UNIVERSITY OF SOUTHERN CALIFORNIA

DEPARTMENT OF CIVIL ENGINEERING

SYNTHESIZING REALISTIC GROUND MOTION ACCELEROGRAMS

by

H.L. Wong and M.D. Trifunac

Report No. CE 78-07

A Report on Research Conducted Under a Contract
from the U.S. Nuclear Regulatory Commission

Los Angeles, California

September, 1978

ABSTRACT

In this report, a method for generating artificial strong motion accelerogram for use in engineering design is presented. It utilizes characterization of strong shaking in terms of (1) earthquake magnitude and epicentral distance, or (2) Modified Mercalli Intensity at the recording station. The effects of geologic environment on the amplitudes and duration of strong shaking have been included. The resulting accelerograms have Fourier amplitude spectra and frequency dependent duration characteristics which agree with observed strong motion accelerations. The phase and group arrival times are chosen to agree with the dispersion model at the site.

INTRODUCTION

After 45 years of strong motion recording programs in the western United States, less than 200 significant strong motion accelerograms have been recorded, processed, and analyzed (Hudson, 1976). While this data represents a unique and invaluable collection for studies of strong earthquake ground motion, it does not cover all different recording conditions to represent a complete observational basis for use in engineering design. Thus, for certain engineering applications it is necessary to estimate future shaking at a site, often at the limit or outside the range of parameters for which recorded data is now available. Furthermore, considerable variability in the characteristics of recorded motion under similar conditions may require a characterization of future shaking in terms of an ensemble of accelerograms rather than just one or two "typical" records.

In many analyses of earthquake engineering, particularly those which deal with the nonlinear response of structures, the entire analysis must be performed in the time domain because the superposition techniques break down. The time records used for such analyses can be either recorded accelerograms or synthetic seismograms.

This and related requirements have created a need for the development of techniques for generation of artificial time histories that simulate realistic ground motions with different degrees of detail and from different viewpoints. In this report, we review some of the major contributions to this problem of generating artificial accelerograms and present a refinement of the method presented by Trifunac (1971b).

Apparent irregularity of early recorded accelerograms (Housner, 1947) and the limited number of records in the 1950's have led some investigators to explore the possibility of modeling strong ground shaking by means of random time functions of simple but known properties. Housner (1955), for example, assumed that an accelerogram could be modeled by a series of one-cycle sine-wave pulses; others used a series of pulses distributed randomly in time (Goodman, et. al., 1955; Hudson, 1956; Rosenblueth, 1956; Bycroft, 1960; Rosenblueth and Bustamante, 1962). On the basis of such artificial time functions of known statistical properties, it became possible to study the response of hysteretic structures (Housner and Jennings, 1964) and to design for the effects of seismic forces on the basis of probability methods (e.g., Tajimi, 1960; Goto and Kameda, 1969; Penzien and Liu, 1969).

With the increasing number of recorded accelerograms in the 1950's and early 1960's, however, it became clear (Bolotin, 1960) that the nonstationarity of ground motion can influence structural response significantly. This prompted the development of methods for construction of artificial accelerograms using nonstationary random time series analysis (e.g., Bogdanoff, et. al., 1961; Cornell, 1964; Amin and Ang, 1966; Goto, et. al., 1966; Shinozuka and Sato, 1967; Jennings, et. al., 1968; Goto and Toki, 1969). The nonstationarity in these models was achieved typically by (a) multiplying stationary random time series by a nonstationary envelope function, by (b) changing the frequency content of artificial accelerograms as a function of time, and by (c) superimposing simple earthquake sources with some phase delay in time (e.g., Rascon and Cornell, 1969) to represent propagation of a simple earthquake source (e.g., Honda, 1957) by means of radiated P and S waves only.

Recent observational studies of strong ground motion have shown that a typical strong motion record consists of near-field, intermediate field, body waves and surface waves contributing different amounts to the total result; depending on the earthquake source mechanism and on the wave path (e.g., Trifunac, 1971a; Trifunac, 1972a,b; Trifunac, 1973). Empirical studies of spectral characteristics (Trifunac, 1976, 1978) and frequency dependent duration (Trifunac and Westermo, 1976a,b) have further shown the dependence on the geologic environment of the recording station. Consequently, realistic artificial accelerograms should have nonstationary frequency, amplitude and duration characteristics that agree with the trends which are present in the recorded accelerograms.

While choosing a suitable accelerogram for a particular analysis, many factors must be taken into account. For example, the characteristics of an accelerogram depend on the distance between the source and the site, some measure of the size of the earthquake, and also the geology surrounding the site. The recorded seismograms cannot be modified in a simple way to satisfy the requirements at all sites and thus site dependent artificial accelerograms are needed.

The majority of the proposed methods for the generation of synthetic accelerograms fall into two categories: (1) methods that utilize random functions, and (2) methods that involve source mechanism and wave propagation models. Using the former methods, the resulting accelerograms do not always have a correct frequency content for engineering applications and the frequency characteristics of the time record are often uniform from beginning to the end of the record. For a recorded accelerogram, the frequency contained in the earlier part is generally higher. Using the latter methods, a more physically consistent record can be generated, but it is impossible to model all the details of the source as well as the wave path adequately for the complete frequency range of interest (e.g., 0.05 Hz to 30Hz). Because of the simplifications, the records generated often lack proper physical high frequency characteristics when compared with recorded accelerograms.

This report presents a method for constructing synthetic accelerograms which have a given Fourier amplitude spectrum, $F(\omega)$, and a given duration. The Fourier amplitude spectrum and the duration can be obtained from correlation with earthquake parameters. The times of arrival of the waves are derived from the dispersive properties of the site; i.e., the phase and group velocities for the lowest modes of surface waves. This method thus introduces the characteristics of each site into the resulting artificial accelerogram.

THEORETICAL BASIS

To construct an accelerogram from time independent quantities such as a Fourier amplitude spectrum, it is first necessary to understand the processes by which these quantities are obtained in the recorded accelerograms. It is from this understanding that one can better determine what information is modified by the forward mapping and hence, what needs to be restored. Most empirical scaling procedures neglect the phase of the spectrum since a correlation involving the phase of the Fourier transform is equivalent in difficulty to correlating the time histories themselves. Instead, just the modulus of the Fourier transform (a typical example is shown in Figure 1) is typically correlated with pertinent scaling parameters. These correlations may take many different forms depending on which parameters are used to characterize strong ground motion (Trifunac, 1976, 1978).

To describe the method presented in this report, we begin by considering a group of harmonic waves having a Fourier transform of the form

$$F_1(\omega) = \begin{cases} c_1 e^{-i(\omega-\omega_n)t_1^* + i\phi_1} & \text{for } \omega_n - \Delta\omega \le \omega \le \omega_n + \Delta\omega, \\ c_1 e^{-i(\omega+\omega_n)t_1^* - i\phi_1} & \text{for } -\omega_n - \Delta\omega \le \omega \le -\omega_n + \Delta\omega, \\ 0 & \text{otherwise} \quad . \end{cases} \qquad (1)$$

$|F_1(\omega)|$ has a constant amplitude, c_1 and its wave form in the time domain is

$$f_1(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F_1(\omega) e^{i\omega t} d\omega = Q_1(t)\cos(\omega_n t + \phi_1) \quad , \qquad (2)$$

in which $Q_1(t)$ is an envelope function

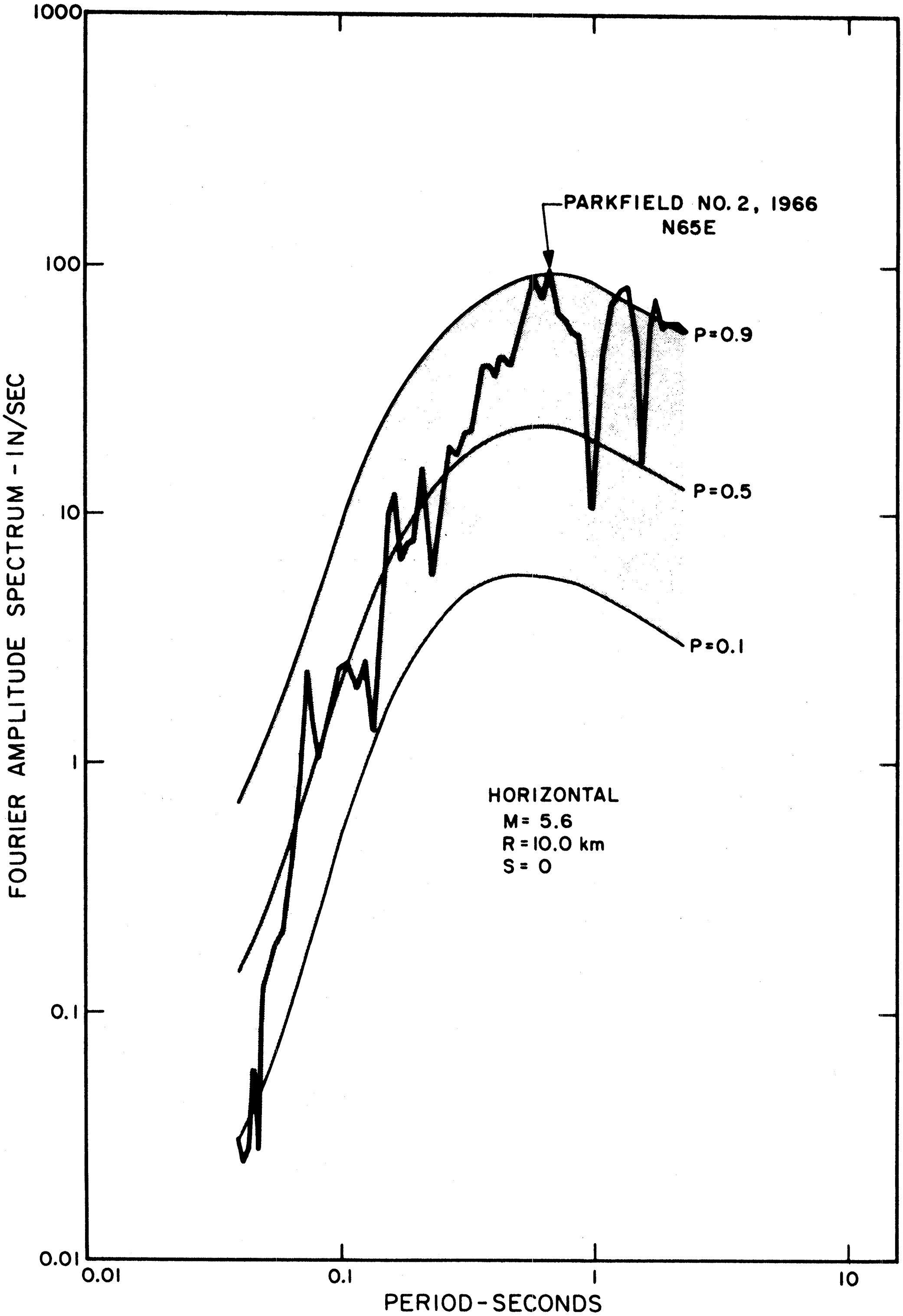


Figure 1

Fourier amplitude spectrum for N65E component of strong motion acceleration recorded during Parkfield, California, earthquake of 1966. Average (p=0.5) and the 80% confidence interval (between p=0.1 and 0.9) for Fourier amplitude spectra for M = 5.6, epicentral distance, R = 10 km and alluvium site condition (s=0) after Trifunac (1976) are also shown.

$$Q_1(t) = \frac{2c_1}{\pi} \frac{\sin\Delta\omega(t-t_1^*)}{(t-t_1^*)} \quad . \tag{3}$$

The function $Q_1(t)$ has its maximum at $t=t_1^*$, and it decreases as $|t-t_1^*|$ increases. A simple illustration of $f_1(t)$ is shown in Figure 2 (top). The quantity t_1^* can be viewed here as the arrival time for the wave group $f_1(t)$.

