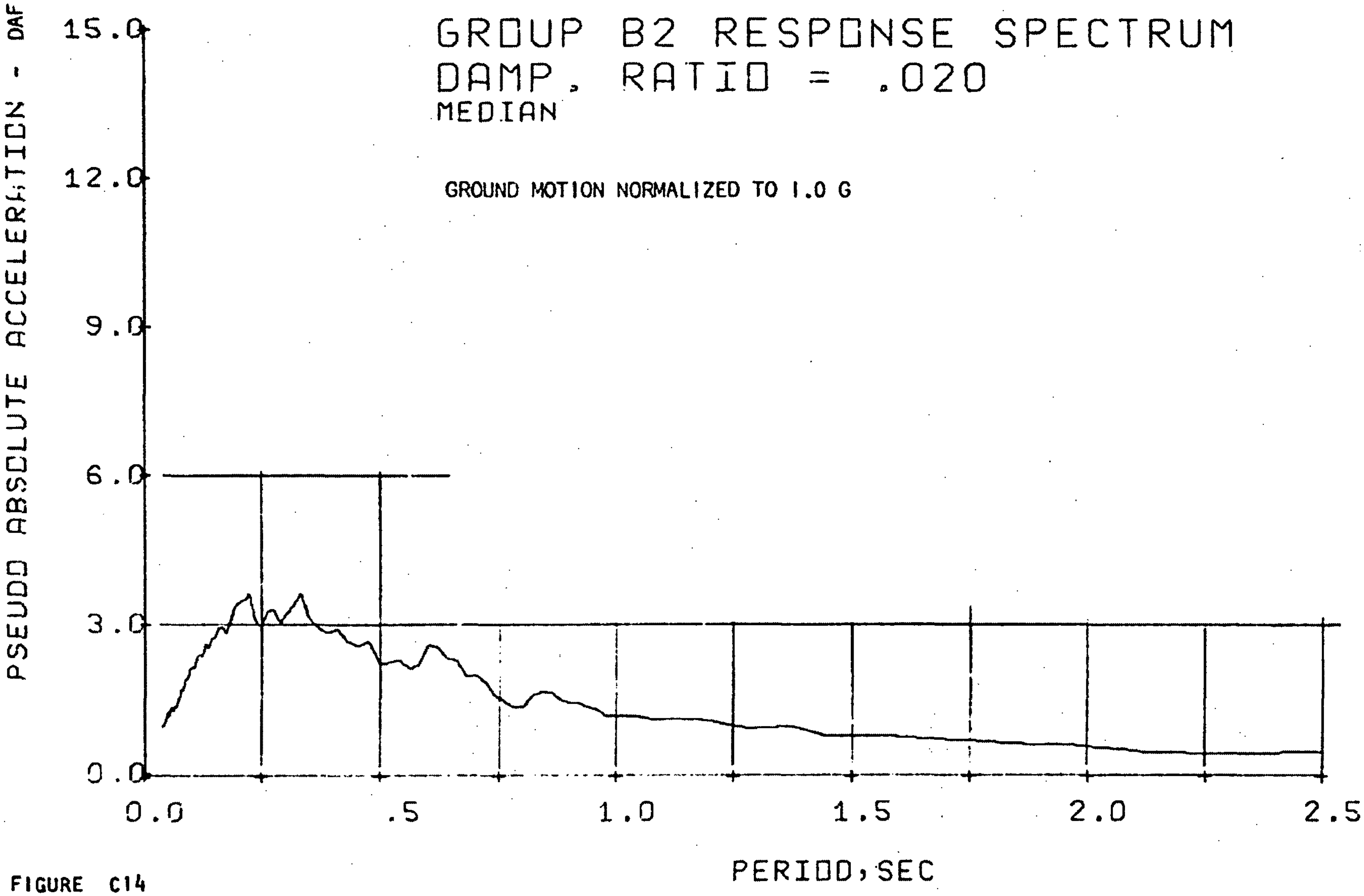

GROUP B2 RESPONSE SPECTRUM
DAMP. RATIO = .020
MEDIAN
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C14

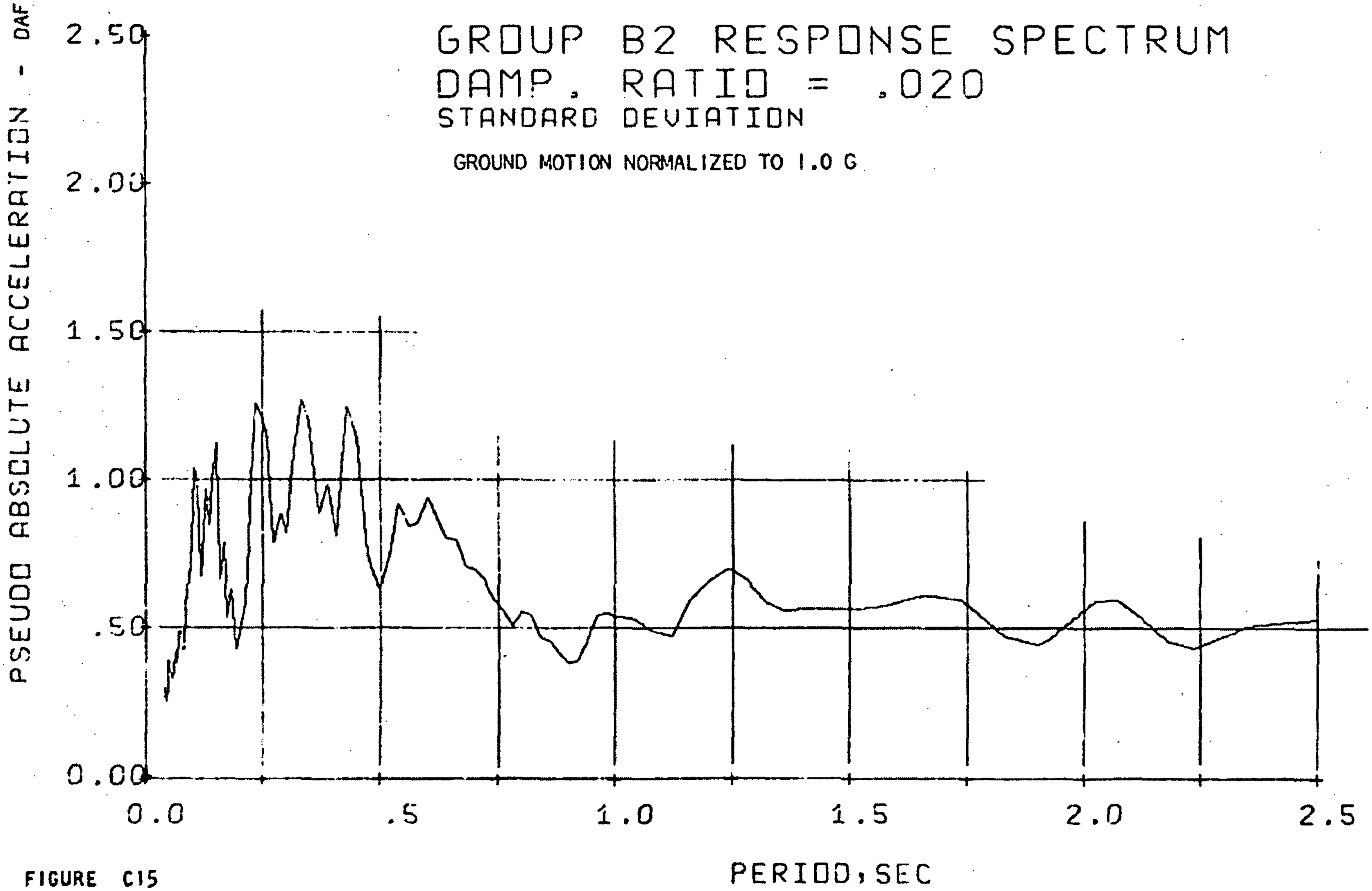

GROUP B2 RESPONSE SPECTRUM
DAMP. RATIO = .020
STANDARD DEVIATION
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C15

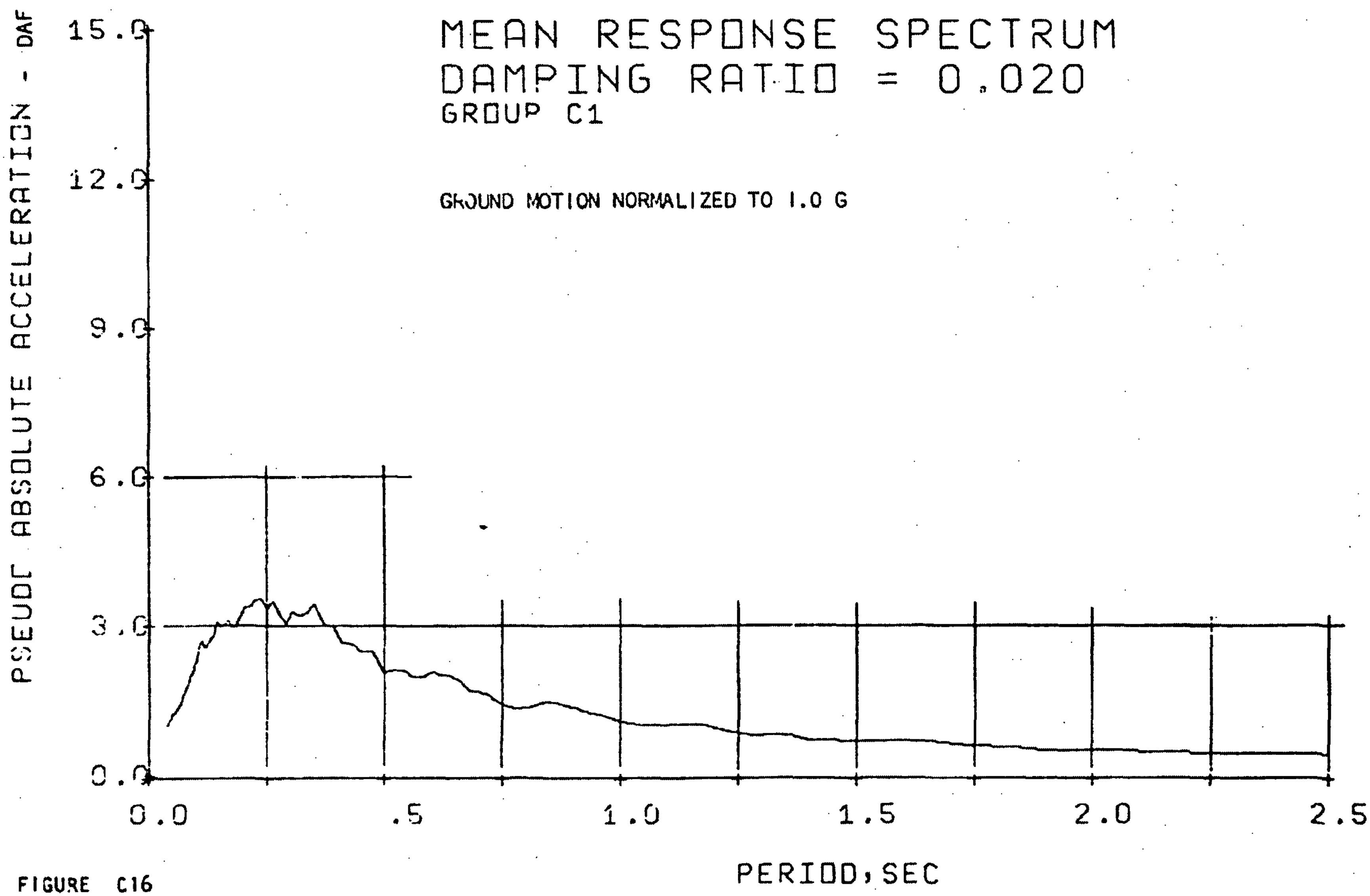

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP C1
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C16