Consider now a second group of waves (Figure 2, middle)

$$f_2(t) = \frac{2c_2}{\pi} \frac{\sin\Delta\omega(t-t_2^*)}{(t-t_2^*)} \cos(\omega_n t + \phi_2) \quad . \tag{4}$$

It has a constant Fourier amplitude $|F_2(\omega)|$ of c_2 over the same frequency band as $f_1(t)$, i.e.,

$$F_2(\omega) = \begin{cases} c_2 e^{-i(\omega-\omega_n)t_2^* + i\phi_2} & \text{for } \omega_n - \Delta\omega \le \omega \le \omega_n + \Delta\omega \\ c_2 e^{-i(\omega+\omega_n)t_2^* - i\phi_2} & \text{for } -\omega_n - \Delta\omega \le \omega \le -\omega_n + \Delta\omega \\ 0 & \text{otherwise} \quad . \end{cases} \tag{5}$$

When these two groups of waves are superimposed as

$$g(t) = f_1(t) + f_2(t) \quad , \tag{6}$$

the Fourier amplitude of $g(t)$ is no longer constant, and becomes

$$|G(\omega)| = |F_1(\omega) + F_2(\omega)| = \sqrt{c_1^2 + c_2^2 + 2c_1c_2\cos[(\omega-\omega_n)(t_1-t_2) + (\phi_2-\phi_1)]} \quad , \tag{7}$$

a function of ω over the interval, $\omega_n - \Delta\omega \le |\omega| \le \omega_n + \Delta\omega$. The examples of the functions $g(t)$ and $|G(\omega)|$ are plotted in Figure 2 (bottom).

The oscillatory characteristics of $|G(\omega)|$ about its mean are such that the amplitude is controlled by the difference in amplitudes of c_1 and c_2 and the rate of oscillation is controlled by the difference

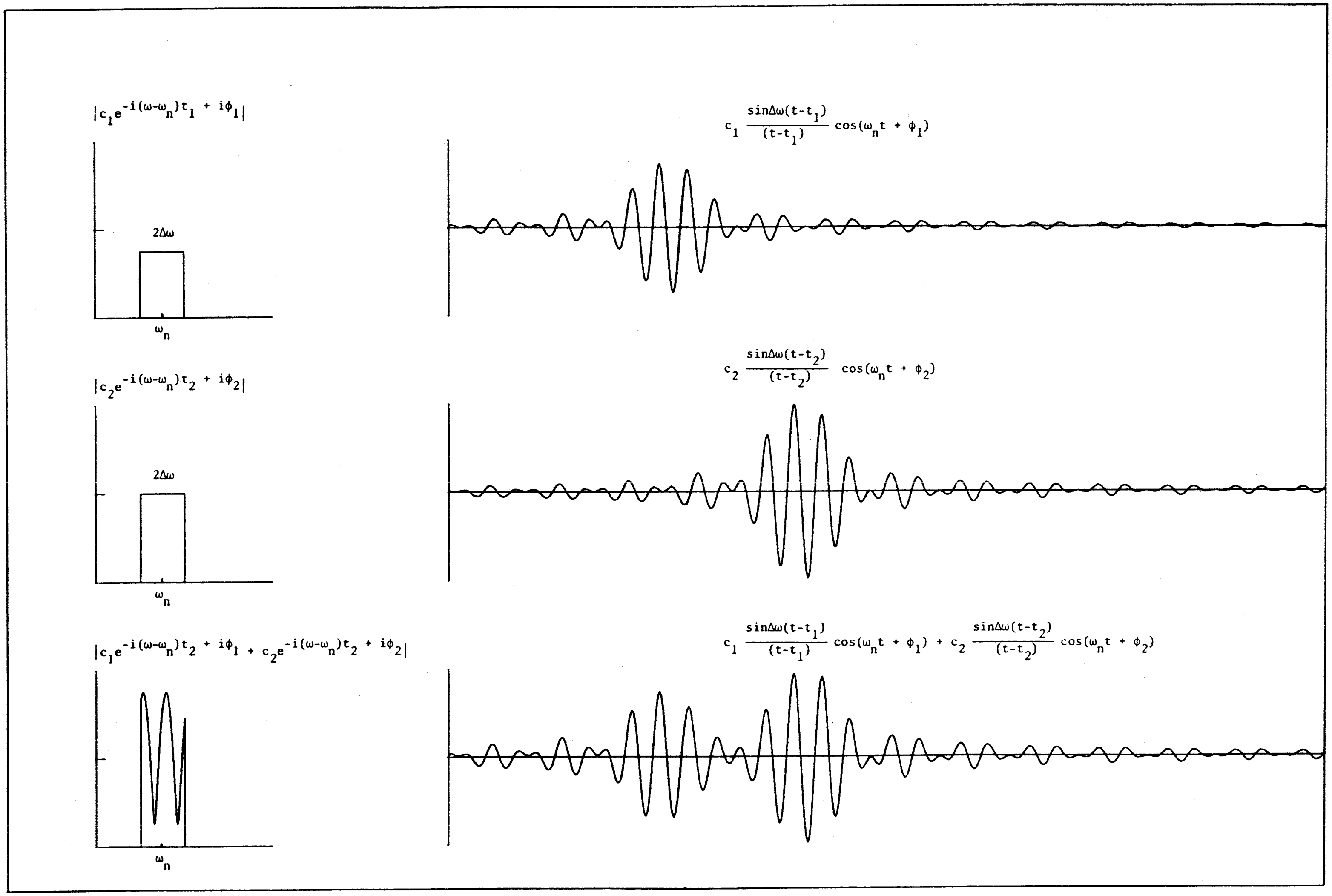


Figure 2

Functions $f_1(t)$ (top), $f_2(t)$ (middle), and $f_1(t) + f_2(t)$ bottom) and their Fourier amplitude spectra.

in arrival time, $(t_1 - t_2)$. Therefore, the irregularities of a typical Fourier amplitude spectrum (Figure 1) can be thought of as being the interferences caused by many wave groups arriving at the site with different amplitudes and at different times.

To reconstruct an accelerogram from the Fourier amplitude spectrum, one must have the following additional information: (1) the arrival times, and (2) the relative amplitude of different waves. For the latter task, only relative amplitudes are needed because the absolute amplitude of the combined time history is constrained by a given Fourier amplitude of complete artificial accelerograms. Much of the required information on the overall spectrum amplitudes and shape is readily available. Detailed information on the relative amplitudes of surface waves to body waves, depends strongly on the source mechanism and the wavepath and is more difficult to derive. Hence, it is necessary to assume some of these parameters on the basis of previous seismological observations. The procedures used to generate the complete accelerogram are described in the next section.

GENERATION OF SYNTHETIC ACCELEROGRAMS

Wave propagation studies have shown that in an inhomogeneous medium the surface waves and body waves travel at different velocities. Furthermore, in layered media, surface waves travel in a dispersive manner, their velocities depending on the material properties of the medium, the frequency of wave motion, and the geometrical configuration of the layers. The group velocities for a particular site can be estimated either by processing of previous records using techniques in observational seismology or by theoretical calculations. At present, most theoretical models are based on horizontal parallel layers. An example is shown in Figure 3, in which an approximate profile for the El Centro, California site is used. Although the assumption of horizontal layers is a restrictive one, it is advantageous to use theoretically calculated dispersion curves for the generation of different phases of arrival times because experimentally derived results may not be available for all sites and it is also difficult to obtain them for high frequencies.

Once the dispersion curves have been computed, the arrival times of the m^{th} mode at ω_n can be written as

$$t^*_{nm} = \frac{R}{U_m(\omega_n)} \tag{8}$$

where R is the distance from the source to the station and $U_m(\omega_n)$ is the group velocity of the m^{th} mode at the frequency band centered at ω_n.

One can select the frequency bands narrow enough, i.e., $\Delta\omega_n$ small enough so that $U_m(\omega)$ is approximately constant throughout, $\omega_n - \Delta\omega_n \leq \omega \leq \omega_n + \Delta\omega_n$. Then the contribution to the total accelerogram from this particular frequency band can be expressed as

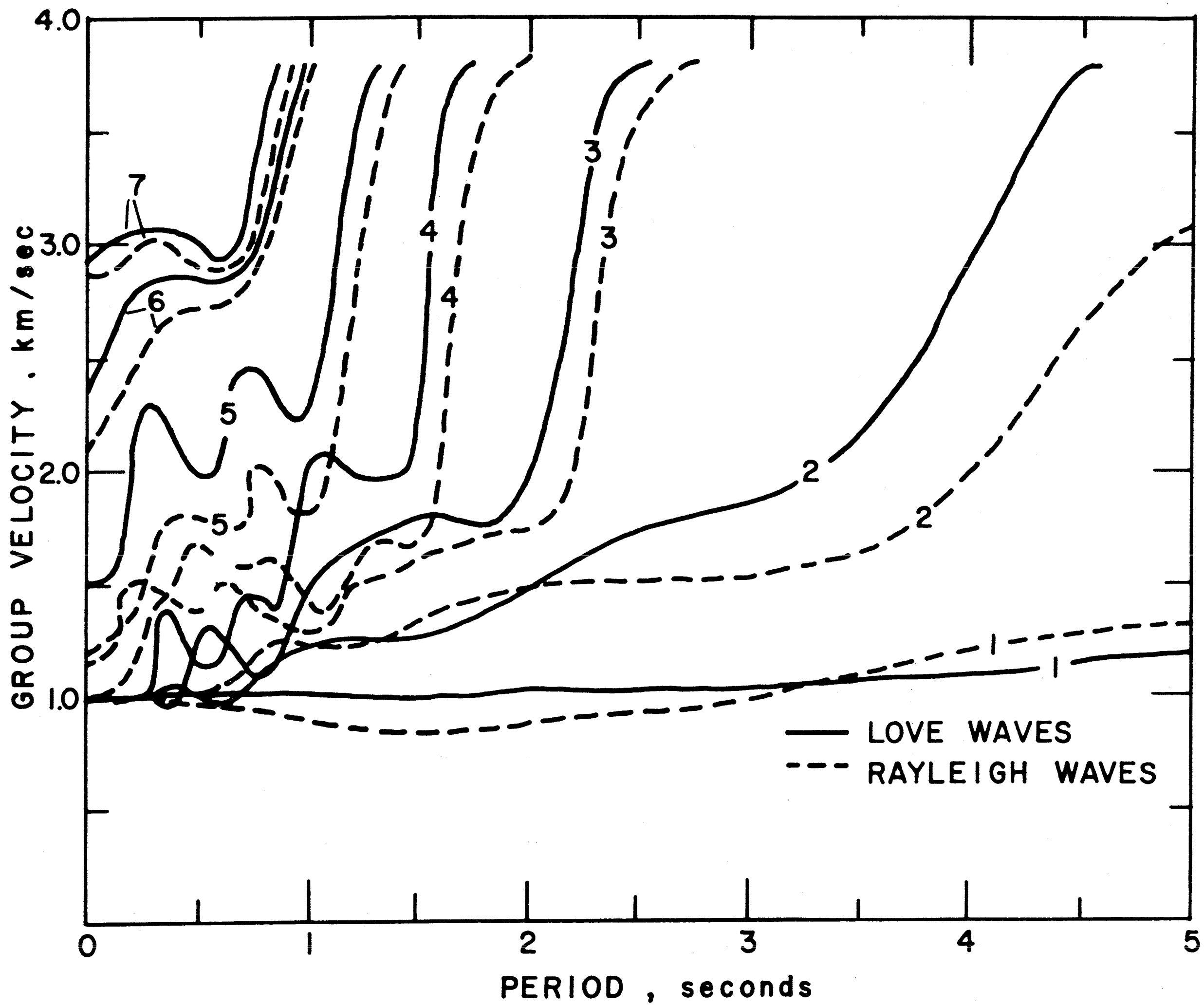


Figure 3

Love and Rayleigh-wave group velocity dispersion curves for El Centro, California (Trifunac, 1971b).

$$h_n(t) = \sum_{m=1}^{M} \alpha_n A_{nm} \frac{\sin\Delta\omega_n(t-t^*_{nm})}{(t-t^*_{nm})} \cos(\omega_n t + \phi_n) \tag{9}$$

where M is the total number of surface wave modes, ϕ_n is a phase introduced to include the effect of source dislocation and other miscellaneous effects along the propagation path, ω_n is the center frequency, and t^*_{nm} is the arrival time of the m^{th} mode given by equation (8). The amplitude of each mode is currently defined as $\alpha_n A_{nm}$, A_{nm} being the relative amplitudes of different surface wave modes and α_n is a scale factor to be used for determining the final amplitude through a specified Fourier amplitude spectrum, $FS(\omega_n)$.

With all the different waves arriving at different instances, the Fourier amplitude of $h_n(t)$,

$$|H_n(\omega)| = \begin{cases} \left| \sum_{m=1}^{M} \frac{\pi}{2} \alpha_n A_{nm} e^{-i((\omega-\omega_n)t_{nm} - \phi_n)} \right|, & \omega_n - \Delta\omega \le |\omega| \le \omega_n + \Delta\omega_n \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

is an irregular function over a narrow band of $2\Delta\omega$. We match its mean amplitude so that

$$\frac{\int_{\omega_n-\Delta\omega_n}^{\omega_n+\Delta\omega_n} |H_n(\omega)|\,d\omega}{2\Delta\omega_n} = FS(\omega_n) \quad . \tag{11}$$

Thus, by substituting equation (10) into (11), one can solve for the scale factor α_n as

$$\alpha_n = \frac{2\Delta\omega_n FS(\omega_n)}{\frac{\pi}{2}\int_{\omega_n-\Delta\omega_n}^{\omega_n+\Delta\omega_n} \left| \sum_{m=1}^{M} A_{nm} e^{-i((\omega-\omega_n)t^*_{nm} - \phi_n)} \right| d\omega} \tag{12}$$

A similar procedure can be applied to other frequency bands within the frequencies of interest. For a Fourier analysis divided into N non-overlapping bands, the total accelerogram can be expressed as

$$a(t) = \sum_{n=1}^{N} \alpha_n \sum_{m=1}^{M} A_{nm} \frac{\sin\Delta\omega_n(t-t^*_{nm})}{(t-t^*_{nm})} \cos(\omega_n t + \phi_n) \quad . \tag{13}$$

As pointed out by Trifunac (1971b) body P- and S-waves could be modeled, for purposes of generating artificial accelerograms for use in engineering response calculations, in two different ways. One approach would consist of adding two bursts of energy to the surface wave motions modeled by (9). Another simpler approach adopted in this paper is to merely add "higher order modes" to the dispersion curves of surface waves and to select A_{nm} so that contributions of these modes "represent" P- and S-wave arrivals. Surface wave modes 6 and 7 in Figure 3 have been chosen in this manner for examples shown in this work. In the following sections, the methods for calculating various parameters such as A_{nm} and ϕ_n will be discussed.

1) <u>Calculation of A_{nm} and ϕ_n</u>

Depending upon the faulting mechanism and the wave paths to the site, various amplitudes of body and surface waves will be excited. Some methods have been developed in seismology for the partitioning of radiated energy, but for strong motion and for near field shaking, scaling of spectral amplitudes based on the empirical scaling laws derived from recorded accelerograms may be preferable. For the accelerograms presented in this report, A_{nm} was chosen to be as proposed by Trifunac (1971b).

The values of A_{nm} as a function of frequency have been given as

$$A_{nm}(\omega_n) = A_1(m)A_2(\omega_n) \tag{14}$$

where

$$A_1(m) = |\exp(-(m-m_o)^2/2C_o^2) + C_R X_{Rm}| \quad ,$$

and

$$A_2(\omega_n) = |B_o \exp(-(\omega_n-\omega_p)^2/2\omega_B^2) + B_R X_{Rm}| \quad .$$

X_{Rm} and X_{Rn} are random numbers between -1 and 1, the other constants are defined in Table I. The phase ϕ_n is assumed to be random between $-\pi$ and π.

2) Fourier Amplitude Spectra and Duration

Since the smoothed Fourier amplitude spectra are necessary for defining the absolute amplitude, and the duration is needed to determine the time length of strong motion acceleration, it is useful to summarize here empirical relationships for these quantities in terms of the simple earthquake scaling parameters. Following the work of Lee, Westermo and Trifunac (Trifunac, 1976; Trifunac, 1978, Trifunac and Westermo, 1976a,b; Trifunac and Lee, 1978; Westermo and Trifunac, 1978, 1979) the Fourier amplitude spectra and duration can be

TABLE I

m	C_o	m_o	C_R	B_o	ω_p	ω_B	B_R
1	3	5	0.2	1.5	10	5	0.1
2	3	5	0.2	1.5	10	5	0.1
3	3	5	0.2	1.5	10	5	0.1
4	3	5	0.2	2.0	25	15	0.1
5	3	5	0.2	2.0	25	15	0.1
6	3	6	0.2	3.0	30	10	0.3
7	3	7	0.2	1.5	30	5	0.25

estimated in terms of four sets of parameters. These parameters are briefly described in the following paragraphs.

(i) For the description of the size of an event at a given site, either the Modified Mercalli Intensity, I_{MM}, or the magnitude, M, and the epicentral distance, R, can be used.

(ii) For the description of geologic conditions at a site, either the site parameter, s, or the depth of sedimentary layer, h, can be used. The site parameter, s=0, represents the alluvial sites, s=2 the rock sites, and s=1 the sites with intermediate geological conditions. For a continuous description of a site, the depth, h, in kilometers, can be employed to represent the thickness of the sedimentary layer overlying the basement rock. The characteristics of s=0 are roughly equivalent to h=4 km, and s=2 is roughly equivalent to h=0.

(iii) For distinguishing the horizontal and vertical components of ground motion, the parameter, v, has been introduced. v=0 for horizontal and v=1 for vertical motion.

(iv) For a description of the way the data is distributed about the mean trends of the empirical models, the confidence level, p_a, was introduced. It approximates the probability that either the Fourier amplitude or the duration will not be exceeded for a given set of parameters. In the regression analyses of the Fourier amplitude spectra, a parameter, p_ℓ, is occasionally used instead of p_a. In using p_ℓ, the distribution of data is approximated by a linear trend through the mean, while in using p_a, the distribution of Fourier amplitudes is assumed to be Gaussian. Anderson and

Trifunac (1977) have shown that the relationship

$$p_a = \int_{-\infty}^{p_\ell} \frac{1}{\sqrt{2\pi}\sigma(T)} \exp\left[-\frac{1}{2}\left(\frac{\varepsilon-\mu(T)}{\sigma(T)}\right)^2\right] d\varepsilon \qquad (15)$$

can be used to relate p_a to p_ℓ. In this expression, $\mu(T)$ and $\sigma(T)$ represent the mean and standard deviation at period T of a Fourier spectrum. It has been shown that in the range of $0.1 \le p_\ell \le 0.9$, p_ℓ and p_a are nearly the same.

3) <u>The Empirical Scaling of Fourier Amplitude Spectra</u>

This section summarizes the regression relations developed for scaling Fourier amplitude spectra. Since these regression analyses were performed independently over frequency, all the coefficients in Table III are listed as functions of period $T = 1/f = 2\pi/\omega$.

(A) <u>The Fourier amplitude spectra, FS(T), in terms of M, R, s, v, and p_ℓ are given by</u>

$$\log_{10} FS(T) = \log_{10} A_o(R) - a(T)p_\ell - c(T) - d(T)s - e(T)v - g(T)R$$

$$+ \begin{cases} M - b(T)M_{min} - f(T)M_{min}^2 & \text{for } M \le M_{min}, \\ M - b(T)M - f(T)M^2 & \text{for } M_{min} \le M \le M_{max}, \\ M_{max} - b(T)M_{max} - f(T)M_{max}^2 & \text{for } M \ge M_{max}, \end{cases} \qquad (16)$$

where

$$M_{min} = -\frac{b(T)}{2f(T)}, \text{ and } M_{max} = \frac{1-b(T)}{2f(T)} .$$

The term $\log_{10} A_o(R)$ is the attenuation function proposed by Richter (1958) for the local magnitude scale in southern California (Table II). To correctly apply this method to another region, the coefficients in equation (16), or a comparable equation,

TABLE II

$\log_{10} A_o(R)$ Versus Epicentral Distance R*

R (km)	$-\log_{10} A_o(R)$	R (km)	$-\log_{10} A_o(R)$	R (km)	$-\log_{10} A_o(R)$
0	1.400	140	3.230	370	4.336
5	1.500	150	3.279	380	4.376
10	1.605	160	3.328	390	4.414
15	1.716	170	3.378	400	4.451
20	1.833	180	3.429	410	4.485
25	1.955	190	3.480	420	4.518
30	2.078	200	3.530	430	4.549
25	2.199	210	3.581	440	4.579
40	2.314	220	3.631	450	4.607
45	2.421	230	3.680	460	4.634
50	2.517	240	3.729	470	4.660
55	2.603	250	3.779	480	4.685
60	2.679	260	3.828	490	4.709
65	2.746	270	3.877	500	4.732
70	2.805	280	3.926	510	4.755
80	2.920	290	3.975	520	4.776
85	2.958	300	4.024	530	4.797
90	2.989	310	4.072	540	4.817
95	3.020	320	4.119	550	4.835
100	3.044	330	4.164	560	4.853
110	3.089	340	4.209	570	4.869
120	3.135	350	4.253	580	4.885
130	3.182	360	4.295	590	4.900

* Only the first two digits may be assumed to be significant.