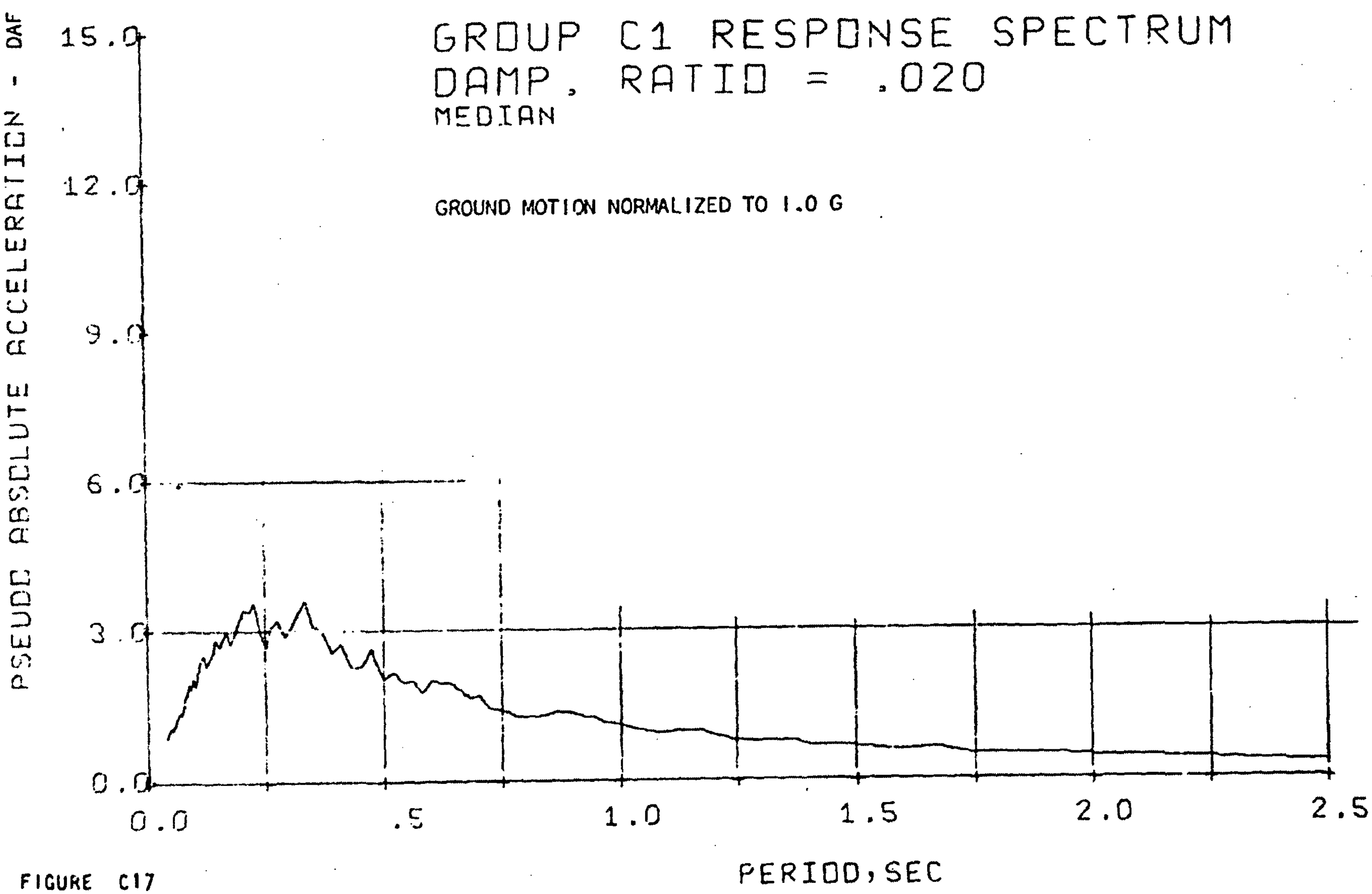

GROUP C1 RESPONSE SPECTRUM
DAMP. RATIO = .020
MEDIAN
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C17

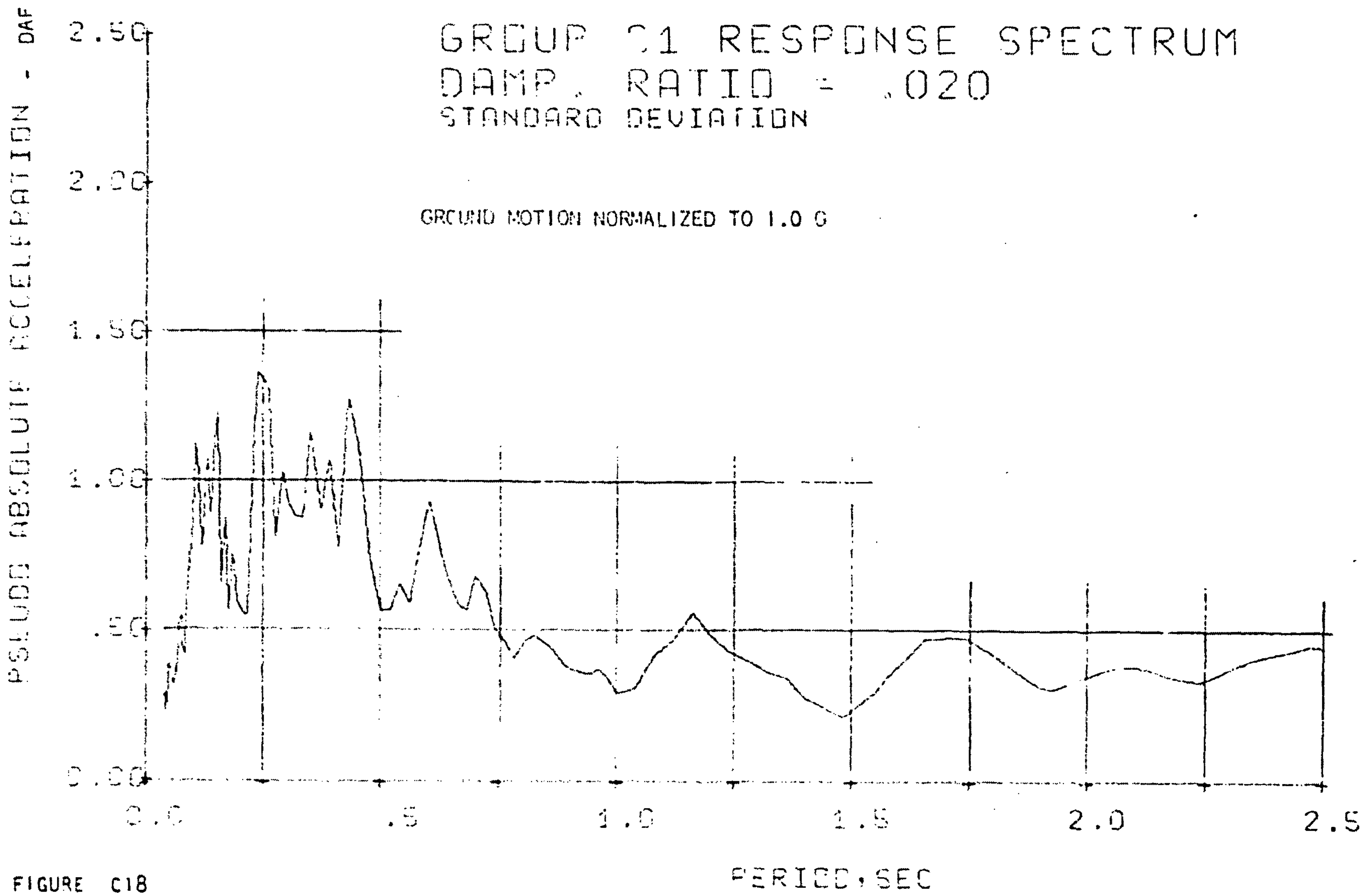
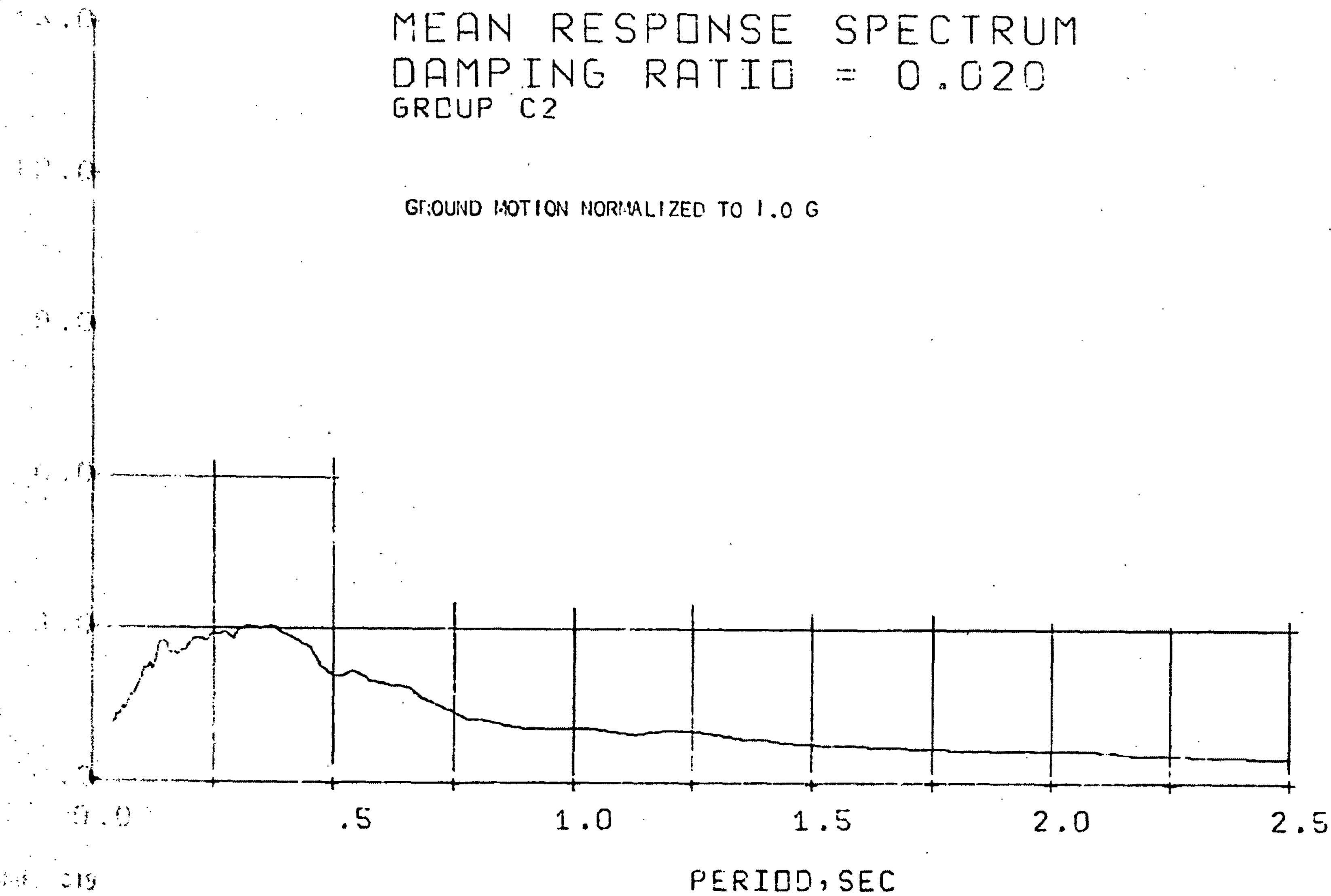

GROUP C1 RESPONSE SPECTRUM
DAMP. RATIO = .020
STANDARD DEVIATION
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
2.50
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C18



MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP C2
GROUND MOTION NORMALIZED TO 1.0 G
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

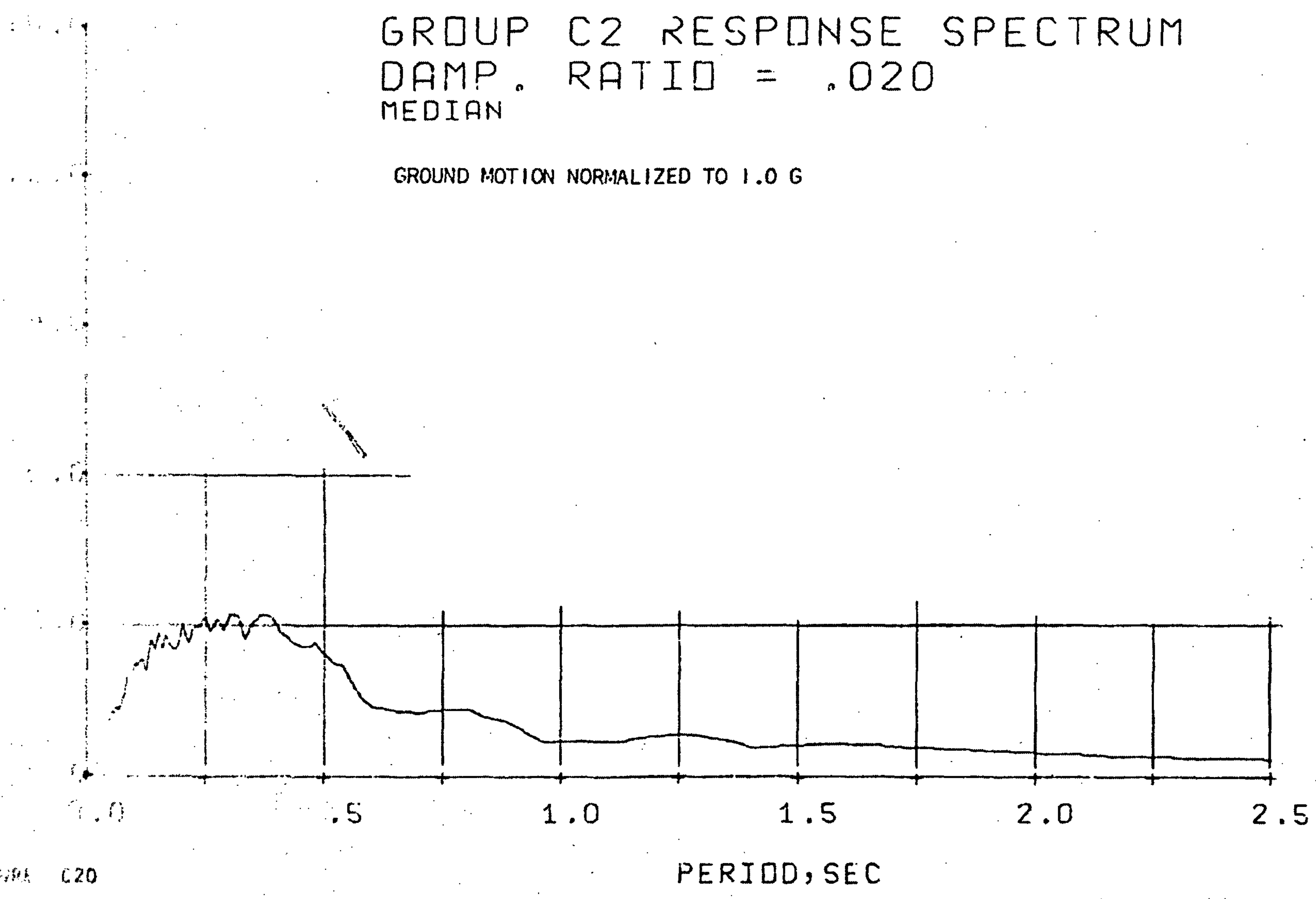

GROUP C2 RESPONSE SPECTRUM
DAMP. RATIO = .020
MEDIAN
GROUND MOTION NORMALIZED TO 1.0 G
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C20

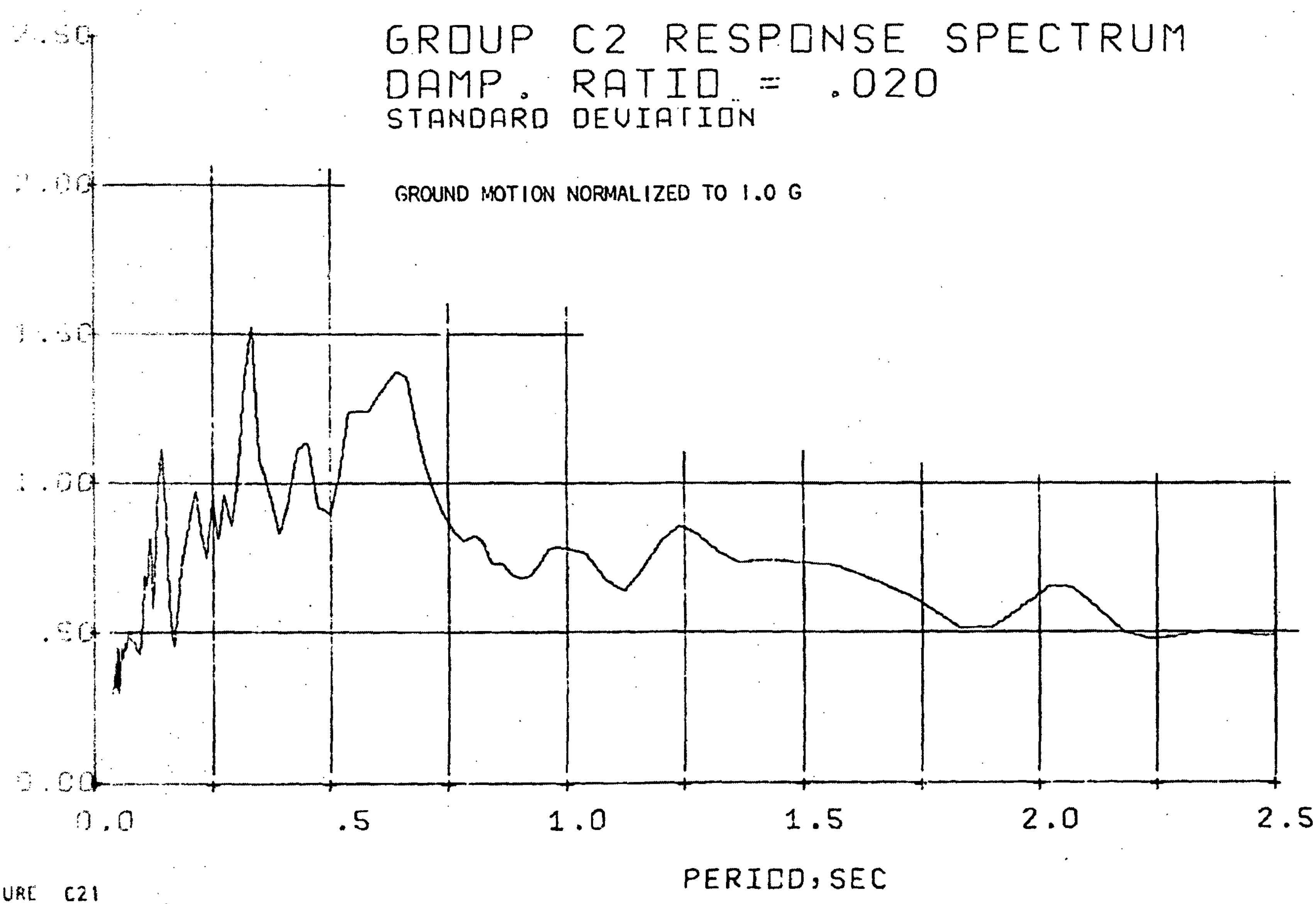

GROUP C2 RESPONSE SPECTRUM
DAMP. RATIO = .020
STANDARD DEVIATION
GROUND MOTION NORMALIZED TO 1.0 G
2.00
1.50
1.00
.50
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C21

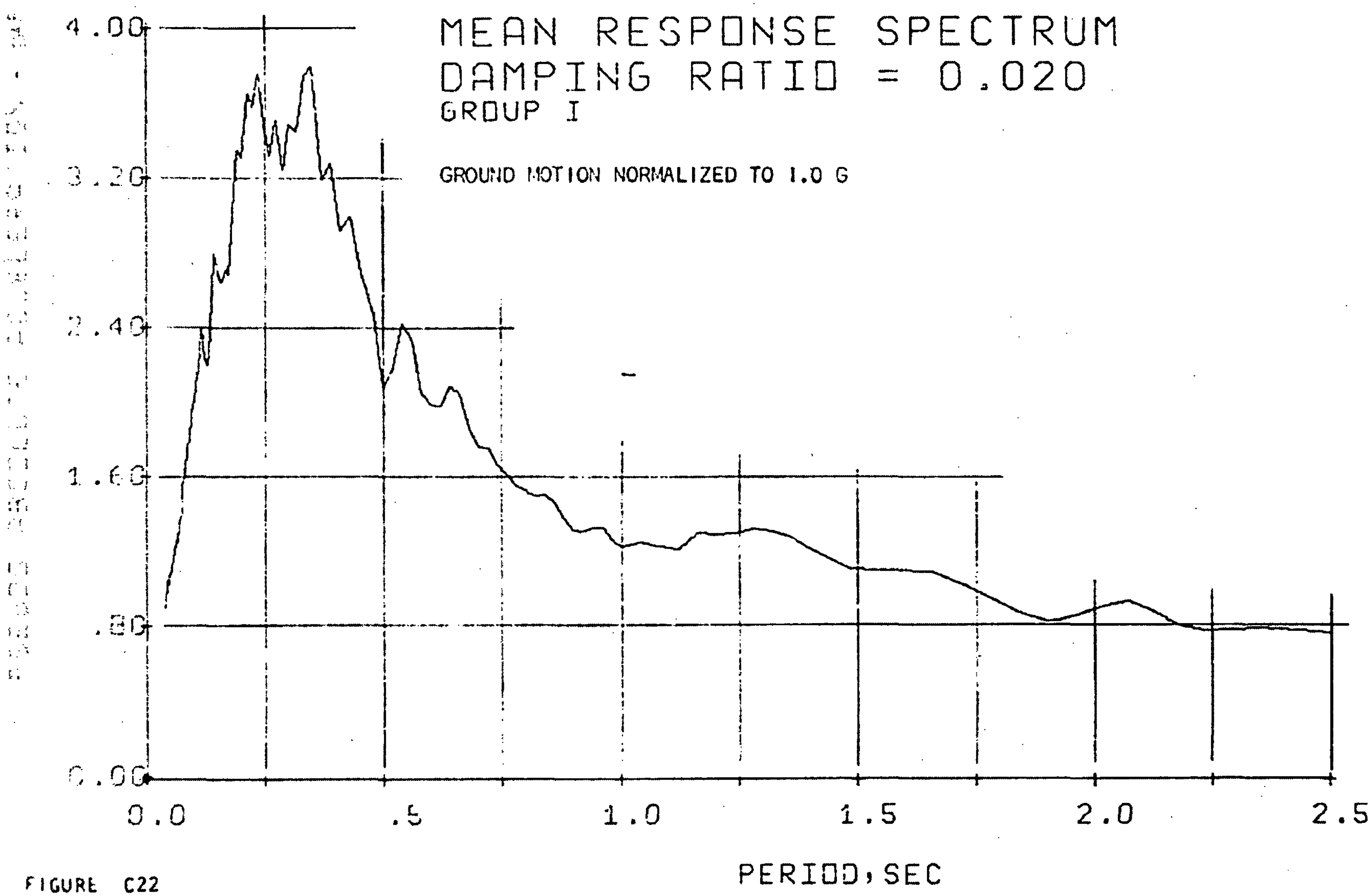

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP I
GROUND MOTION NORMALIZED TO 1.0 G
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C22

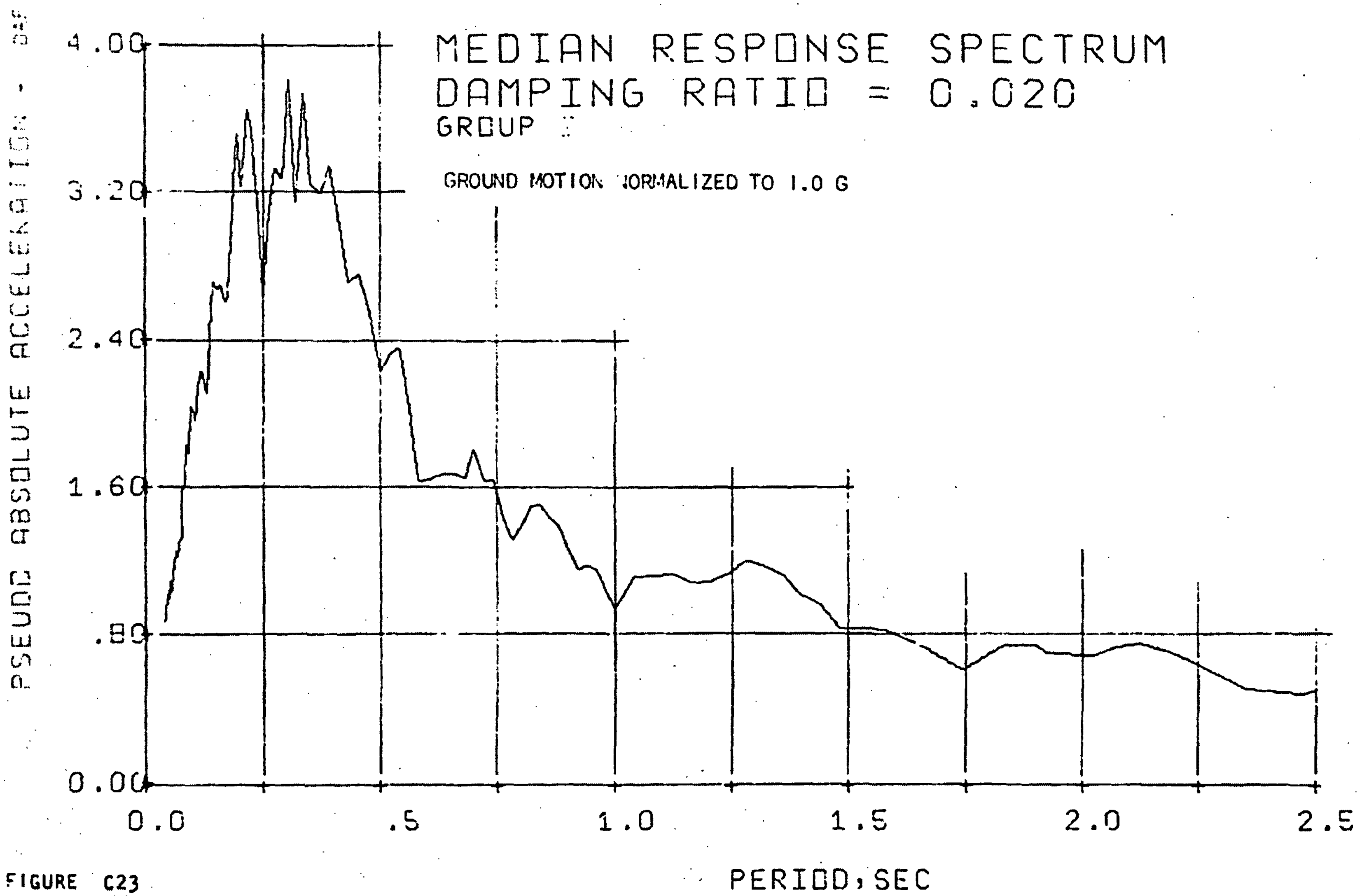

MEDIAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C23

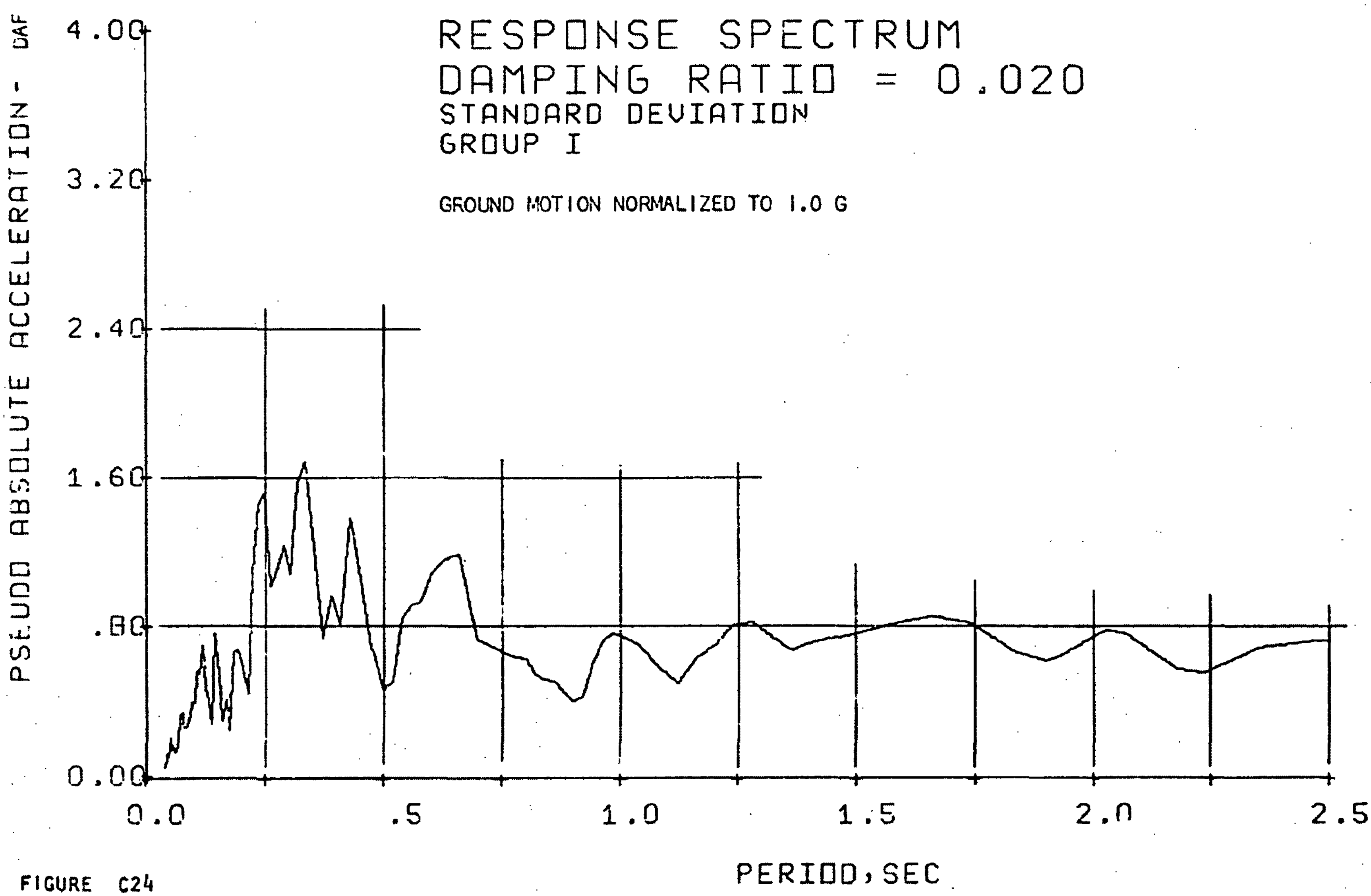

RESPONSE SPECTRUM
DAMPING RATIO = 0.020
STANDARD DEVIATION
GROUP I
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C24

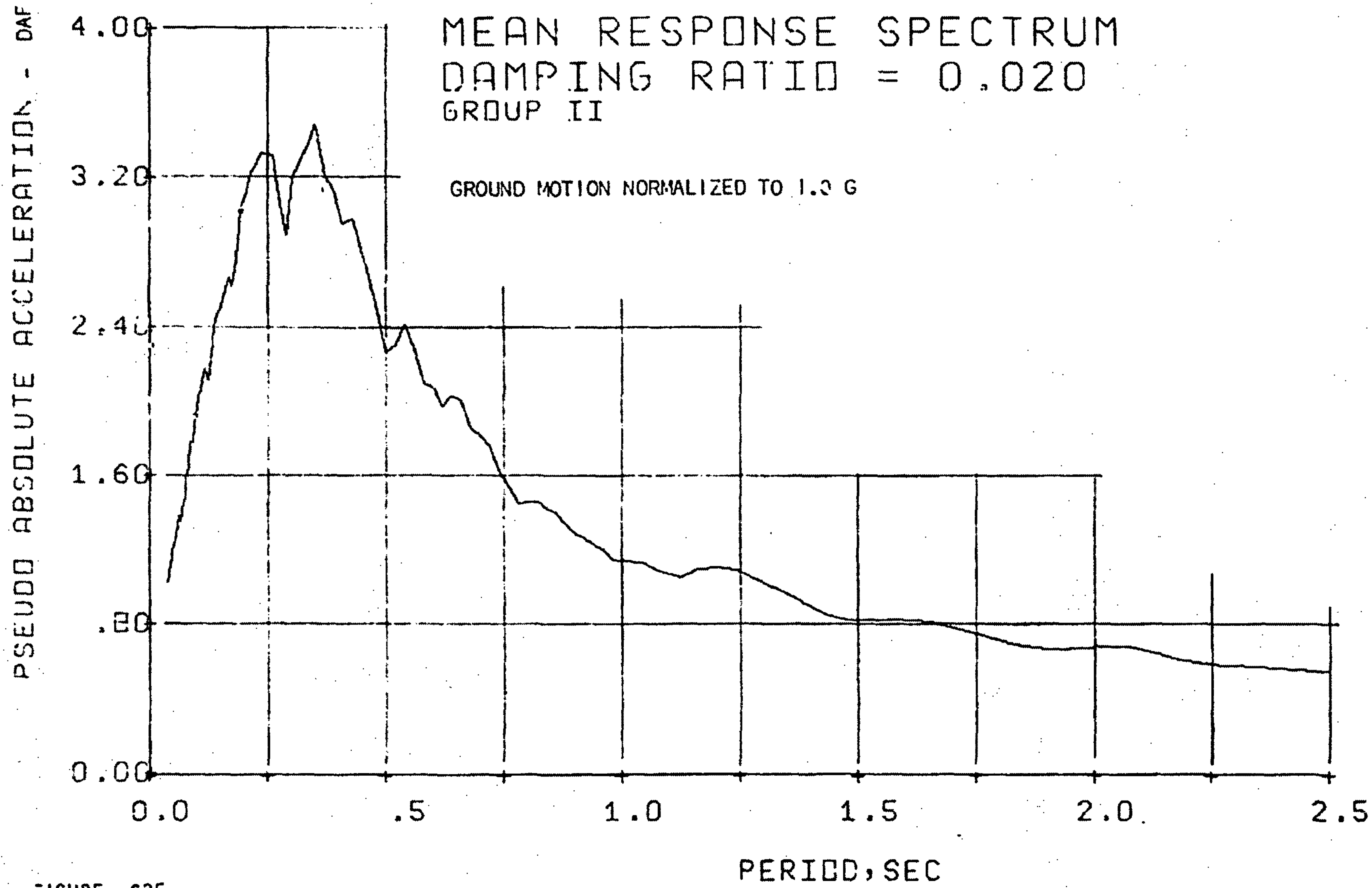

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP II
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C25