TABLE IIIA

Regression Coefficients for Fourier Amplitudes.
Parameters: M, R, s, v, p_ℓ

log(T)	a(T)	b(T)	c(T)	d(T)	e(T)	10f(T)	1000g(T)	σ(T)	μ(T)
-1.398	-1.688	-1.086	7.615	-0.018	-0.098	1.320	-0.441	0.301	0.492
-1.150	-1.620	-1.380	7.892	-0.080	-0.026	1.527	-0.869	0.300	0.502
-0.903	-1.517	-1.418	7.344	-0.068	0.094	1.542	-1.052	0.299	0.500
-0.655	-1.445	-1.216	6.249	0.011	0.229	1.364	-0.940	0.289	0.488
-0.407	-1.460	-1.053	5.587	0.102	0.304	1.206	-0.709	0.281	0.479
-0.159	-1.514	-1.129	5.913	0.163	0.319	1.227	-0.610	0.280	0.479
0.088	-1.549	-1.499	7.328	0.189	0.309	1.469	-0.753	0.287	0.488
0.336	-1.570	-2.592	11.230	0.197	0.288	2.250	-1.033	0.301	0.511
0.584	-1.601	-4.042	16.381	0.200	0.281	3.300	-1.258	0.312	0.532
0.831	-1.630	-4.699	18.875	0.204	0.292	3.775	-1.352	0.302	0.522
1.079	-1.633	-4.872	19.715	0.203	0.297	3.900	-1.375	0.289	0.492

should be derived entirely from data of that region. However, in the absence of such data, a reasonable approximation would be to replace the term $\log_{10}A_o(R)$ derived for southern California with one applicable to the region considered. The values of the coefficients, a(T), b(T), c(T), d(T), e(T), f(T), g(T) are tabulated versus $\log_{10}T$ in Table IIIA. The values of $\sigma(T)$ and $\mu(T)$ are used to convert p_a to p_ℓ in terms of equation (15).

(B) <u>The Fourier amplitude spectra, FS(T) in terms of I_{MM}, s, v, and p_ℓ</u> are given by

$$\log_{10}FS(T) = a(T)p_\ell + b(T)I_{MM} + c(T) + d(T)s + e(T)v. \qquad (17)$$

The coefficients, a(T), b(T), c(T), d(T), and e(T) are tabulated in Table IIIB. $\sigma(T)$ and $\mu(T)$ are to be used in conjunction with equation (15) to convert p_a to p_ℓ. p_a is given by the user but p_ℓ must be used in equation (17).

(C) <u>The Fourier amplitude spectra, FS(T), in terms of M, R, h, v and p_ℓ</u>. The form of the regression equation employed here is similar to that of equation (16) except that the term -d(T)s is replaced by -d(T)h, i.e.,

$$\log_{10}FS(T) = \log_{10}A_o(R) - a(T)p_\ell - c(T) - d(T)h - e(T)v - g(T)R$$
$$+ \begin{cases} M - b(T)M_{min} - f(T)M_{min}^2 & \text{for } M \le M_{min}, \\ M - b(T)M - f(T)M^2 & \text{for } M_{min} \le M \le M_{max}, \\ M_{max} - b(T)M_{max} - f(T)M_{max}^2 & \text{for } M \ge M_{max}, \end{cases} \qquad (18)$$

The coefficients, a(T), b(T), c(T), d(T), e(T), f(T), g(T), the mean, $\mu(T)$, and standard deviation, $\sigma(T)$, are tabulated in Table IIIC.

TABLE IIIB

Regression Coefficients for Fourier Amplitudes.
Parameters: I_{MM}, s, v, p_{ℓ}

log(T)	a(T)	b(T)	c(T)	d(T)	e(T)	σ(T)	μ(T)
-1.398	1.707	0.341	-4.295	0.159	0.011	0.321	0.476
-1.141	1.688	0.312	-3.467	0.222	0.025	0.326	0.496
-0.883	1.559	0.285	-2.523	0.178	-0.104	0.326	0.506
-0.626	1.387	0.272	-1.886	0.092	-0.264	0.315	0.501
-0.368	1.294	0.272	-1.626	0.023	-0.335	0.308	0.496
-0.111	1.316	0.286	-1.667	-0.016	-0.338	0.307	0.497
0.146	1.413	0.312	-1.937	-0.039	-0.277	0.314	0.508
0.404	1.516	0.320	-2.097	-0.079	-0.207	0.333	0.519
0.661	1.537	0.280	-1.947	-0.102	-0.234	0.342	0.522
0.919	1.485	0.216	-1.793	-0.063	-0.214	0.329	0.530
1.176	1.473	0.174	-1.983	-0.032	-0.014	0.318	0.541

TABLE IIIC

Regression Coefficients for Fourier Amplitudes.
Parameters: M, R, h, v, p_ℓ

log(T)	a(T)	b(T)	c(T)	100d(T)	e(T)	10f(T)	1000g(T)	σ(T)	μ(T)
-1.398	-1.000	-1.190	7.050	0.446	-0.047	1.370	-0.410	0.492	0.003
-1.141	-1.000	-1.360	7.050	0.823	-0.014	1.500	-0.514	0.479	0.015
-0.883	-1.000	-1.350	6.250	0.908	0.115	1.490	-1.150	0.435	0.018
-0.626	-1.000	-0.869	4.410	-0.564	0.273	1.110	-2.440	0.390	0.006
-0.368	-1.000	-0.465	3.120	-3.050	0.327	0.787	-3.740	0.379	-0.001
-0.111	-1.000	-0.422	3.150	-4.930	0.326	0.725	-4.470	0.389	0.000
0.146	-1.000	-0.662	4.270	-6.210	0.289	0.849	-4.530	0.406	0.024
0.404	-1.000	-1.020	5.680	-7.970	0.231	1.110	-4.860	0.450	0.072
0.661	-1.000	-1.020	5.610	-8.750	0.250	1.170	-5.780	0.481	0.088
0.919	-1.000	-0.192	2.880	-7.020	0.195	0.598	-6.200	0.469	0.037
1.176	-1.000	0.199	1.780	-2.620	-0.030	0.328	-5.190	0.501	-0.001

(D) The Fourier amplitude spectra, FS(T), in terms of I_{MM}, h, v, and p_ℓ are described by

$$\log_{10} FS(T) = a(T)p_\ell + b(T)I_{MM} + c(T) + d(T)h + e(T)v \ . \tag{19}$$

The coefficients, a(T), b(T), c(T), d(T), e(T), the mean, $\mu(T)$, and the standard deviation, $\sigma(T)$, are tabulated in Table IIID.

Unless a particular situation calls for a specified spectrum, the above empirical scaling functions are capable of producing site dependent Fourier amplitude spectra that are consistent with current observations. Shown in Figures 4 through 8 are some examples calculated for different sets of parameters. In Figures 4, 5, and 6, the smoothed spectra are determined by equations (15) and (16). By varying the parameters M and R, the amplitude as well as the frequency content of the spectra change. The irregular spectra plotted in these figures are the Fourier amplitude spectra obtained by the procedures described earlier. In Figures 7 and 8 examples of amplitude spectra are plotted using two values of MMI: although the distance factor is omitted in the MMI correlations, it is used here to determine the arrival times of different surface wave modes.

4) The Duration of Strong Shaking

For structural analyses that consider fatigue and nonlinear response of structures, the excitation level alone is generally inadequate to characterize the response, and a description of the duration of strong shaking is also necessary. For this reason, in this work the duration is included as an important frequency dependent quantity while generating a synthetic accelerogram.

TABLE IIID

Regression Coefficients for Fourier Amplitudes
Parameters: I_{MM}, h, v, p_ℓ

log(T)	a(T)	b(T)	c(T)	100d(T)	e(T)	σ(T)	μ(T)
-1.398	1.000	0.340	-3.200	-3.370	0.039	0.581	-0.069
-1.141	1.000	0.312	-2.460	-2.920	0.008	0.574	-0.046
-0.883	1.000	0.278	-1.490	-1.980	-0.124	0.523	-0.024
-0.626	1.000	0.269	-1.080	-0.038	-0.281	0.442	-0.020
-0.368	1.000	0.266	-0.951	2.090	-0.343	0.400	-0.016
-0.111	1.000	0.276	-1.030	4.230	-0.347	0.401	-0.012
0.146	1.000	0.308	-1.360	6.730	-0.287	0.426	-0.002
0.404	1.000	0.322	-1.590	9.720	-0.204	0.475	0.010
0.661	1.000	0.277	-1.400	10.500	-0.237	0.496	0.012
0.919	1.000	0.203	-1.120	7.460	-0.226	0.467	-0.010
1.176	1.000	0.175	-1.320	4.400	-0.004	0.500	-0.044

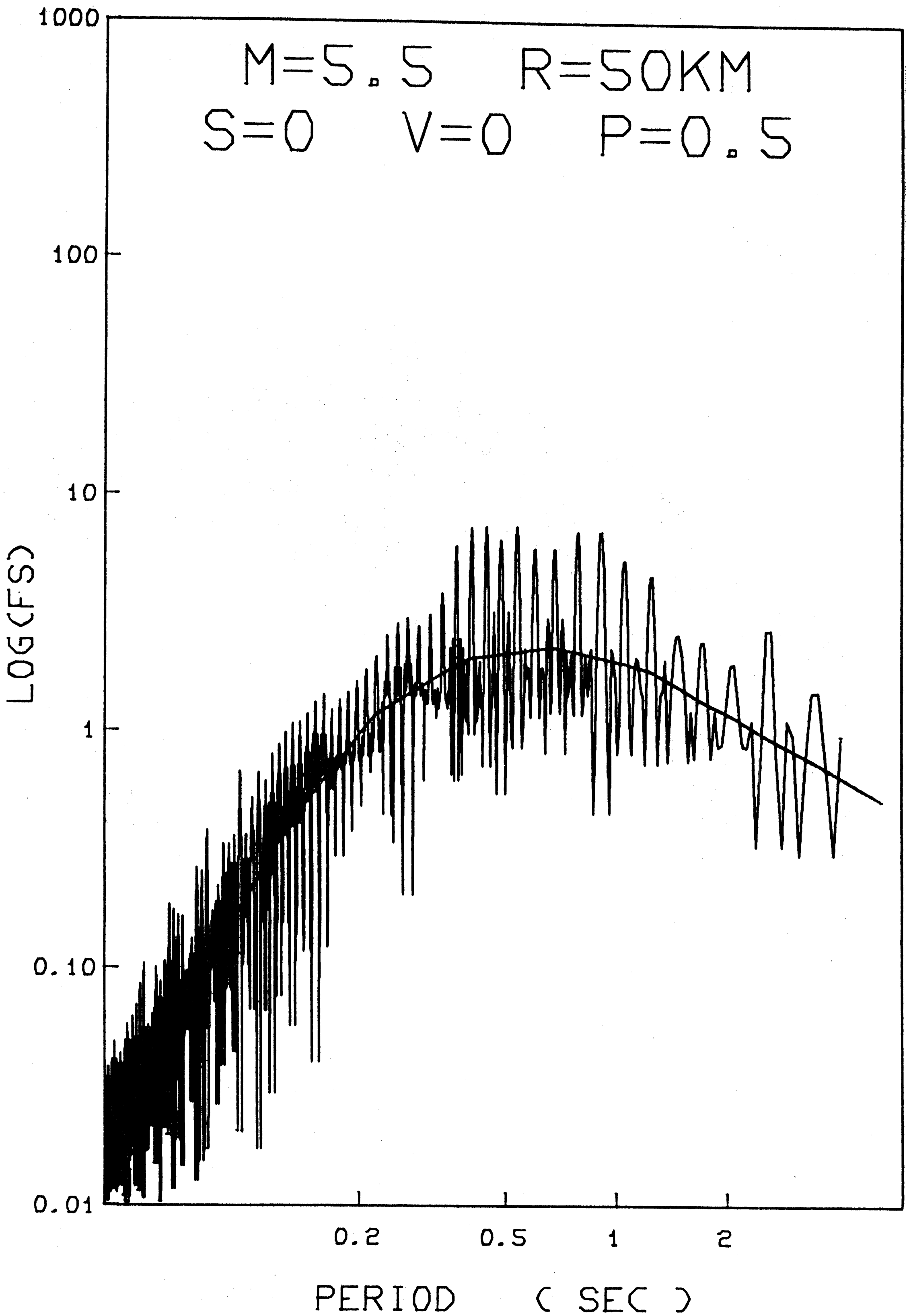

M=5.5 R=50KM
S=0 V=0 P=0.5
1000
100
10
1
0.10
0.01
LOG(FS)
0.2
0.5
1
2
PERIOD (SEC)