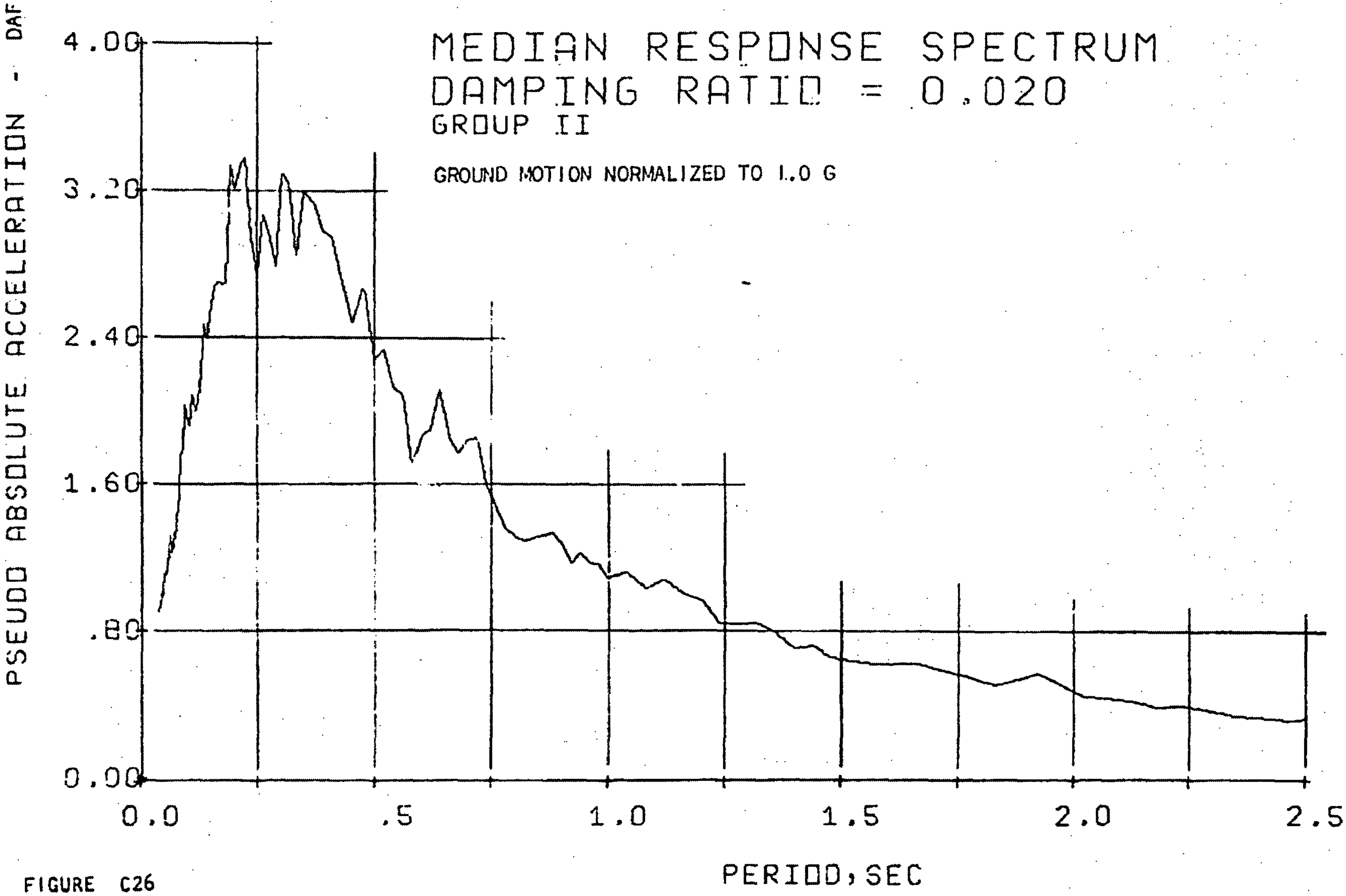
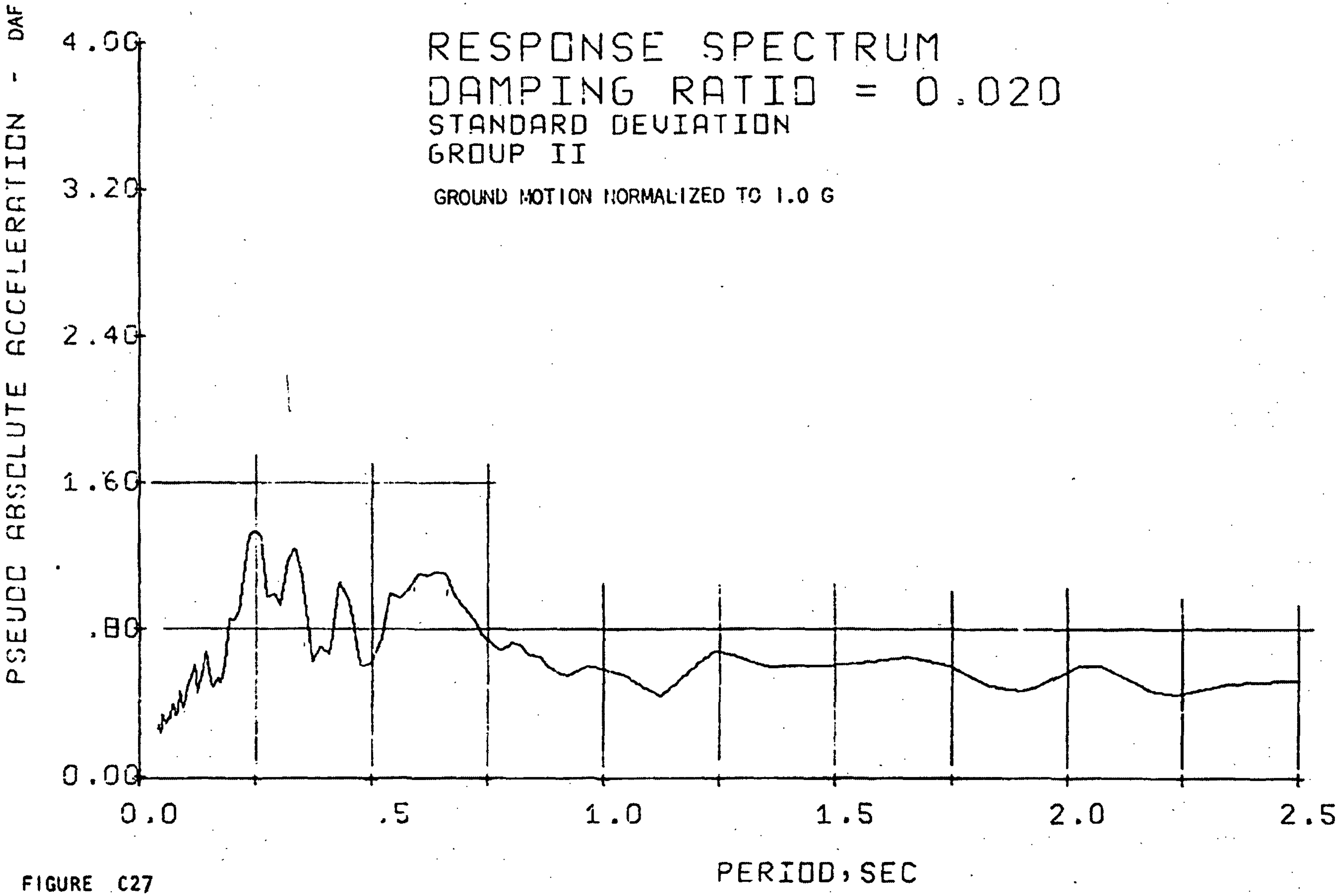
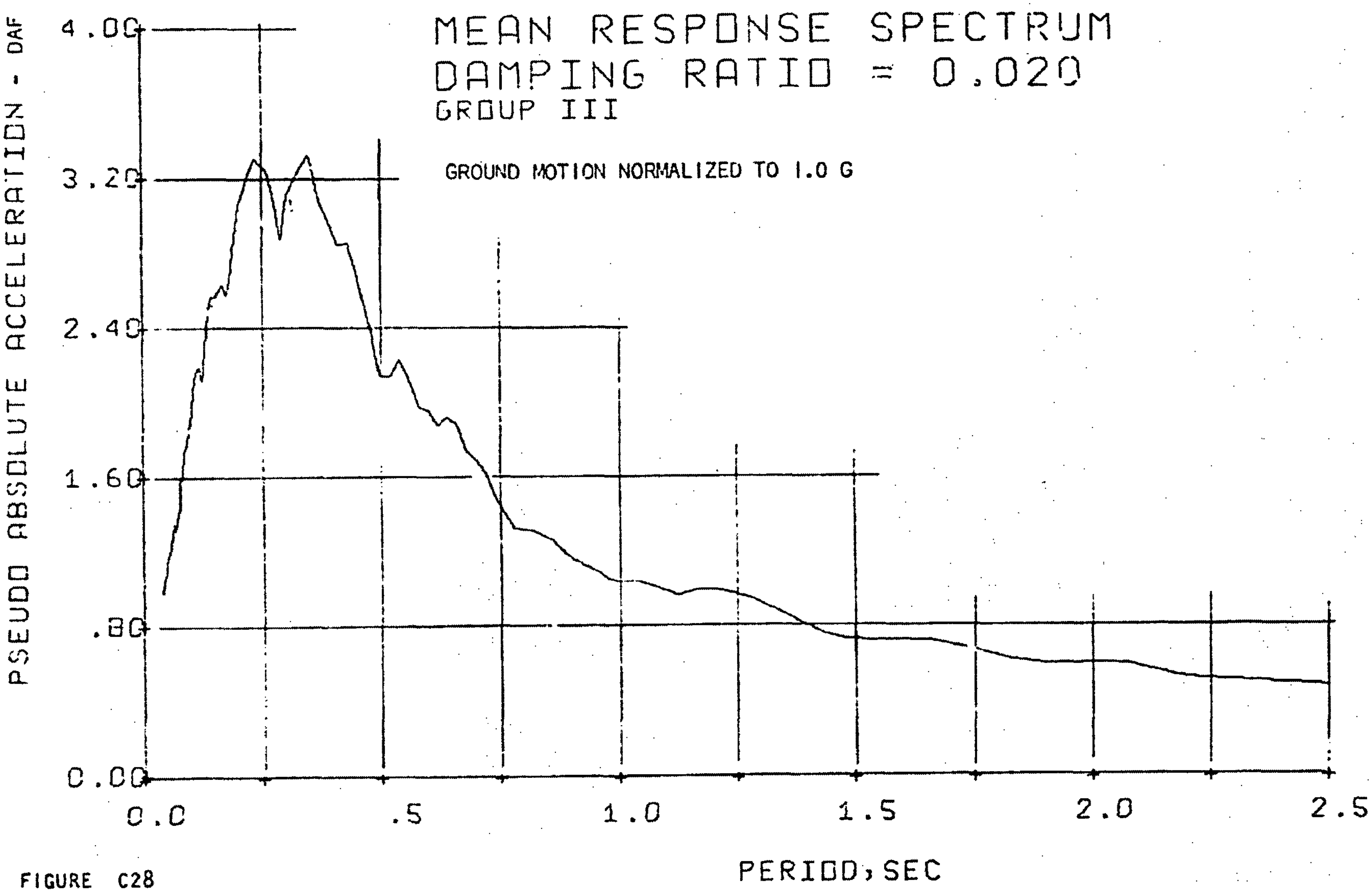

MEDIAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP II
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C26



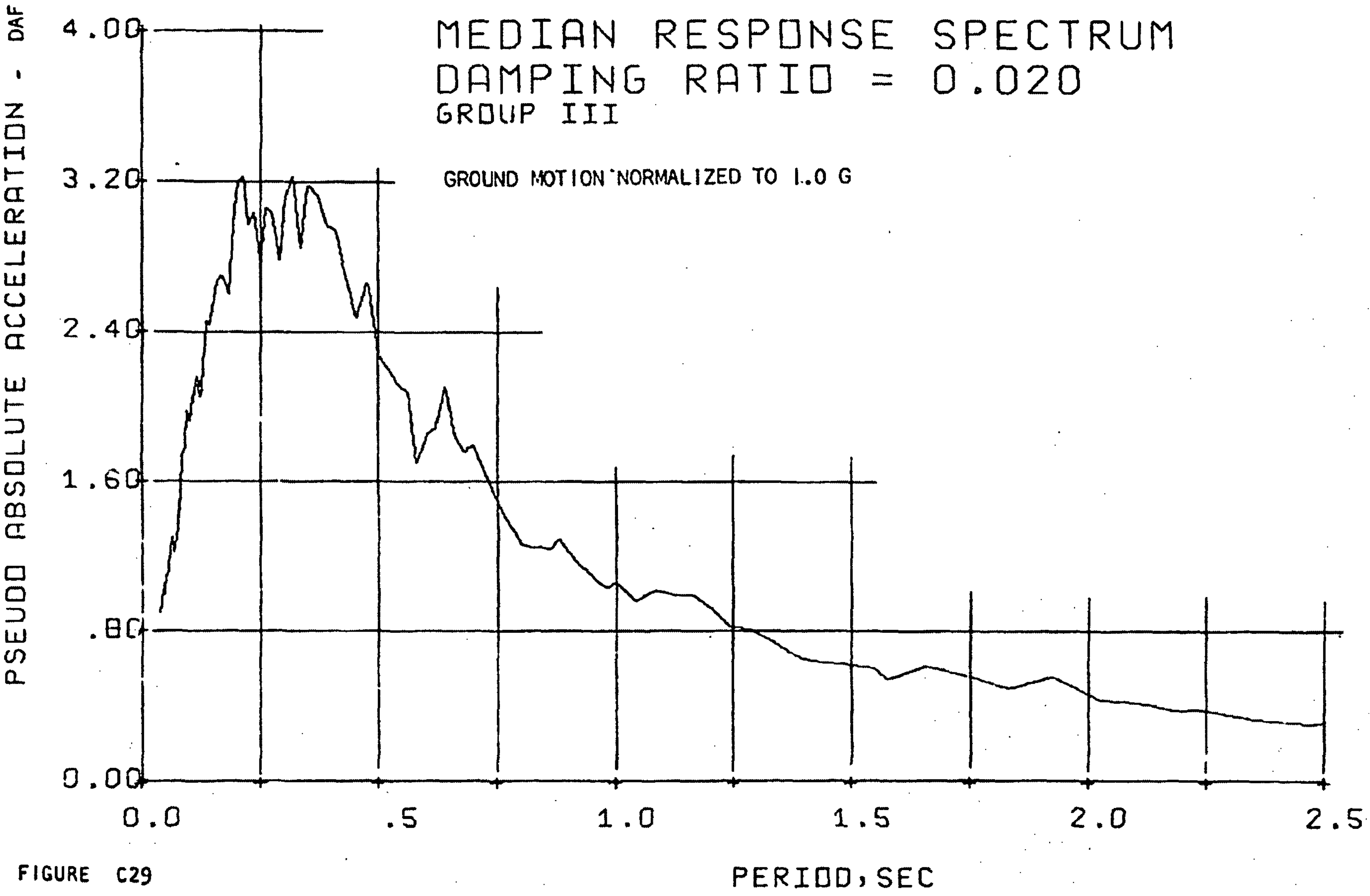
RESPONSE SPECTRUM
DAMPING RATIO = 0.020
STANDARD DEVIATION
GROUP II
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C27



MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP III
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C28



MEDIAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP III
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C29

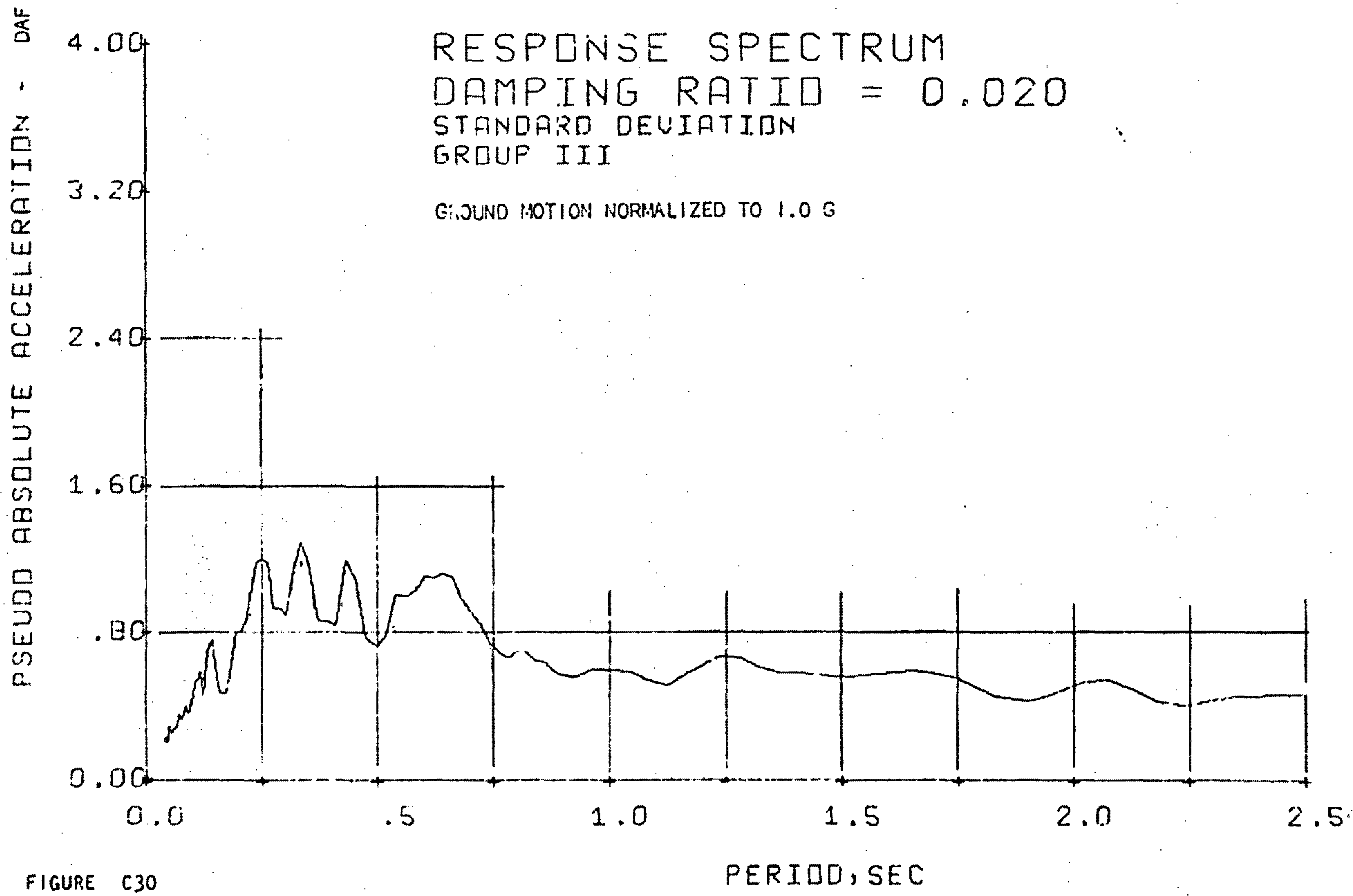

RESPONSE SPECTRUM
DAMPING RATIO = 0.020
STANDARD DEVIATION
GROUP III
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C30

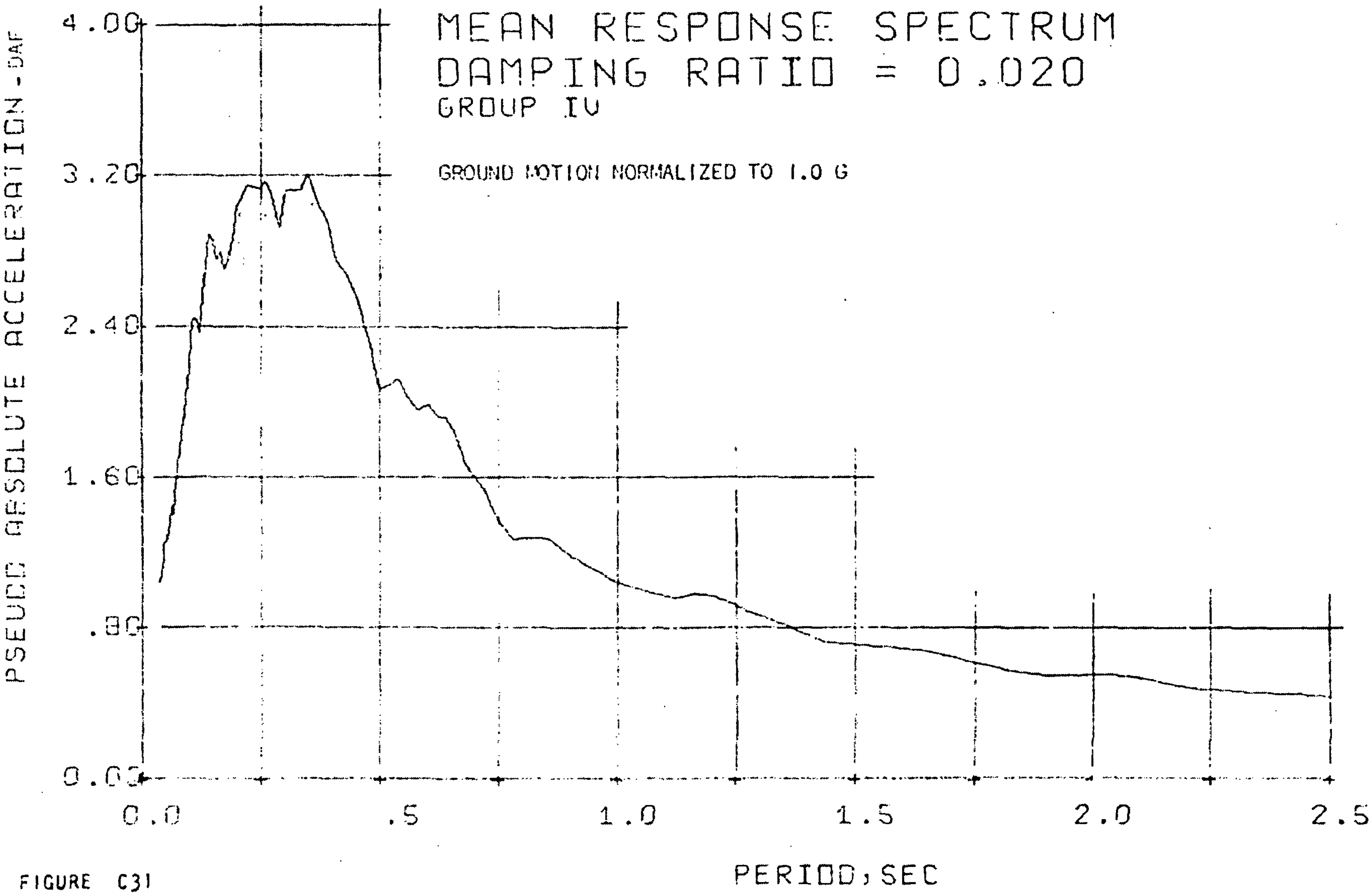

MEAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP IV
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C31

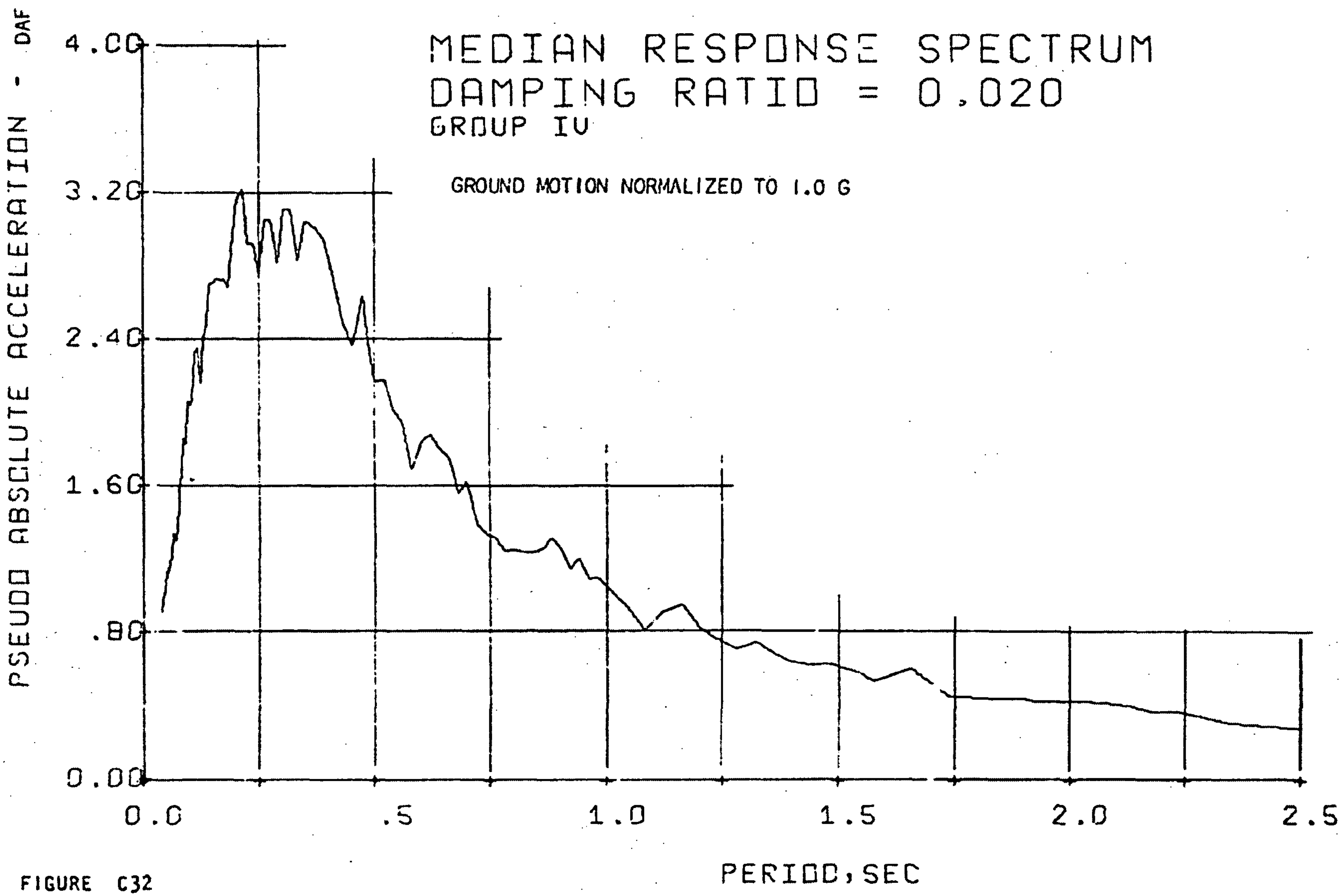
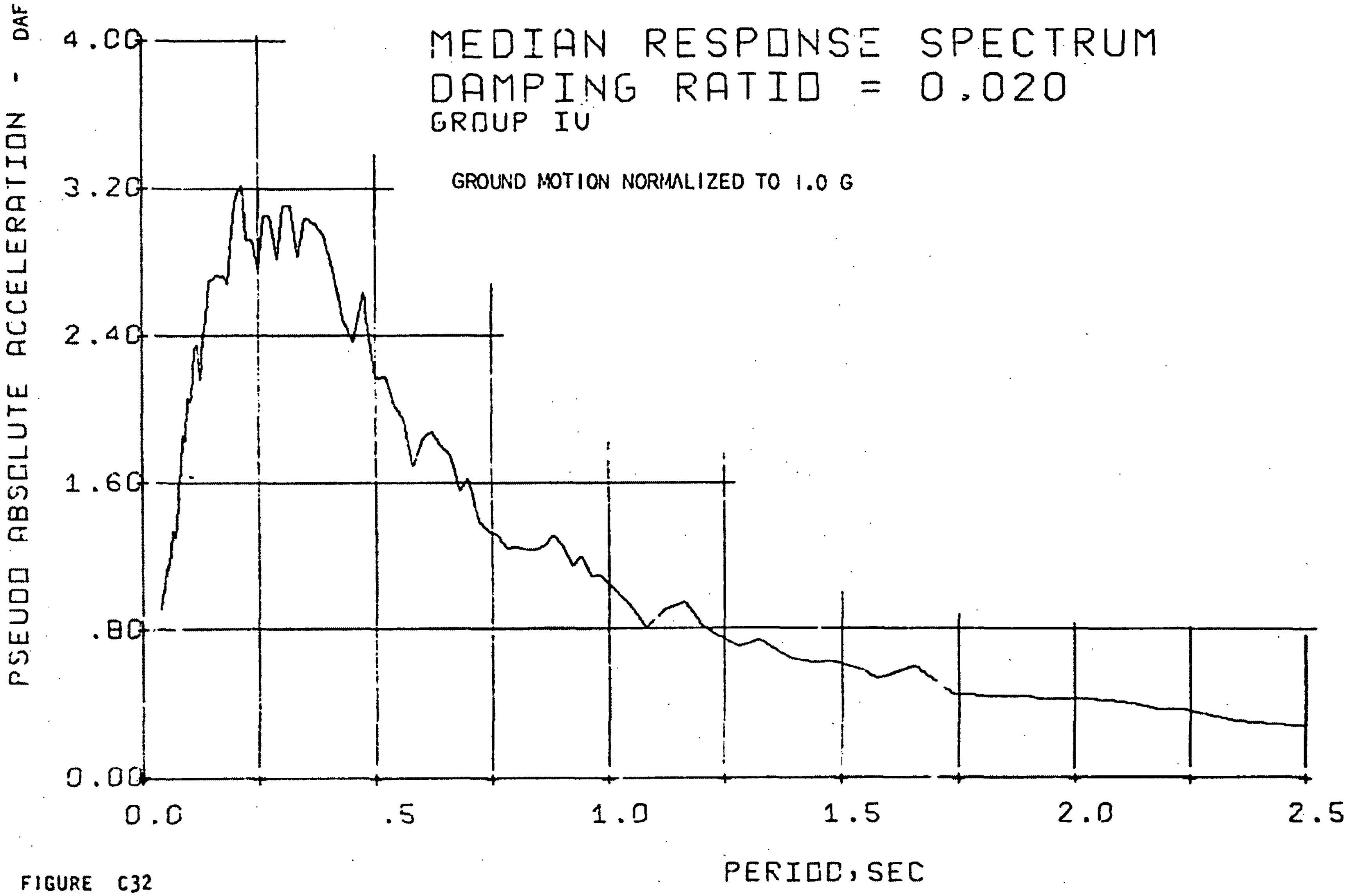

MEDIAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP IV
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

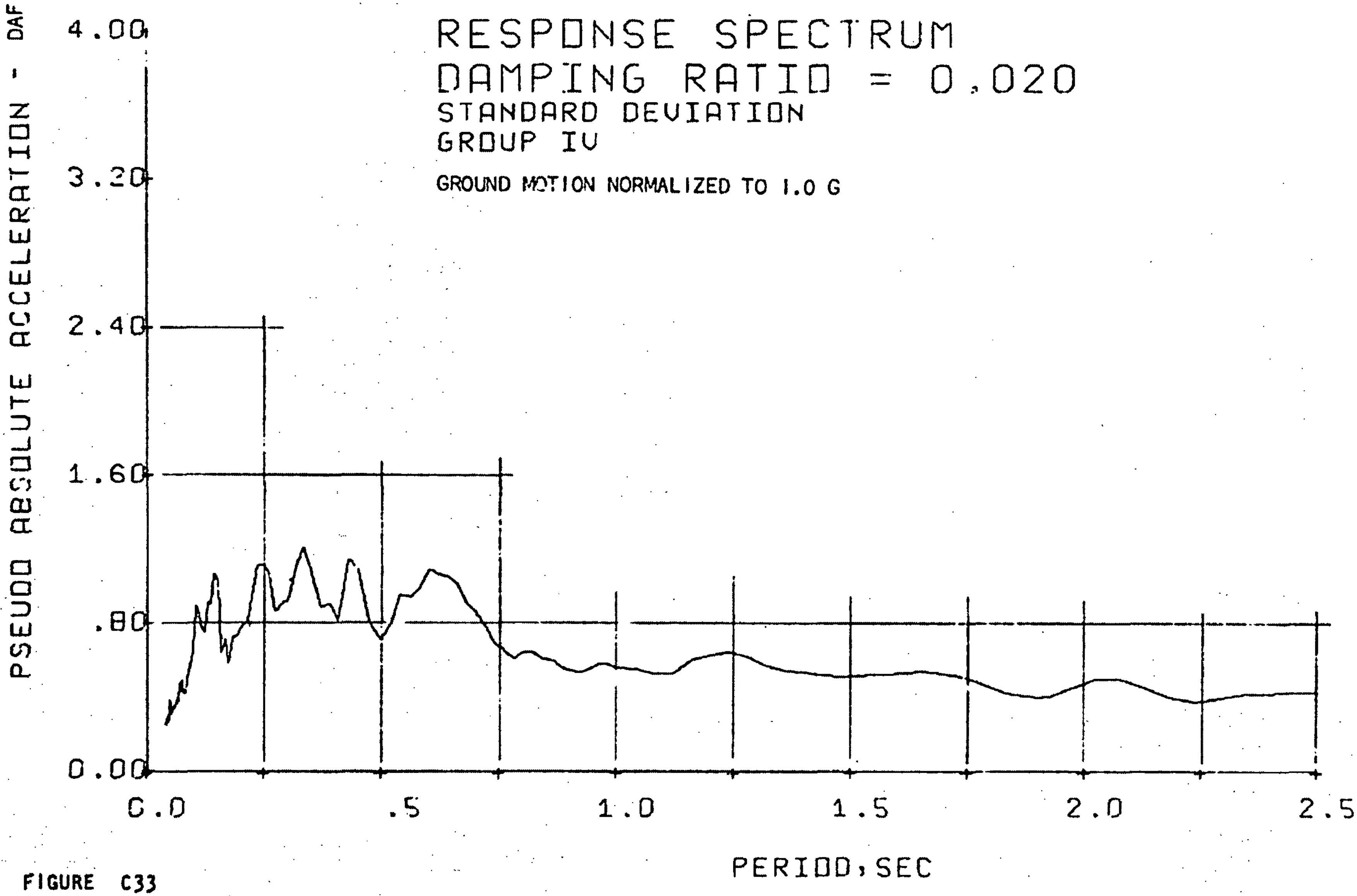
FIGURE C32



MEDIAN RESPONSE SPECTRUM
DAMPING RATIO = 0.020
GROUP IV
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C32

3.3



RESPONSE SPECTRUM
DAMPING RATIO = 0.020
STANDARD DEVIATION
GROUP IV
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
4.00
3.20
2.40
1.60
.80
0.00
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE C33

APPENDIX D

Period-Amplitude-Time (PAT) Plots

Figures D1 through D8

JOHN A. BLUME + ASSOCIATES / ENGINEERS

DAMPING RATIO = .020

PSEUDO ABS. ACCEL.

CONTOUR LEVELS

.6000E+01

.5000E+01

.4000E+01

.3000E+01

.2000E+01

.1000E+01

.6000E+00

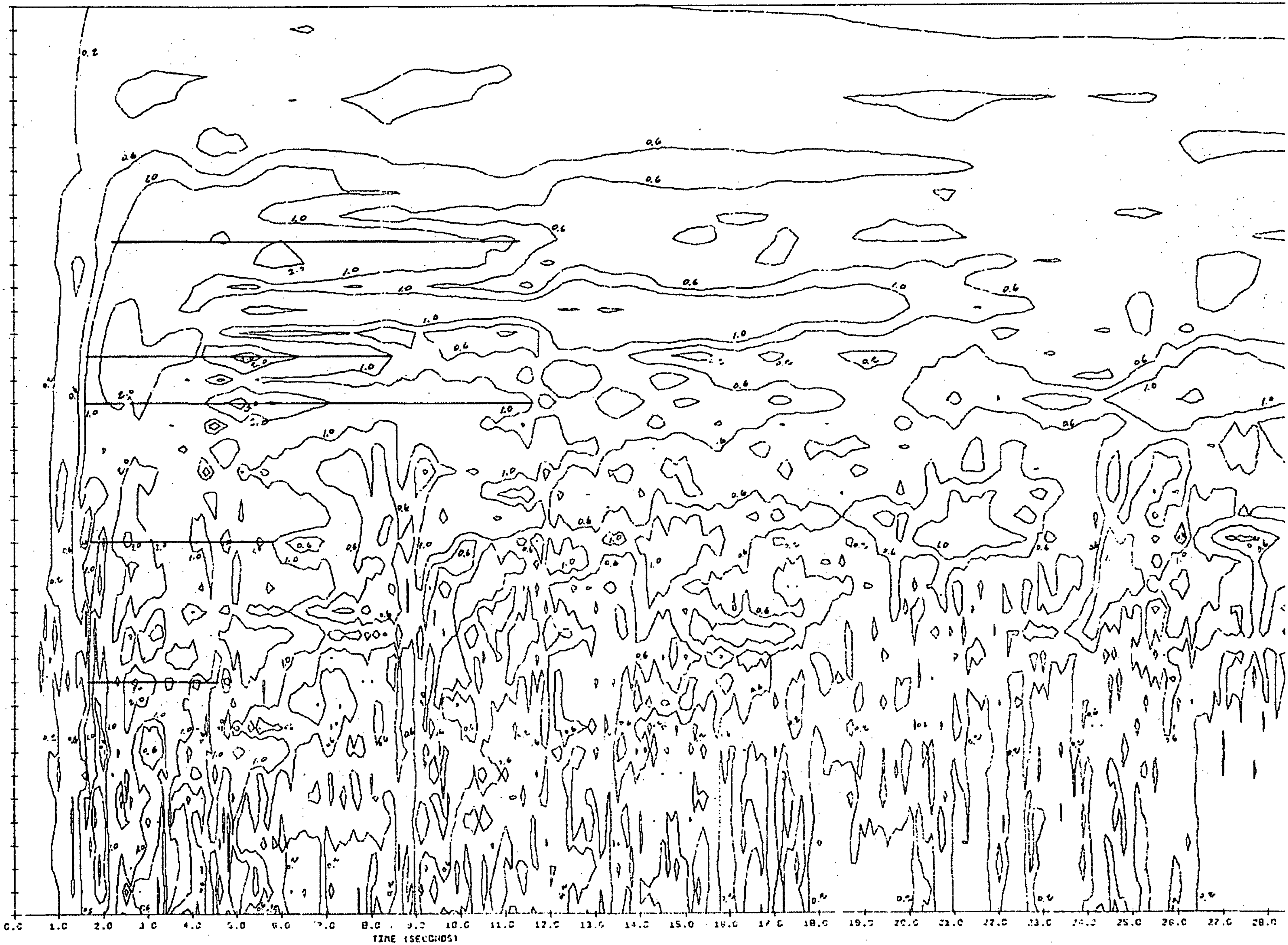
.2000E+00

RESPONSE ENVELOPE SPECTRA (RES) MAP

EL CENTRO, 1940, NS

GROUND MOTION NORMALIZED TO 1.0 G

FIGURE D1


0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 21.0 22.0 23.0 24.0 25.0 26.0 27.0 28.0
TIME (SECONDS)

JOHN A. BLUME + ASSOCIATES / ENGINEERS

DAMPING RATIO = .020

PSEUDO ABS. ACCEL.