Figure 4

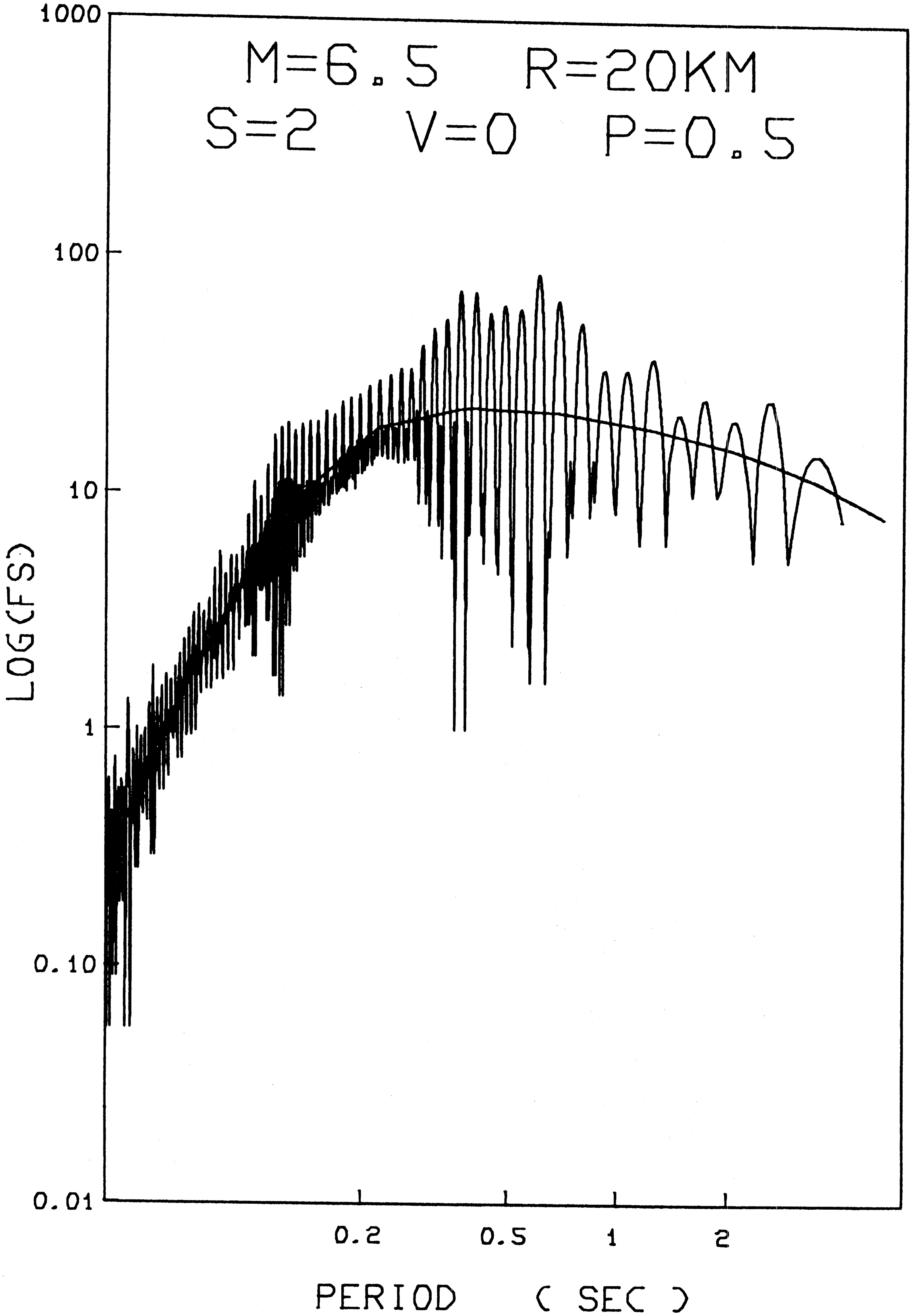

M=6.5 R=20KM
S=2 V=0 P=0.5
1000
100
10
1
0.10
0.01
LOG(FS)
0.2
0.5
1
2
PERIOD (SEC)

Figure 5

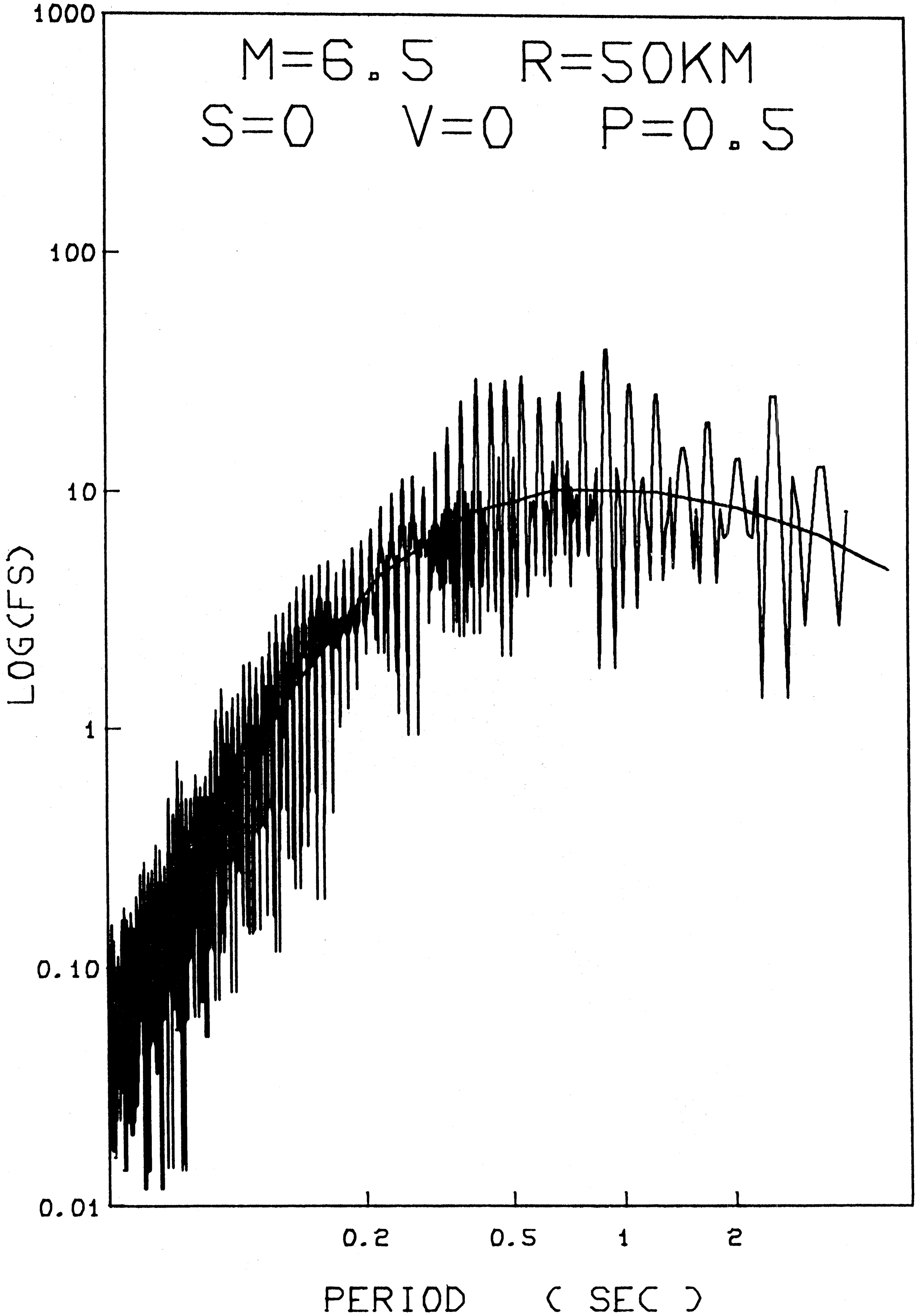

M=6.5 R=50KM
S=0 V=0 P=0.5
1000
100
10
1
0.10
0.01
LOG(FS)
0.2
0.5
1
2
PERIOD (SEC)

Figure 6

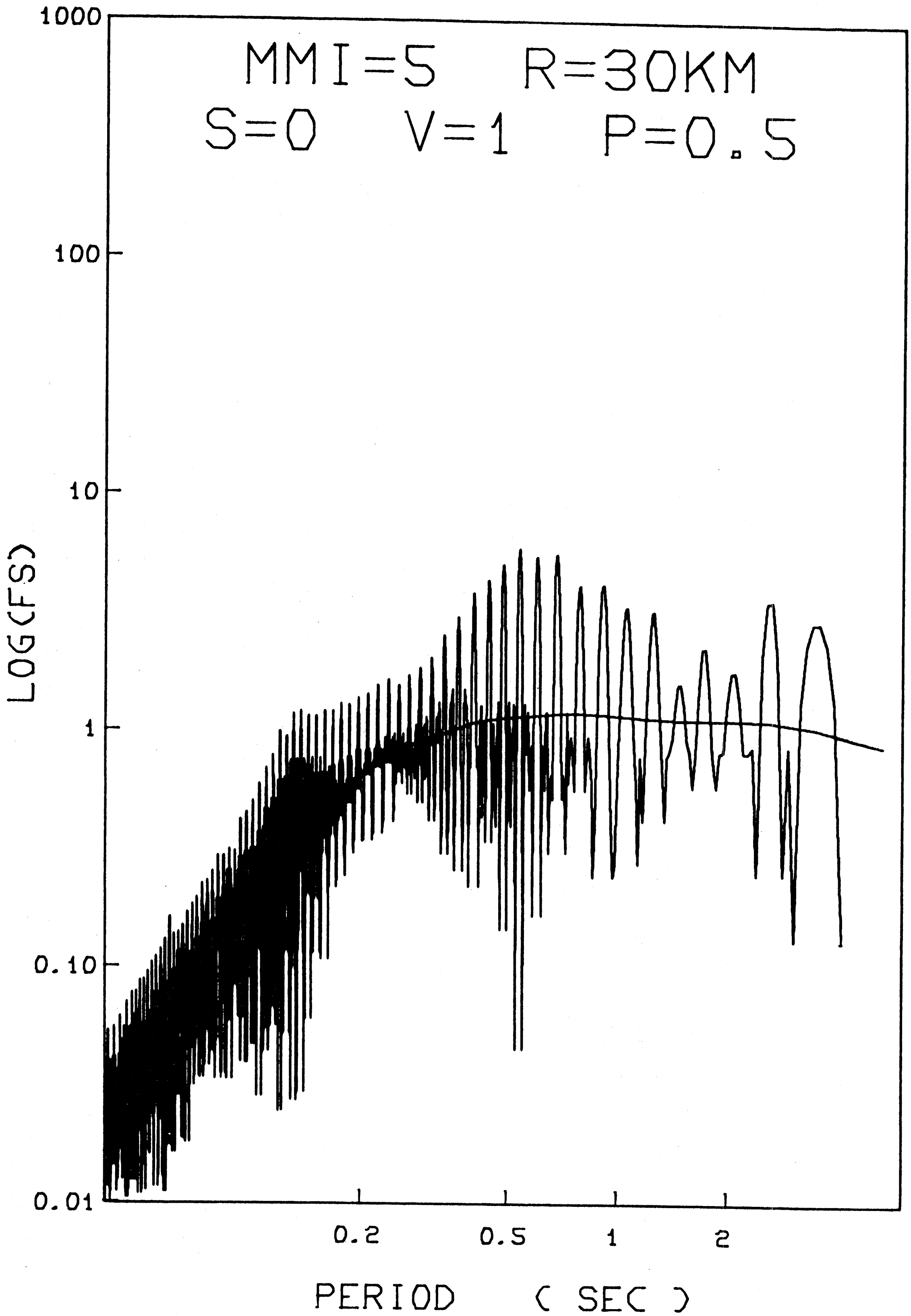

MMI=5 R=30KM
S=0 V=1 P=0.5
1000
100
10
1
0.10
0.01
LOG(FS)
0.2
0.5
1
2
PERIOD (SEC)

Figure 7

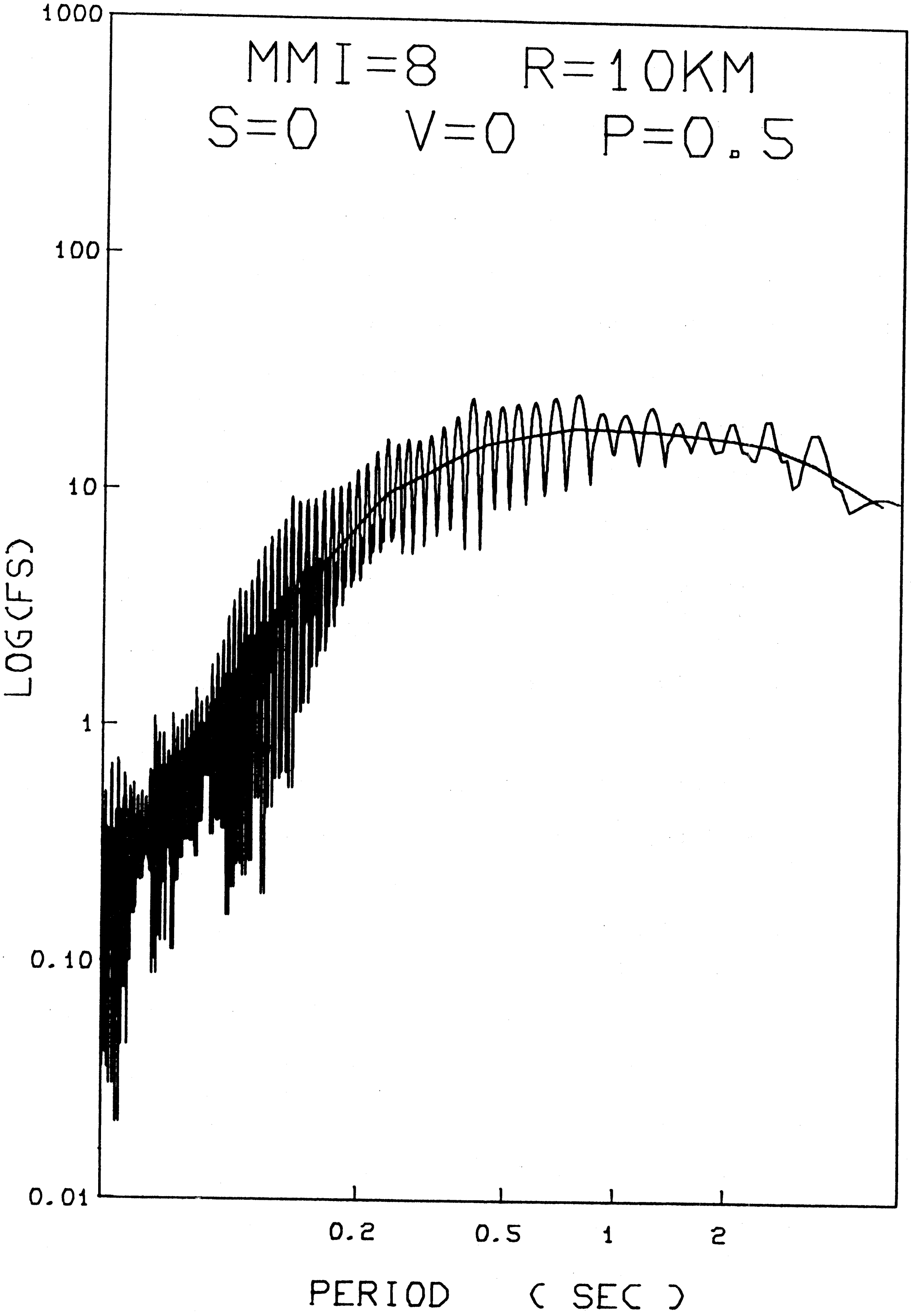

MMI=8 R=10KM
S=0 V=0 P=0.5
1000
100
10
1
0.10
0.01
LOG(FS)
0.2
0.5
1
2
PERIOD (SEC)

Figure 8

The duration of strong shaking is closely related to the difference in arrival times of the fastest and the slowest waves. Thus, if a representative dispersion curve can be derived for the site, it is most likely that such estimate of the duration will be in agreement with the empirical scaling relationships based on recorded accelerograms. However, there are sites where suitable dispersion curves are not available due to either a lack of data or because the geometric characteristics of the site are too complicated for conventional analyses. In these circumstances, a change must be made in the proposed procedures for generating synthetic accelerograms.

A convenient way to vary overall characteristics of synthetic accelerograms is through A_{nm}. As defined in equation (14), A_{nm} is a function of the mode number and frequency. The amplitudes of A_{nm} can be chosen so that the overall Fourier spectrum amplitudes and the frequency dependent duration are compatible with past observations.

Using the definition given by Trifunac and Brady (1975), the duration is estimated by the "energy-like" quantity

$$I(t) = \int_0^t a^2(\tau)d\tau \ . \qquad (20)$$

The duration T is defined so that I(T) is 90% of $I(\infty)$, i.e., T is taken to be the interval in time in which 90% of the seismic energy is contributed to the motion at a point. Since the input vibrational energy represents an important parameter in measurements of fatigue, this definition of duration appears to be useful from structural analysis point of view.

The duration has been correlated with different parameters describing characteristics of strong shaking in a manner similar to that used in scaling the Fourier amplitude spectra. In the work by Trifunac and Westermo (1976a,b), the duration is analyzed in six frequency bands, ranging from 0.125 Hz to 25 Hz as follows:

Band	Frequency Range (Hz)	Center Frequency (Hz)
1	10-25	18
2	4-10	7
3	1.5-4	2.7
4	0.7-1.5	1.1
5	0.3-0.7	0.5
6	0.125-0.3	0.2

These frequency bands have been chosen to span frequencies which are of interest to earthquake engineering research and applications. The durations are analysed independently within each band.

(A) The duration, D, in terms of M, R and s

In this regression analysis, the duration of the horizontal and vertical components are analyzed independently. Therefore, the parameter v is not included and the empirical equation takes the form

$$D = as + bM + cR + d \pm \sigma , \qquad (21)$$

where σ is the standard deviation. The coefficients a, b, c, d, and σ are tabulated in Table IV A for horizontal and vertical component directions. The center frequencies of the six frequency bands are used to identify the frequency content of the time record analyzed.

(B) The duration, D, in terms of I_{MM}

In the analysis of duration in terms of I_{MM}, no site dependent correlations were presented by Trifunac and Westermo (1976b).

TABLE IV A

Regression Coefficients for Duration.
Parameters: M, R, s

HORIZONTAL COMPONENT

	Center Frequency (Hz)					
	18	7	2.75	1.1	0.5	0.22
a	-1.66	-1.38	-2.75	-4.09	-4.82	-3.02
b	0.64	1.32	1.28	-0.36	1.68	-0.43
c	0.13	0.08	0.09	0.08	0.07	0.09
d	1.88	-0.77	1.42	16.41	11.82	22.00
σ	5.89	5.10	5.57	7.41	10.75	12.01

VERTICAL COMPONENT

	Center Frequency (Hz)					
	18	7	2.75	1.1	0.5	0.22
a	-1.04	-1.23	-3.30	-5.83	-6.80	-4.45
b	0.34	1.38	2.12	0.51	-0.47	-1.09
c	0.12	0.08	0.08	0.08	0.06	0.08
d	3.43	-0.57	-0.95	16.16	29.57	30.62
σ	5.34	4.59	5.93	8.86	11.65	12.44

Instead, Table IV B is used to display the dependence of the duration on I_{MM}, v, s and the center frequency, f_c. For the cases where the entries are blank, no data is available; n is the number of data points used in the analysis, x is the mean duration, and σ is the corresponding standard deviation.

(C) The duration, D, in terms of M, R, h and p_a

For this regression analysis, the horizontal and vertical components are again presented separately. For each of these component directions, the correlation takes the form

$$D = a + bM + cR + dh + \varepsilon(p_a) \tag{22}$$

in which $\varepsilon(p_a)$ can be obtained from the inverse of

$$p_a(\varepsilon) = 1 + \alpha_1 e^{\beta_1 \varepsilon} + \alpha_2 e^{\beta_2 \varepsilon} . \tag{23}$$

Given a confidence level, p_a, one must first invert equation (23) by a conventional numerical method to obtain ε, the root of the transcendental equation. The root, $\varepsilon(p_a)$, can then be substituted into equation (22) for the calculation of D. The coefficients a, b, c, and d for equation (22), and α_1, β_1, α_2 and β_2 for equation (23) are tabulated in Table IV C, separated by the component directions and by the center frequencies.