CONTOUR LEVELS

.6000E+01

.5000E+01

.4000E+01

.3000E+01

.2000E+01

.1000E+01

.6000E+00

.2000E+00

RESPONSE ENVELOPE SPECTRA (RES) MAP

EL CENTRO, 1940, EW

GROUND MOTION NORMALIZED TO 1.0 G

FIGURE D2

FI

JOHN A. BLUME + ASSOCIATES / ENGINEERS

DAMPING RATIO = .020

PSEUDO ABS. ACCEL.

CONTOUR LEVELS

.6000E+01

.5000E+01

.4000E+01

.3000E+01

.2000E+01

.1000E+01

.6000E+00

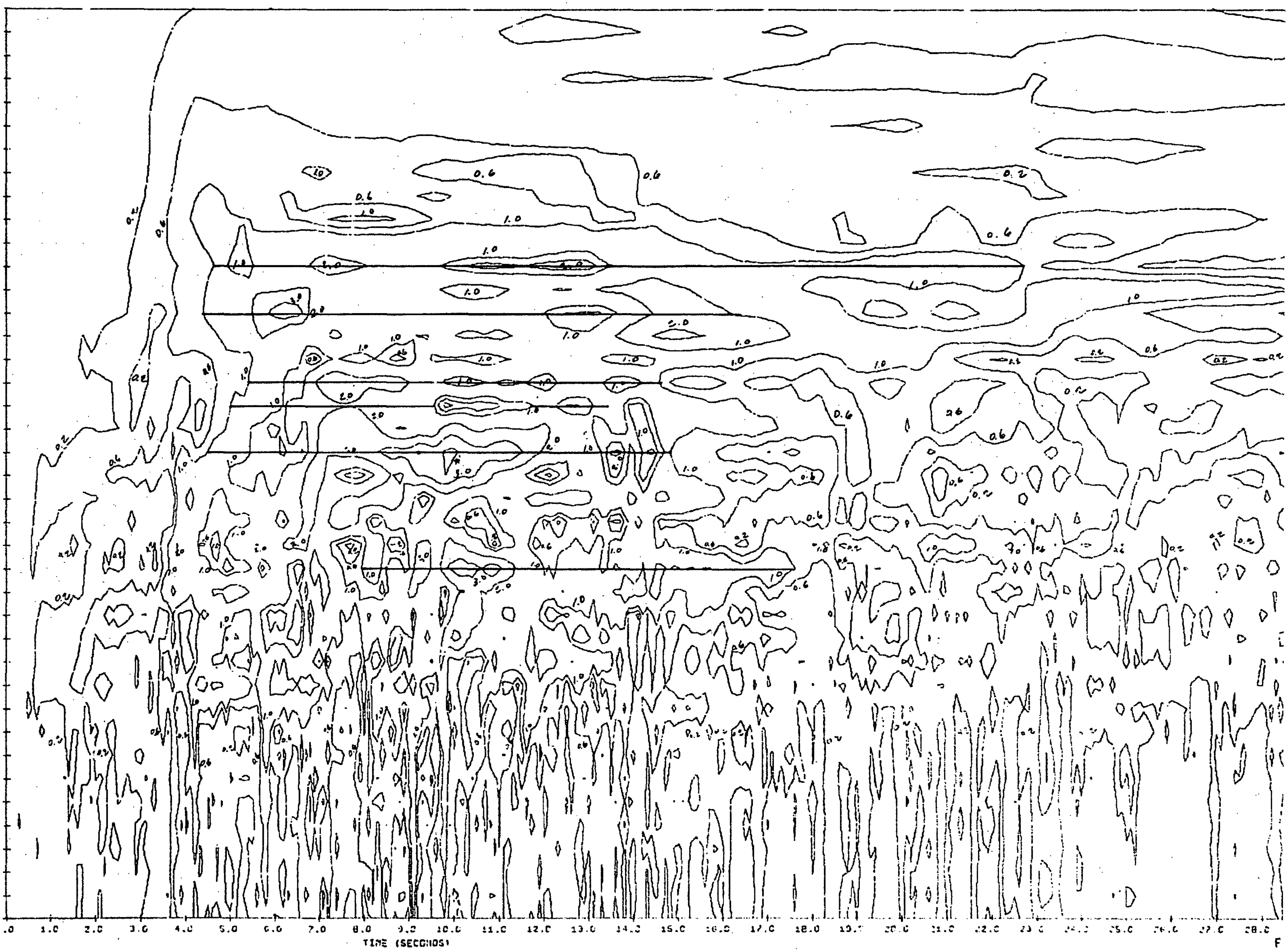
.2000E+00

RESPONSE ENVELOPE SPECTRA (RES) MAP

TAFT, 1952, N21E

GROUND MOTION NORMALIZED TO 1.0 G

FIGURE D3


.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 21.0 22.0 23.0 24.0 25.0 26.0 27.0 28.0
TIME (SECONDS)

F

JOHN A. BLUME & ASSOCIATES / ENGINEERS

DAMPING RATIO - .020

PSEUDO ABS. ACCEL.

CONTOUR LEVELS

.6000E+01

.5000E+01

.4000E+01

.3000E+01

.2000E+01

.1000E+01

.6000E+00

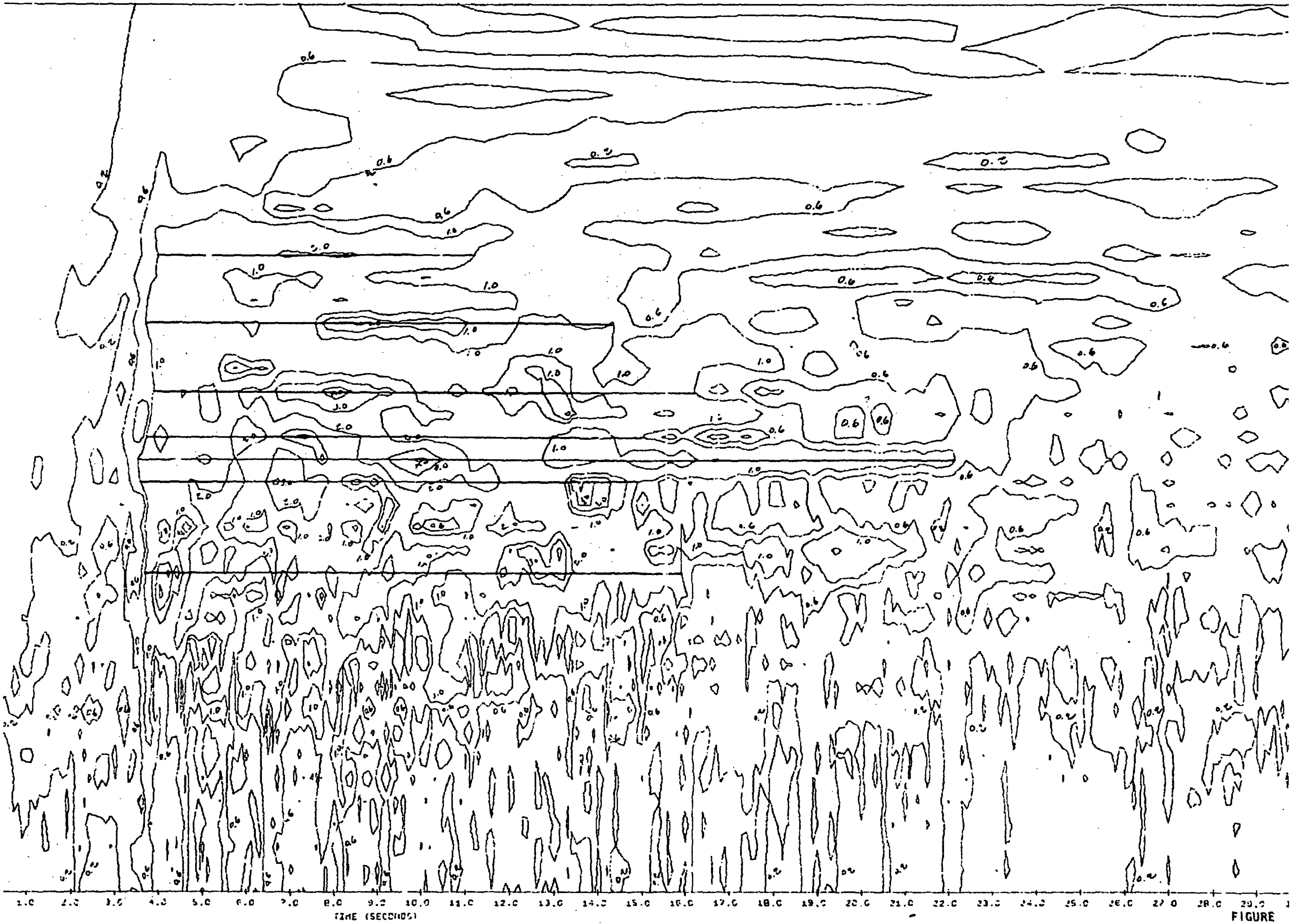
.2000E+00

RESPONSE ENVELOPE SPECTRA (RES) MAP

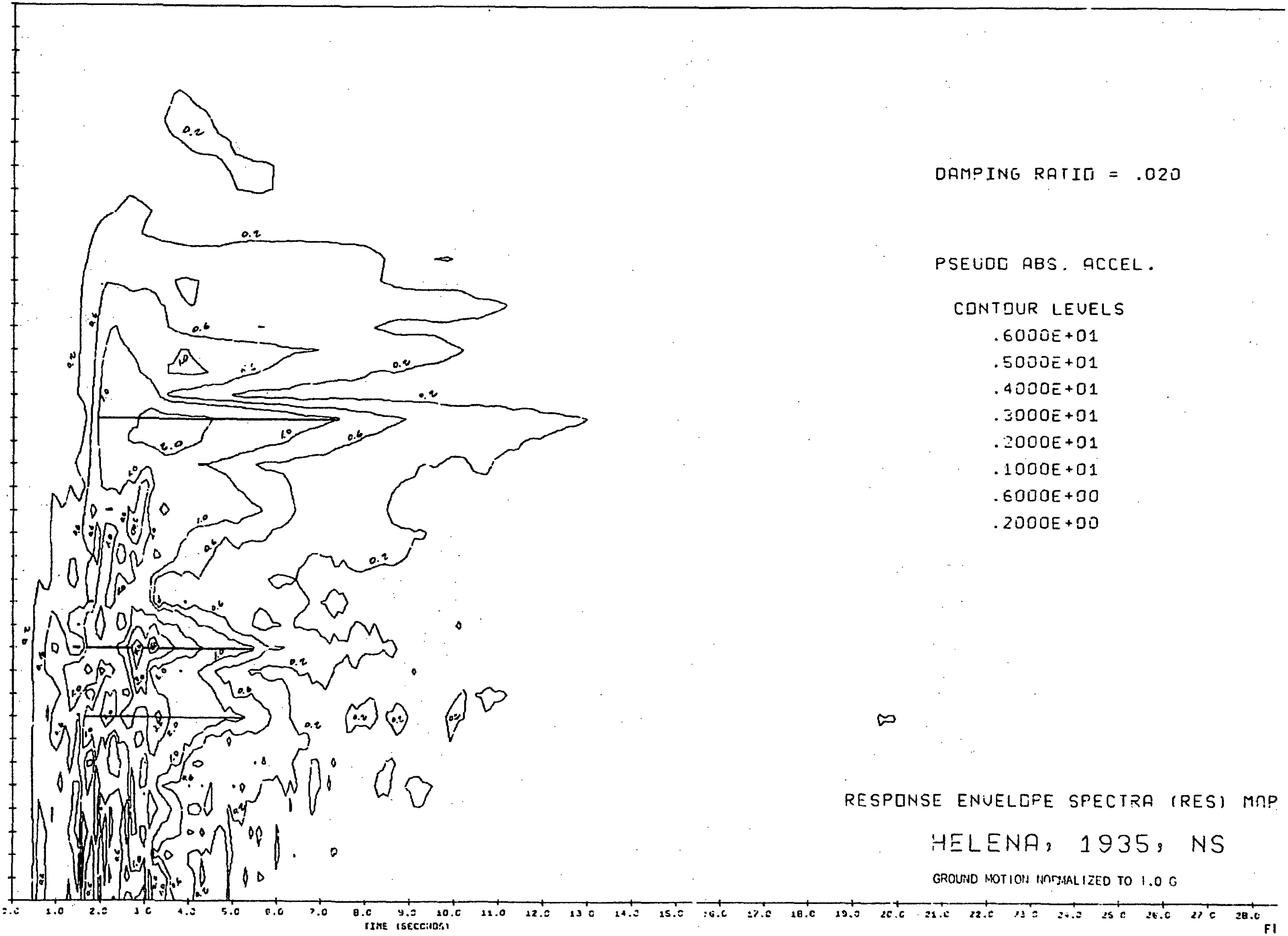
TAFT, 1952, S69E

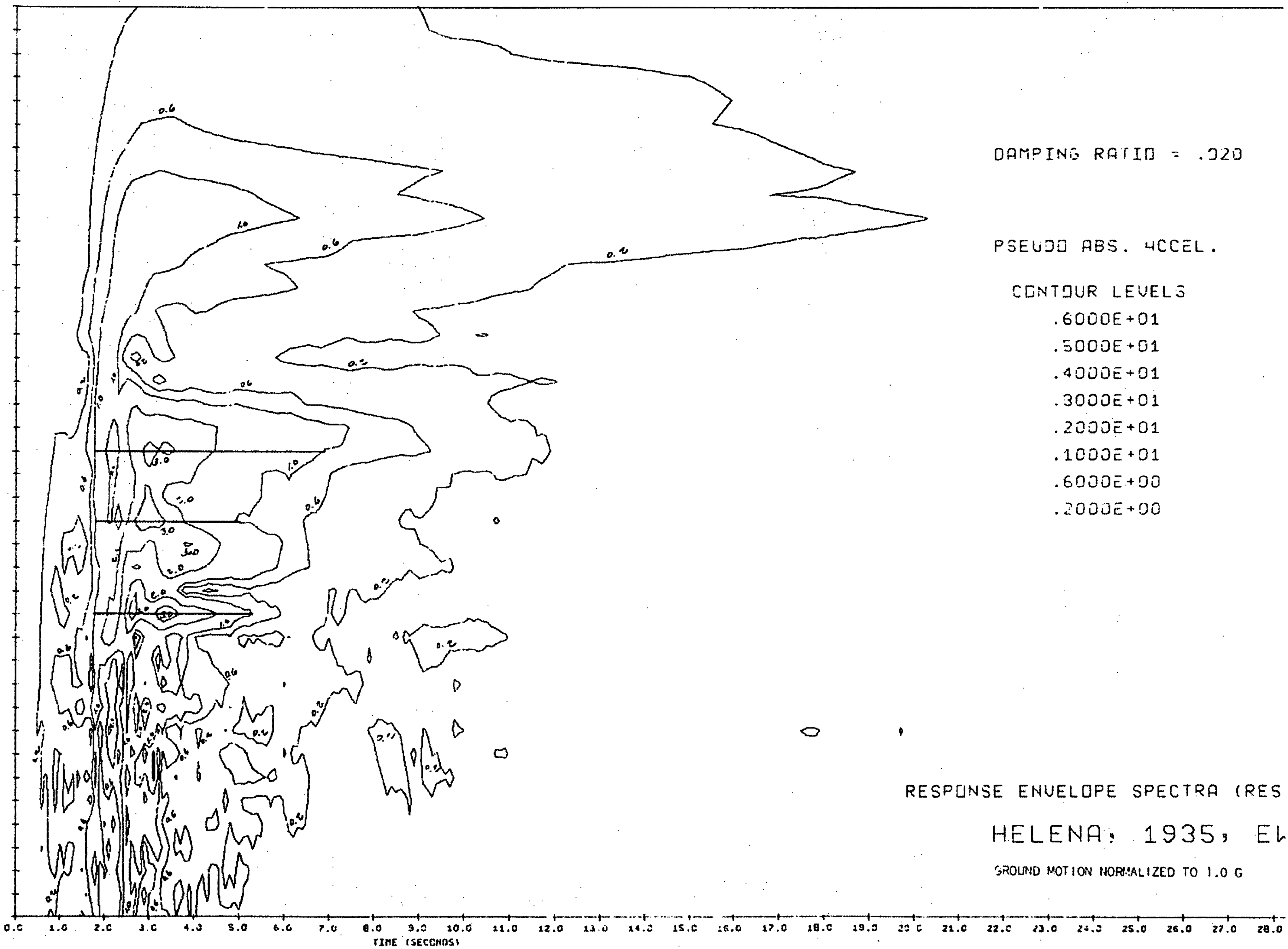
GROUND MOTION NORMALIZED TO 1.0 G

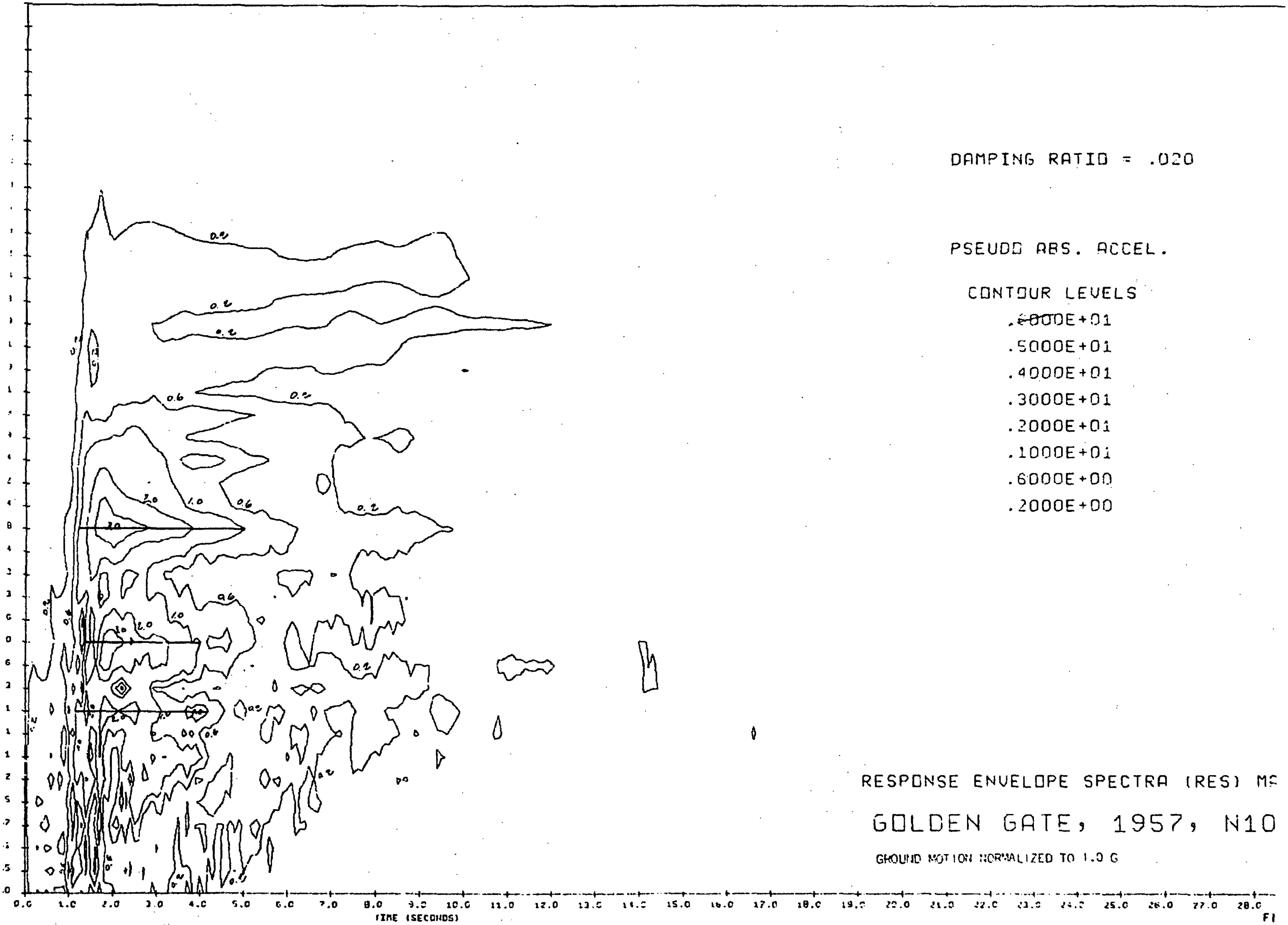
FIGURE D4

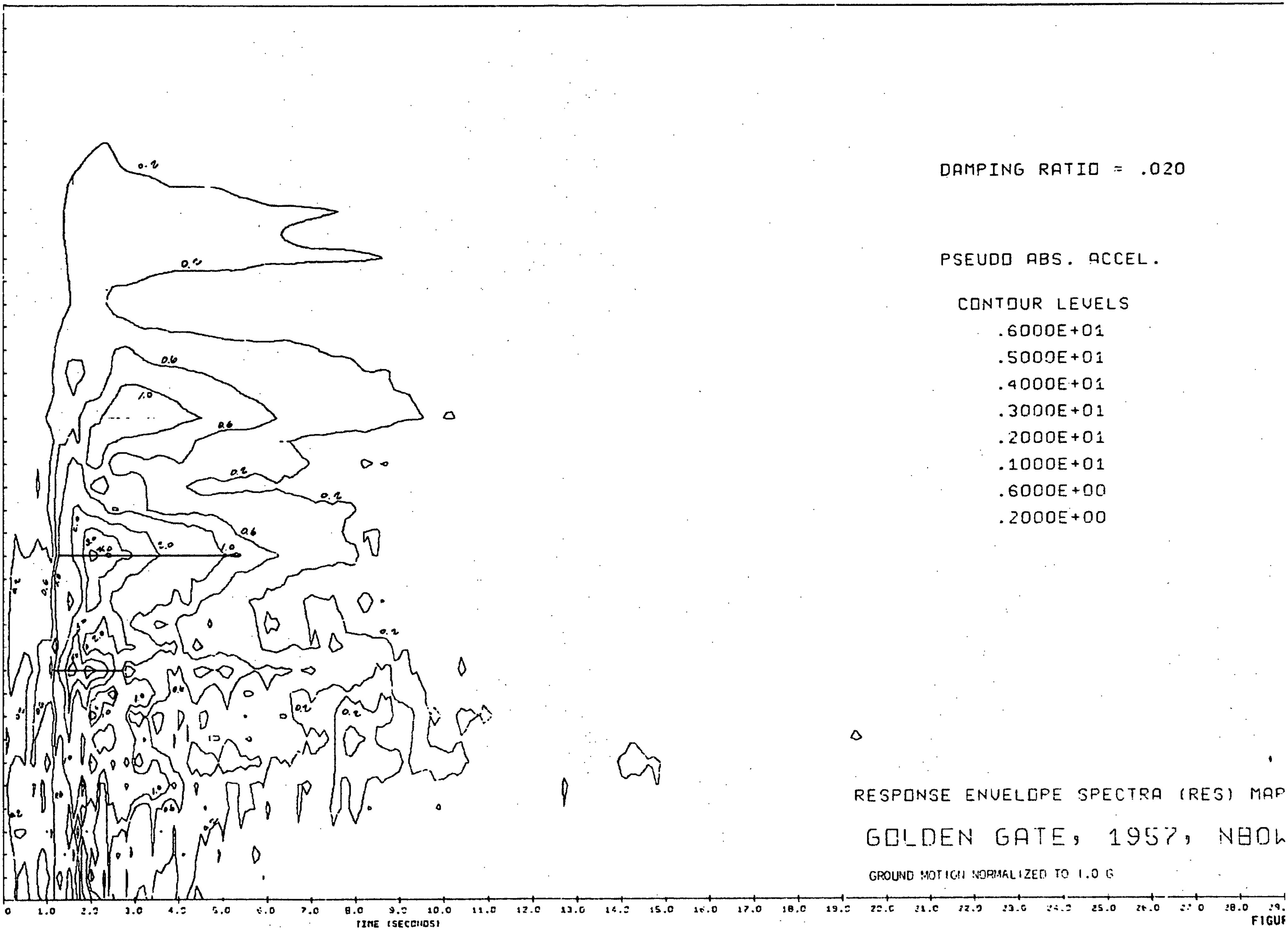


FIGURE


DAMPING RATIO = .020
PSEUDO ABS. ACCEL.
CONTOUR LEVELS
.6000E+01
.5000E+01
.4000E+01
.3000E+01
.2000E+01
.1000E+01
.6000E+00
.2000E+00
RESPONSE ENVELOPE SPECTRA (RES) MAP
HELENA, 1935, NS
GROUND MOTION NORMALIZED TO 1.0 G
TIME (SECONDS)


DAMPING RATIO = .020
PSEUDO ABS. ACCEL.
CONTOUR LEVELS
.6000E+01
.5000E+01
.4000E+01
.3000E+01
.2000E+01
.1000E+01
.6000E+00
.2000E+00
RESPONSE ENVELOPE SPECTRA (RES
HELENA, 1935, EW
GROUND MOTION NORMALIZED TO 1.0 G
TIME (SECONDS)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
24.0
25.0
26.0
27.0
28.0


DAMPING RATIO = .020
PSEUDO ABS. ACCEL.
CONTOUR LEVELS
.6000E+01
.5000E+01
.4000E+01
.3000E+01
.2000E+01
.1000E+01
.6000E+00
.2000E+00
RESPONSE ENVELOPE SPECTRA (RES) MS
GOLDEN GATE, 1957, N10
GROUND MOTION NORMALIZED TO 1.0 G
TIME (SECONDS)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
24.0
25.0
26.0
27.0
28.0
FI



DAMPING RATIO = .020
PSEUDO ABS. ACCEL.
CONTOUR LEVELS
.6000E+01
.5000E+01
.4000E+01
.3000E+01
.2000E+01
.1000E+01
.6000E+00
.2000E+00
RESPONSE ENVELOPE SPECTRA (RES) MAP
GOLDEN GATE, 1957, N80W
GROUND MOTION NORMALIZED TO 1.0 G
TIME (SECONDS)

FIGUR

APPENDIX E

Spectrum Shapes Based on Log Normal Distribution

Figures E1 through E6

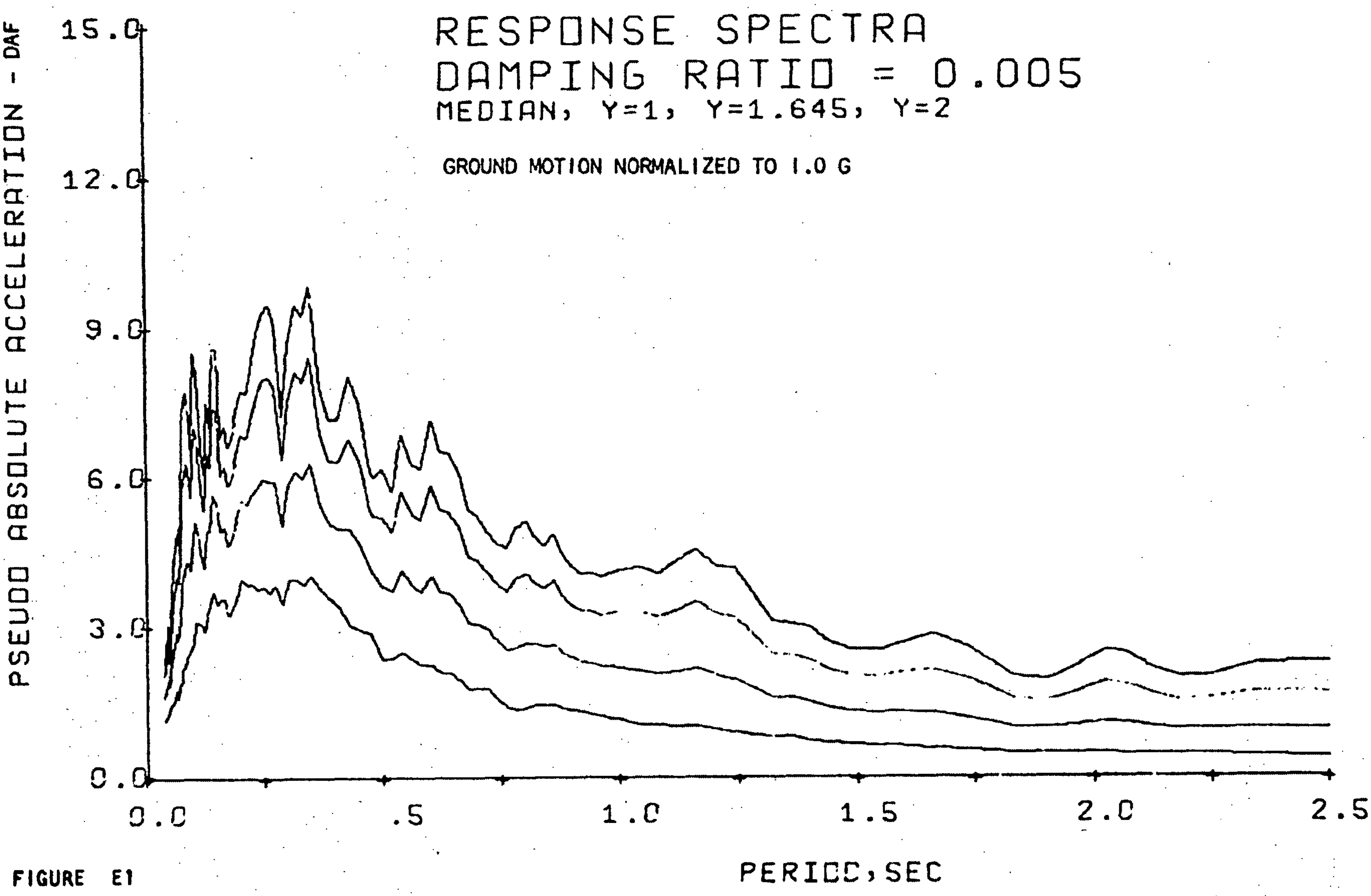

RESPONSE SPECTRA
DAMPING RATIO = 0.005
MEDIAN, Y=1, Y=1.645, Y=2
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE E1

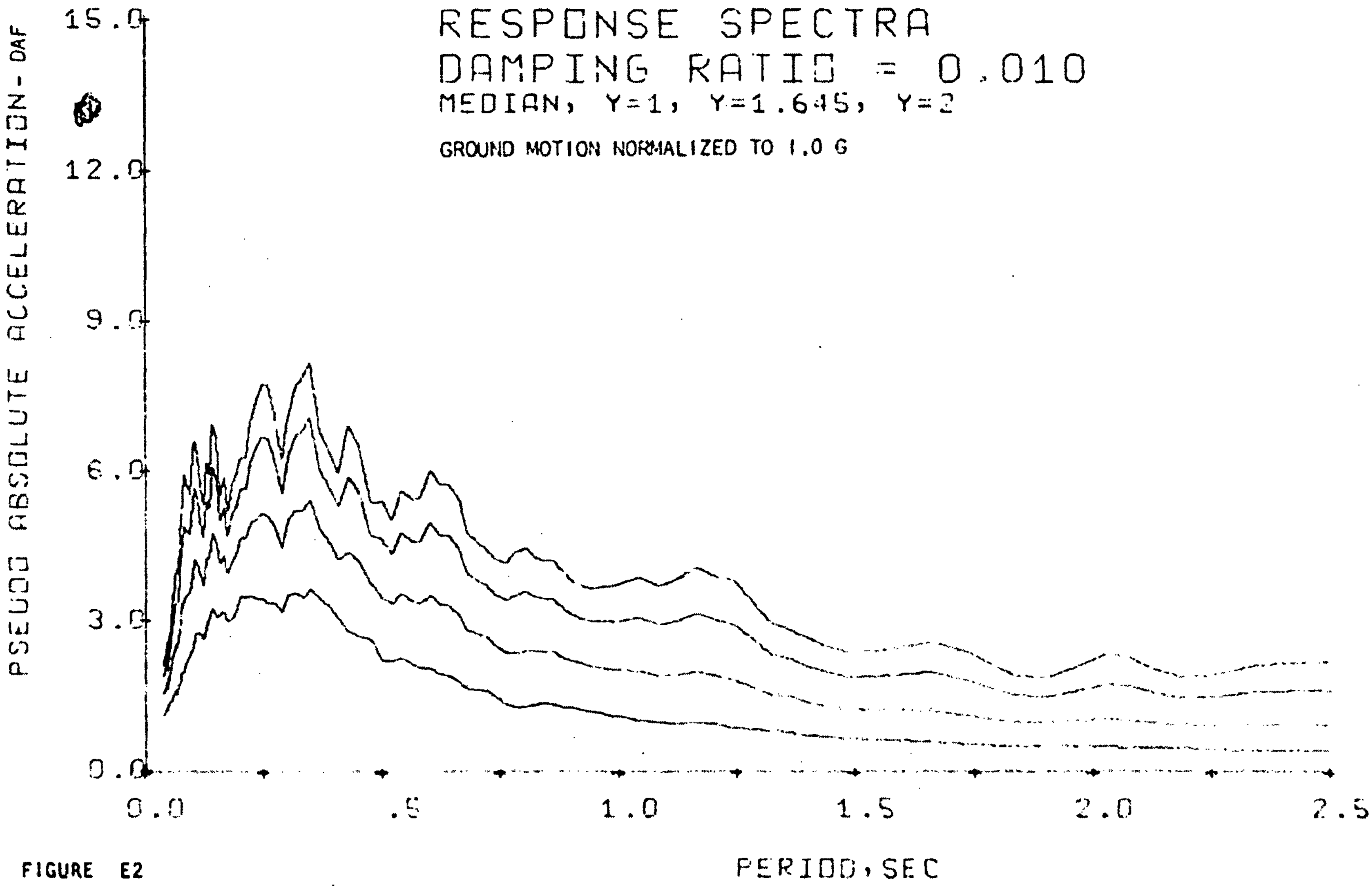

RESPONSE SPECTRA
DAMPING RATIO = 0.010
MEDIAN, Y=1, Y=1.645, Y=2
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE E2