(D) The duration, D, in terms of I_{MM}, h, and p_a

For both the vertical and horizontal directions, the correlation of D takes the form

$$D = a + bI_{MM} + ch + \varepsilon(p_a) \tag{24}$$

TABLE IV B

Means and Standard Deviations of the Duration of Strong Ground Motion for Different Site Conditions and Modified Mercalli Intensities

Site Intensity	Site Class.		$f_c = 0.2$			$f_c = 0.5$			$f_c = 1.1$			$f_c = 2.7$			$f_c = 7.0$			$f_c = 18.0$		
			x	σ	n	x	σ	n	x	σ	n	x	σ	n	x	σ	n	x	σ	n
III	0	Vert.	47.4		1	44.7		1	28.0		1	25.8		1	20.6		1	35.8		1
		Horiz.	42.5		2	35.6		2	24.6		2	17.6		2	13.4		2	25.6		2
	1	Vert.																		
		Horiz.																		
	2	Vert.																		
		Horiz.																		
IV	0	Vert.	43.2		1	41.5		1	54.2		1	49.4		1	34.8		1	53.8		1
		Horiz.	40.2		2	35.9		2	32.2		2	33.3		2	28.2		2	42.7		2
	1	Vert.	33.2		2	38.8		1	30.9		2	18.4		2	17.4		2	27.0		2
		Horiz.	34.9	9.71	4	35.9	3.68	2	26.0	4.40	4	18.2	2.06	4	12.2	4.23	4	19.5	3.03	4
	2	Vert.																		
		Horiz.																		
V	0	Vert.	37.1	16.2	16	31.5	13.9	17	27.1	12.5	17	17.8	9.94	17	15.9	7.21	17	16.8	10.6	17
		Horiz.	30.9	13.8	32	29.6	13.5	34	21.9	10.2	34	16.5	9.20	34	15.1	8.23	34	18.4	12.0	34
	1	Vert.	25.9	11.6	12	25.2	14.5	15	18.9	9.60	15	13.9	4.97	15	12.6	7.21	15	11.3	6.46	15
		Horiz.	25.0	12.4	24	22.6	13.1	30	17.9	8.98	30	12.3	6.14	30	11.9	7.19	30	12.1	6.98	30
	2	Vert.	15.1	8.70	2	14.9	7.70	2	15.2	6.80	2	10.9	1.90	2	7.10	.50	2	8.60	.80	2
		Horiz.	17.1	9.24	4	14.7	6.95	4	8.60	1.56	4	9.80	1.98	4	8.25	.67	4	8.75	1.92	4
VI	0	Vert.	32.4	11.3	43	34.0	12.5	43	28.0	11.0	43	19.9	8.22	43	14.5	7.15	43	14.3	9.73	43
		Horiz.	29.3	12.6	86	29.4	12.7	86	23.8	9.26	86	18.2	8.30	86	13.4	7.13	86	15.8	10.6	86
	1	Vert.	35.4	13.4	15	34.5	13.1	16	21.1	9.20	16	12.3	4.55	16	9.42	3.68	16	11.0	6.94	16
		Horiz.	33.3	12.6	30	30.2	12.3	32	18.6	9.41	32	10.2	4.99	32	7.59	3.99	32	9.24	7.16	32
	2	Vert.	23.4	10.3	7	14.4	7.56	7	10.1	4.20	7	10.1	5.35	7	11.3	4.88	7	8.60	2.56	7
		Horiz.	22.3	9.88	14	14.9	7.48	14	8.69	5.22	14	9.10	4.83	14	9.87	3.59	14	7.87	3.61	14

TABLE IV B (Continued)

Site Intensity	Site Class.		x	σ	n	x	σ	n	x	σ	n	x	σ	n	x	σ	n	x	σ	n
	0	Vert.	24.7	11.3	48	25.5	8.34	49	20.1	6.28	49	14.4	5.58	49	11.3	5.14	49	11.1	4.49	49
		Horiz.	20.2	11.0	96	22.4	8.12	98	14.9	5.28	98	11.4	4.93	98	10.7	6.01	98	11.2	6.20	98
VII	1	Vert.	17.3	7.01	21	16.1	4.04	21	13.4	3.91	21	10.9	3.17	21	9.04	2.64	21	8.81	1.84	21
		Horiz.	11.4	4.00	42	14.9	5.20	42	10.2	2.90	42	8.12	2.35	42	7.80	2.65	42	8.88	3.14	42
	2	Vert.	14.2	4.58	5	11.6	5.14	5	10.1	3.05	5	7.16	2.68	5	5.72	2.98	5	6.16	3.37	5
		Horiz.	12.6	3.22	10	11.5	3.47	10	8.18	3.24	10	4.92	2.50	10	4.98	2.86	10	6.36	3.62	10
	0	Vert.	25.5	17.1	6	35.0	13.1	6	25.3	11.7	6	20.1	10.7	6	13.7	7.74	6	11.7	6.69	6
		Horiz.	25.6	12.9	12	28.5	12.9	12	18.6	8.25	12	15.8	9.41	12	14.0	7.62	12	13.5	8.25	12
VIII	1	Vert.																		
		Horiz.																		
	2	Vert.																		
		Horiz.																		
	0	Vert.																		
		Horiz.																		
IX	1	Vert.																		
		Horiz.																		
	2	Vert.																		
		Horiz.																		
	0	Vert.																		
		Horiz.																		
X	1	Vert.																		
		Horiz.																		
	2	Vert.	11.4		1	5.20		1	6.60		1	6.00		1	7.00		1	8.00		1
		Horiz.	10.4		2	6.90		2	5.70		2	6.30		2	7.10		2	6.20		2

TABLE IV C

Regression Coefficients for Durations.
Parameters: M, R, h, p

HORIZONTAL COMPONENT

	Center Frequency (Hz)					
	18	7	2.75	1.1	0.5	0.22
a/10	0.182	-0.124	0.336	1.574	1.678	3.866
b	0.317	1.174	0.398	-0.980	0.057	-3.460
10c	1.331	0.761	0.937	0.887	0.762	0.865
d	0.536	0.412	1.120	1.411	1.342	1.129
α_1	1.037	1.152	0.043	0.890	0.889	1.250
$10\beta_1$	-3.221	-3.893	-4.474	-1.816	-1.361	-1.039
α_2	-1.464	-1.550	-0.460	-1.315	-1.320	-1.651
$10\beta_2$	-2.849	-3.518	-2.019	-1.586	-1.181	-0.956

VERTICAL COMPONENT

	Center Frequency (Hz)					
	18	7	2.75	1.1	0.5	0.22
a/10	0.320	-0.108	0.120	1.847	2.580	4.263
b	0.070	1.216	1.099	-1.021	-1.351	-3.598
10c	1.262	0.818	0.851	0.901	0.732	0.910
d	0.592	0.485	1.525	2.174	2.198	1.363
α_1	1.034	1.139	0.396	0.887	0.890	1.241
$10\beta_1$	-3.753	-4.254	-3.137	-1.678	-1.274	-0.981
α_2	-1.469	-1.563	-0.821	-1.311	-1.315	-1.660
$10\beta_2$	-3.308	-3.797	-2.415	-1.463	-1.111	-0.889

TABLE IV D

Regression Coefficients for Durations.
Parameters: I_{MM}, h, p

HORIZONTAL COMPONENT

	Center Frequency (Hz)					
	18	7	2.75	1.1	0.5	0.22
a/10	2.719	2.027	2.563	3.644	4.281	5.362
b	-2.755	-1.676	-2.325	-3.340	-3.458	-4.686
c	1.095	0.882	1.770	2.112	2.080	1.230
α_1	1.145	0.108	0.963	1.381	0.305	0.313
$10\beta_1$	-3.111	-4.539	-2.614	-1.631	-1.511	-1.147
α_2	-1.508	-0.429	-1.290	-1.723	-0.695	-0.664
$10\beta_2$	-2.841	-2.987	-2.386	-1.522	-1.142	-0.921

VERTICAL COMPONENT

	Center Frequency (Hz)					
	18	7	2.75	1.1	0.5	0.22
a/10	2.458	1.762	2.261	3.313	4.576	5.531
b	-2.295	-1.348	-1.968	-3.008	-3.946	-5.290
c	1.211	0.908	1.579	1.734	1.679	1.422
α_1	1.160	0.439	0.887	1.248	0.072	1.397
$10\beta_1$	-3.190	-3.852	-2.881	-1.601	-1.946	-1.027
α_2	-1.485	-0.906	-1.473	-1.863	-0.567	-1.914
$10\beta_2$	-2.954	-2.935	-2.304	-1.332	-0.892	-0.907

in which $\varepsilon(p_a)$ can be calculated by equation (23). The coefficients a, b, and c for equation (24), and α_1, β_1, α_2 and β_2 for equation (23) are tabulated in Table IV D, again separated by the component directions and by the center frequencies.

EXAMPLES OF ARTIFICIAL ACCELEROGRAMS

Following the development in equations (8) to (13), and with scaling in terms of equations (14) to (24), one can readily develop a computer program to calculate a synthetic accelerogram. Many numerical algorithms can be applied, but since the Fourier transform must be generated first to match a given Fourier amplitude spectrum, e.g., equations (11) and (12), it is efficient to simply invert the Fourier transform multiplied by the appropriate scale factors, α_n, as given in equations (10) and (12). The result is equivalent to the sum in equation (13).

In the program SYNACC (Appendix A), the Fast Fourier Transform (FFT) algorithm is used to invert the Fourier transform, making the entire process very efficient. One restriction of FFT, however, is that the number of sample points, N, must be an integral power of 2. Thus, given a time increment of Δt, N can be chosen as the nearest 2^n so that

$$N \sim \frac{L}{\Delta t} , \qquad (25)$$

where L is the approximate desired length of the synthetic record. Once Δt and N are given, the increment $\Delta\omega$ in the frequency domain is given as

$$\Delta\omega = \frac{2\pi}{N\Delta t} = \frac{2\pi}{L} . \qquad (26)$$

This increment, $\Delta\omega$, is fixed for a given L. This may present a problem if a smaller $\Delta\omega$ is desired. To decrease $\Delta\omega$ but holding Δt fixed, the only option is to increase N so that

$$N_1 = 2^m N \ , \quad L_1 = 2^m L \ , \quad m > 1 \ , \tag{27}$$

where N_1 is the number of points to be used in FFT although N is the actual number of points desired. In SYNACC, the length L is approximated by dividing the epicentral distance by the slowest velocity of the dispersion curve, the length used for calculation by FFT is 2L. Thus, only the first half of the 2N calculated points are kept as the synthetic accelerogram. Using this approach, the results of FFT typically differ from the actual summation of equation (13) by less than 1%.

Running on an IBM 370/158 or an equivalent, the central processing unit time required to generate one accelerogram using SYNACC is approximately 10 to 20 seconds. Since the core requirement for SYNACC is small, this program can easily be implemented on a mini-computer. The examples presented in this report have been calculated by a "Data General Nova-3" mini-computer. The time required for each accelerogram is approximately 2 minutes.

Figures 9 through 29 present examples of artificial accelerograms computed for different scaling parameters and using frequency dependent duration. In addition to synthetic acceleration, the digital plots of these figures show the frequency (cycle/sec) and time (sec) dependent envelopes in equation (13), normalized so that the largest amplitude is equal to 5. To avoid cluttering and to show the significant contribution to synthesized acceleration, in these figures, we present these amplitudes only for $f < 5.75$ cps. All accelerograms were calculated, however, for $0.07 \leq f \leq 25$ cps.