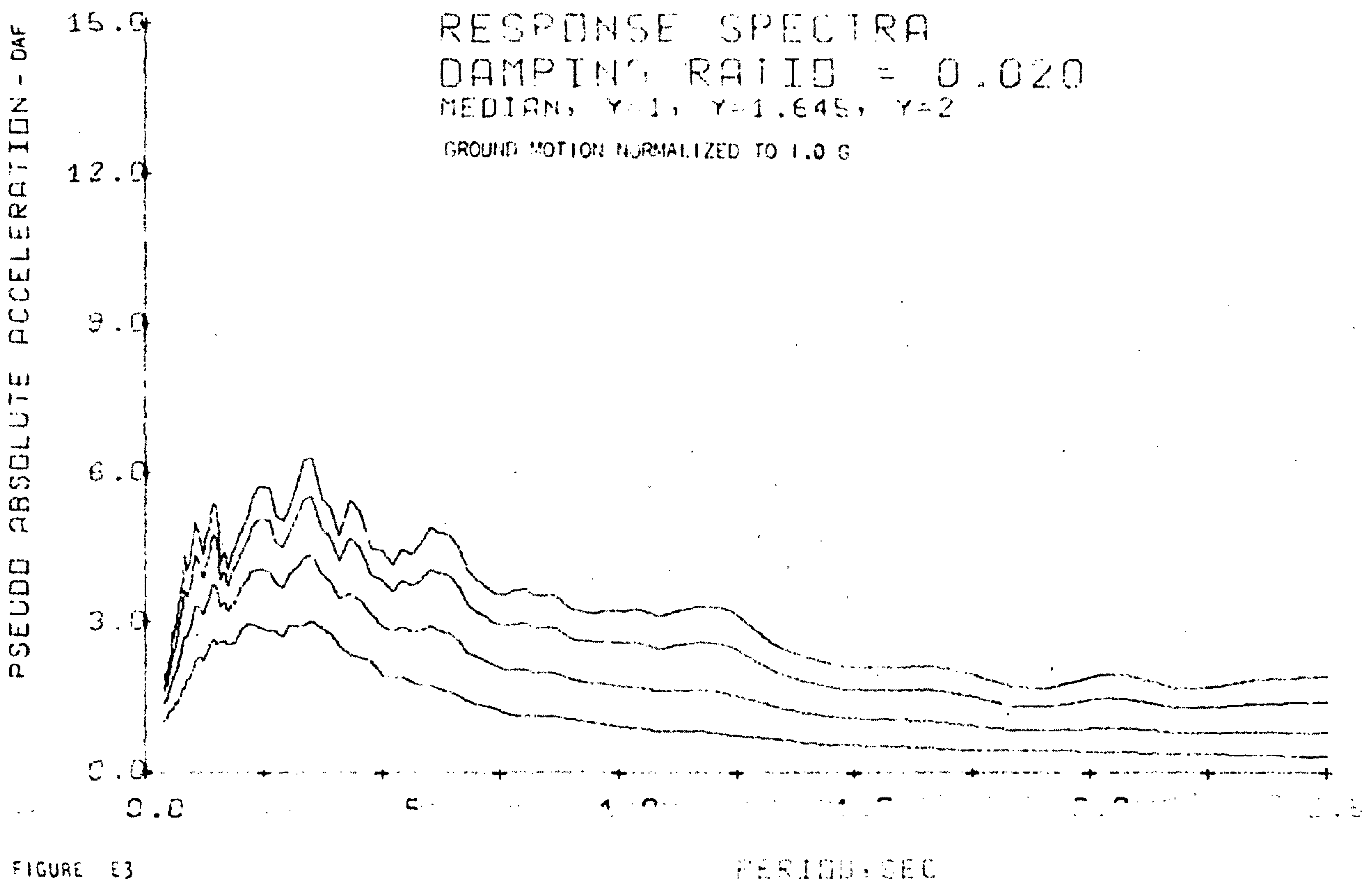

RESPONSE SPECTRA
DAMPING RATIO = 0.020
MEDIAN, Y=1, Y=1.645, Y=2
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
PERIOD, SEC

FIGURE E3

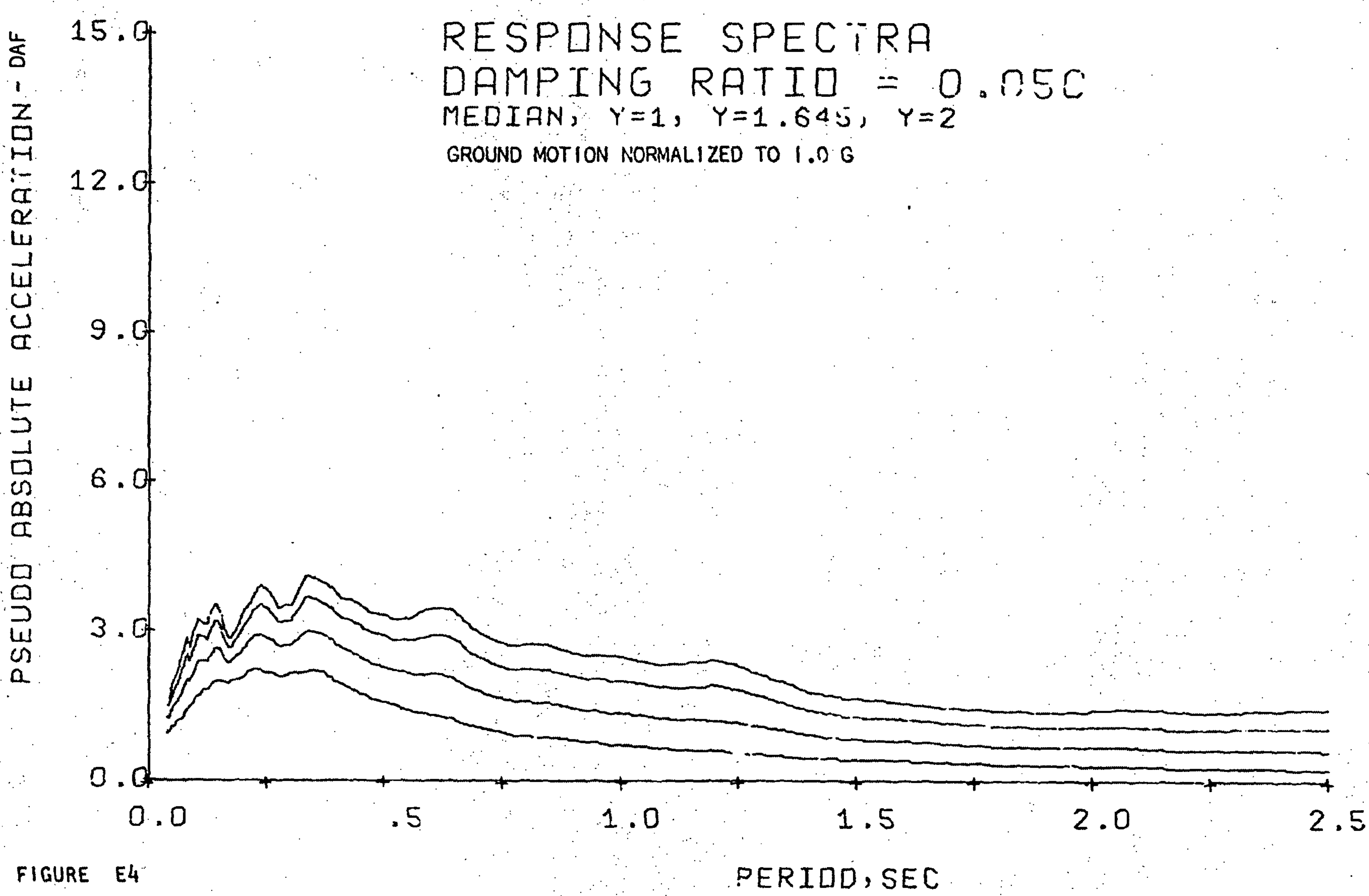

RESPONSE SPECTRA
DAMPING RATIO = 0.05C
MEDIAN, Y=1, Y=1.645, Y=2
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE E4

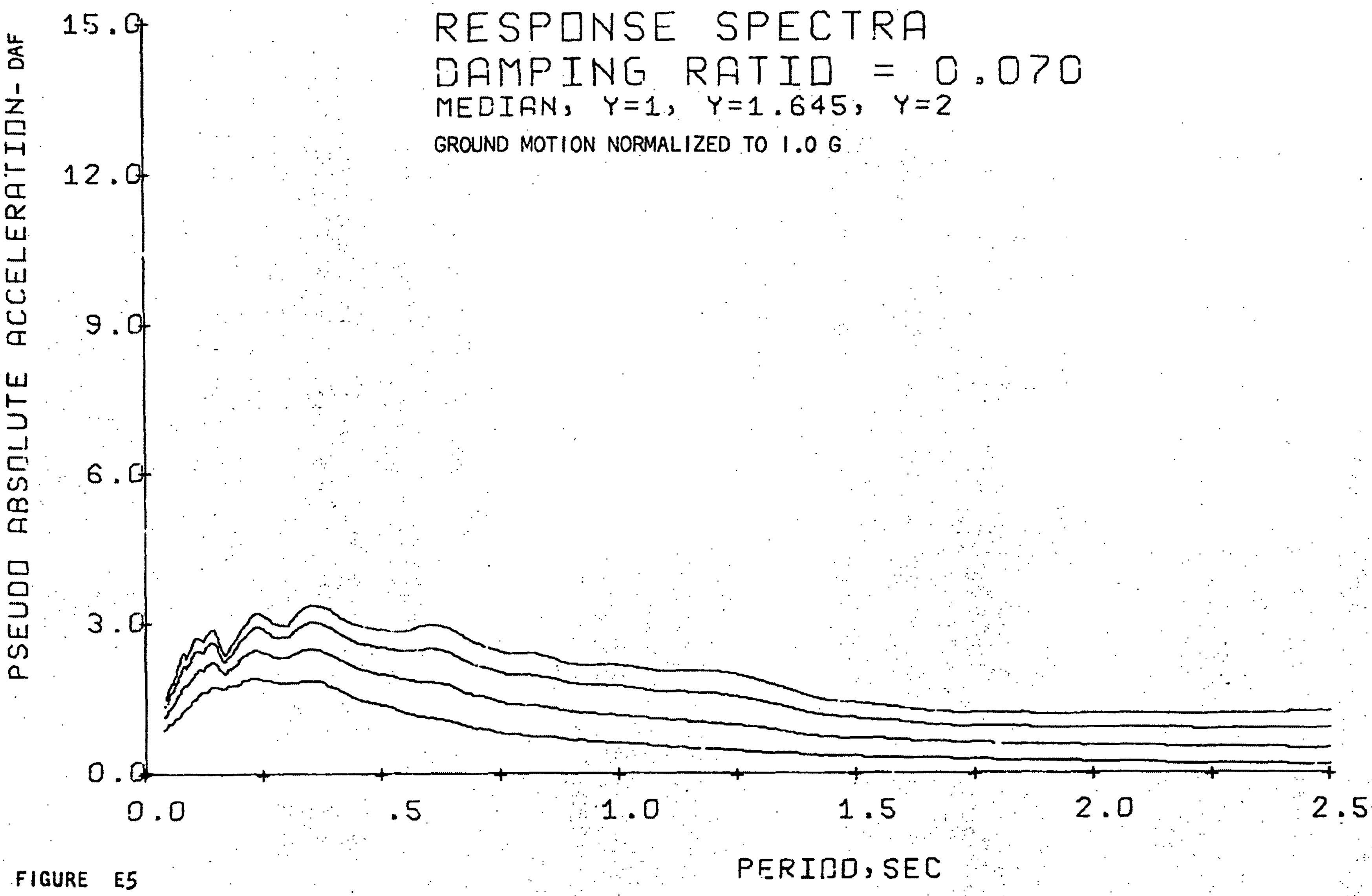

RESPONSE SPECTRA
DAMPING RATIO = 0.070
MEDIAN, Y=1, Y=1.645, Y=2
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION- DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE E5

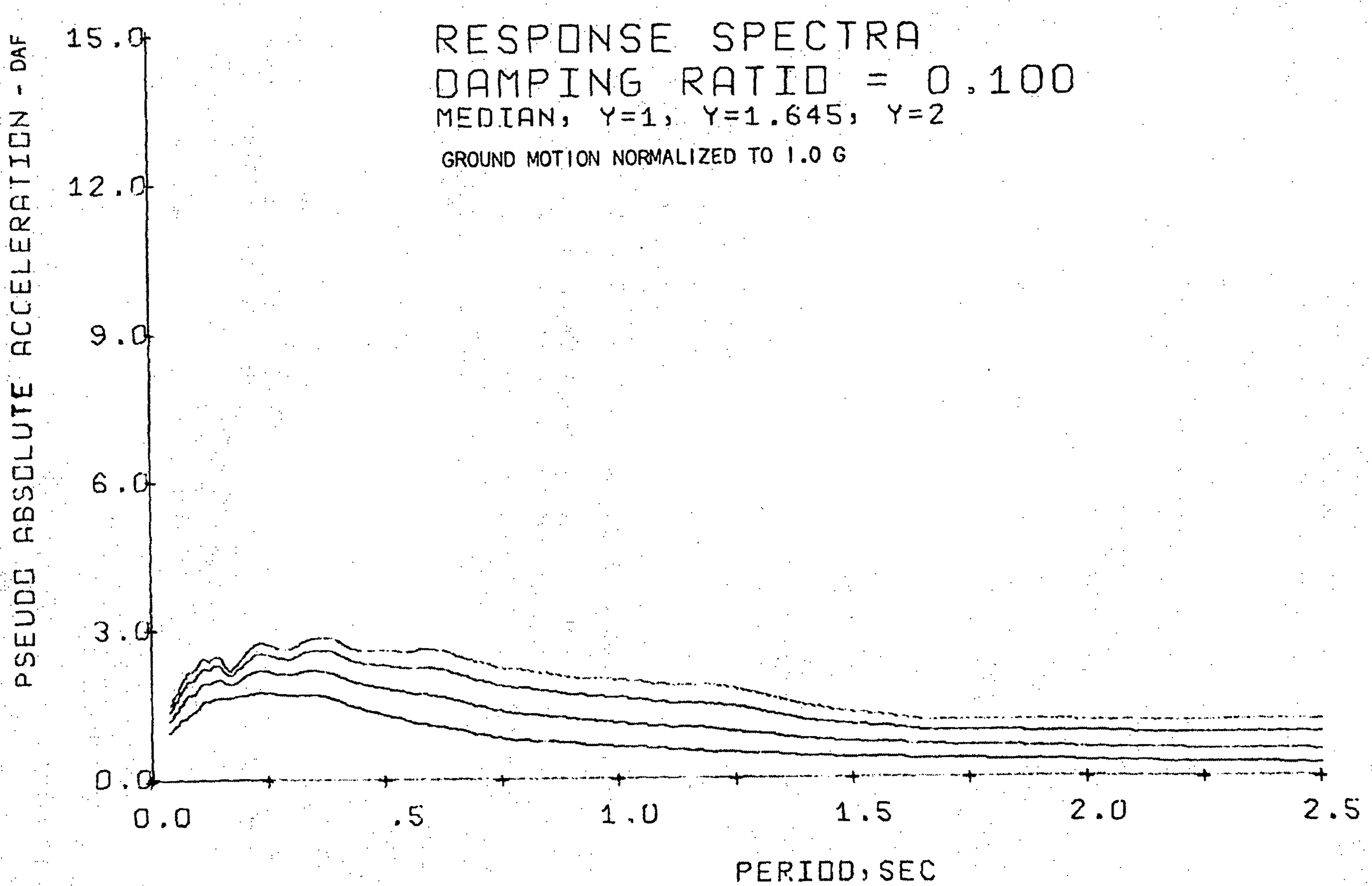

RESPONSE SPECTRA
DAMPING RATIO = 0.100
MEDIAN, Y=1, Y=1.645, Y=2
GROUND MOTION NORMALIZED TO 1.0 G
PSEUDO ABSOLUTE ACCELERATION - DAF
15.0
12.0
9.0
6.0
3.0
0.0
0.0
.5
1.0
1.5
2.0
2.5
PERIOD, SEC

FIGURE E6