Figures 9, 10 and 11 show the affect of increasing magnitude ($M = 5.5$,

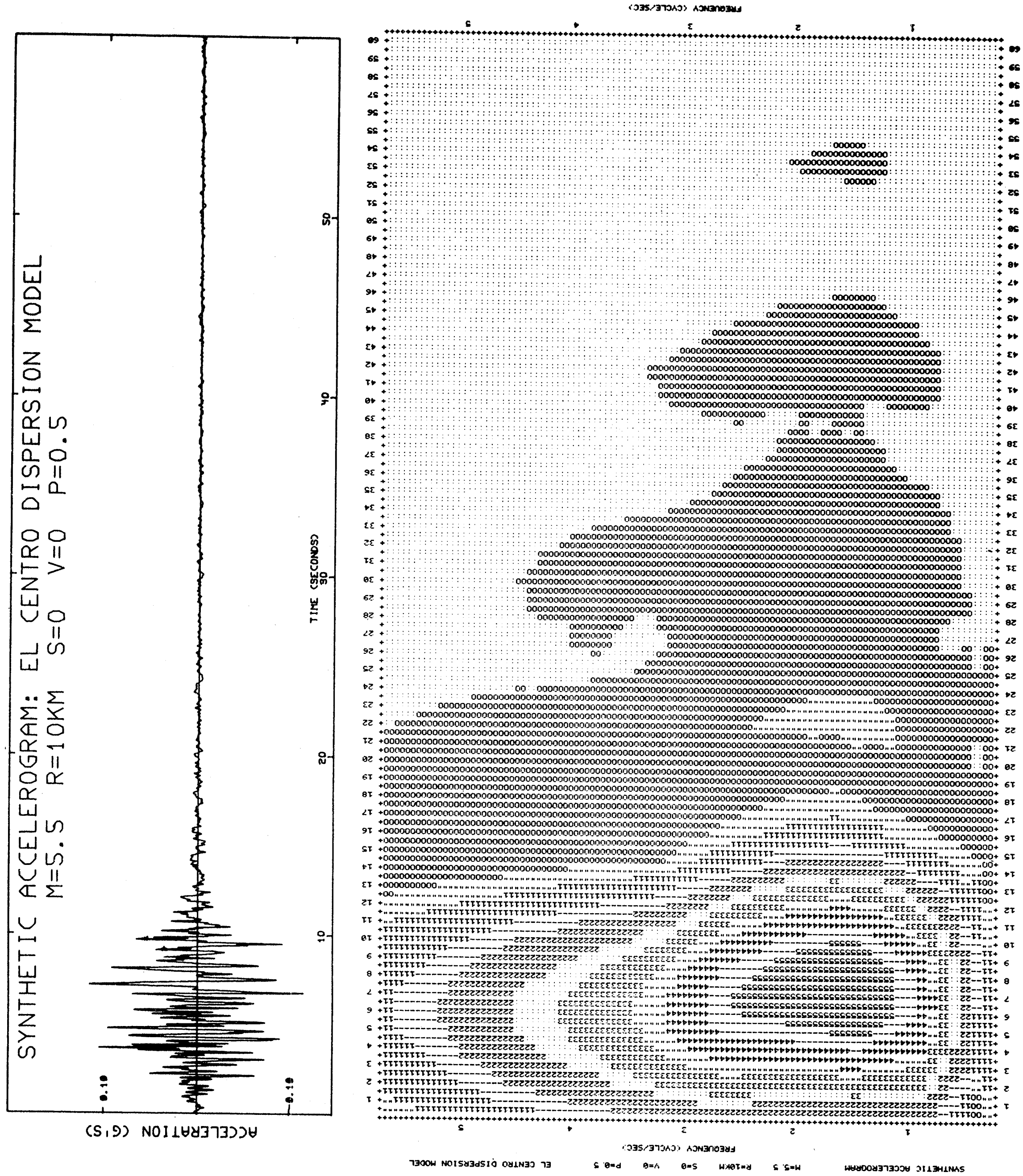

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=5.5 R=10KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 9

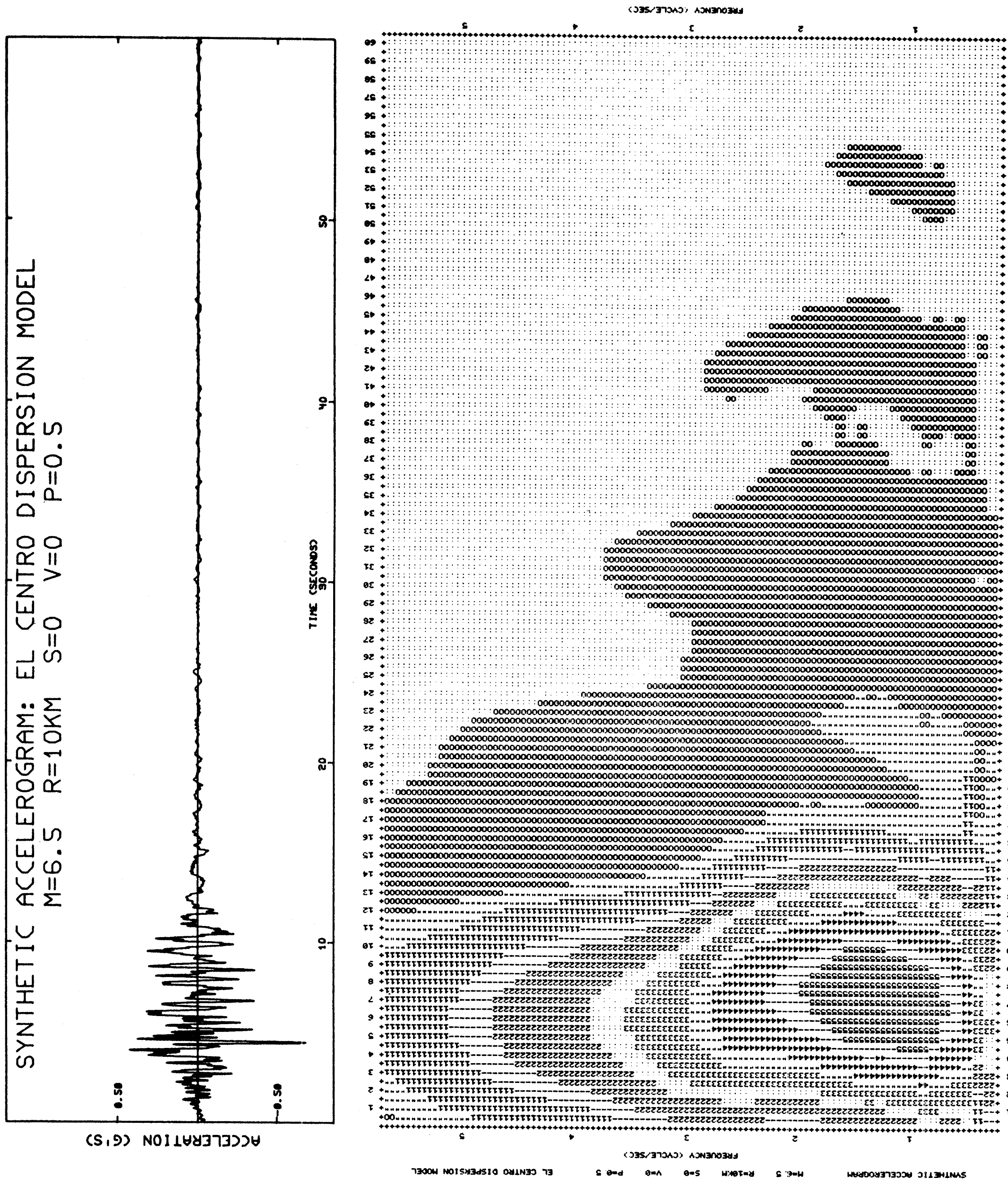

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=6.5 R=10KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 10

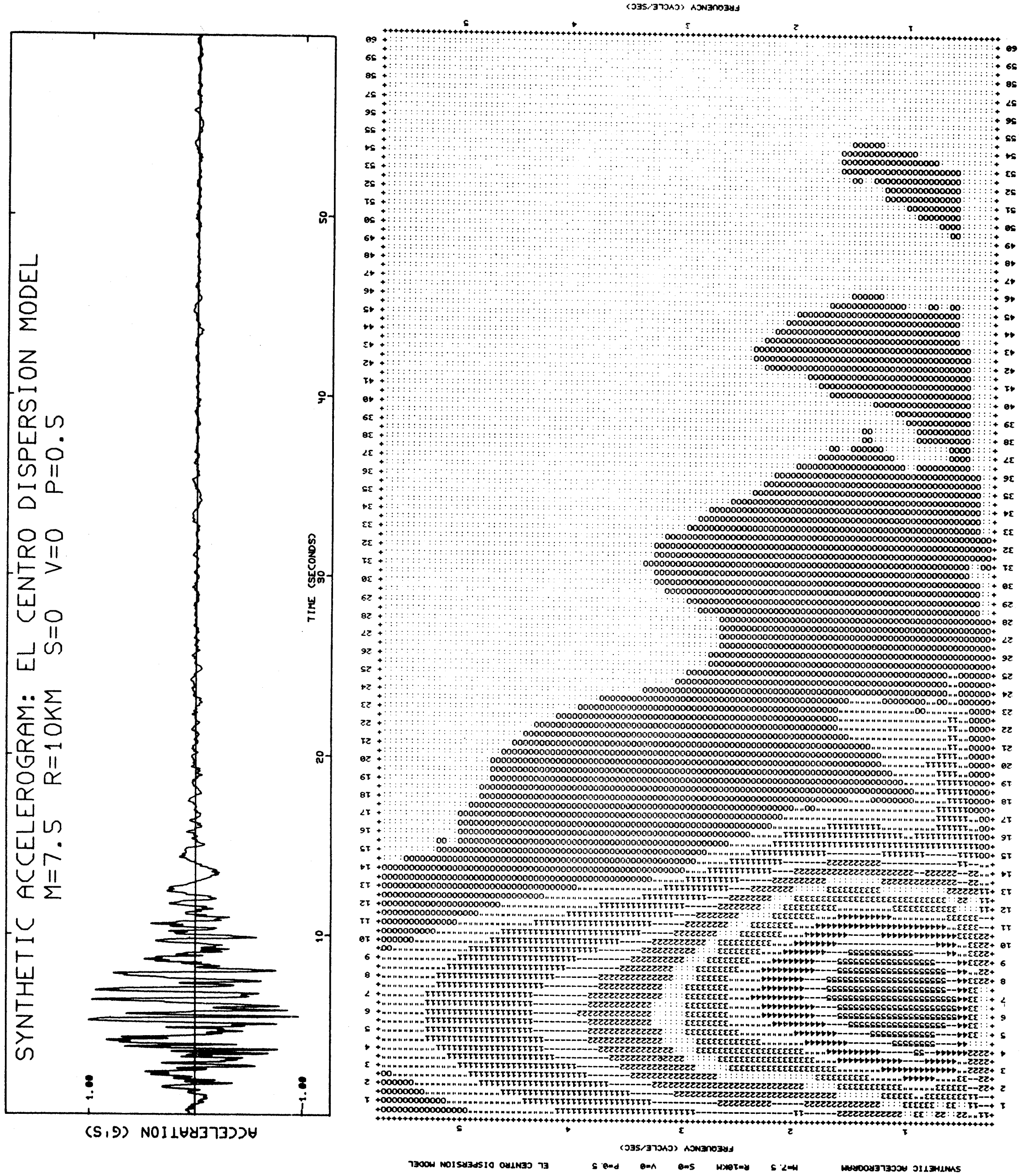

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=7.5 R=10KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 11

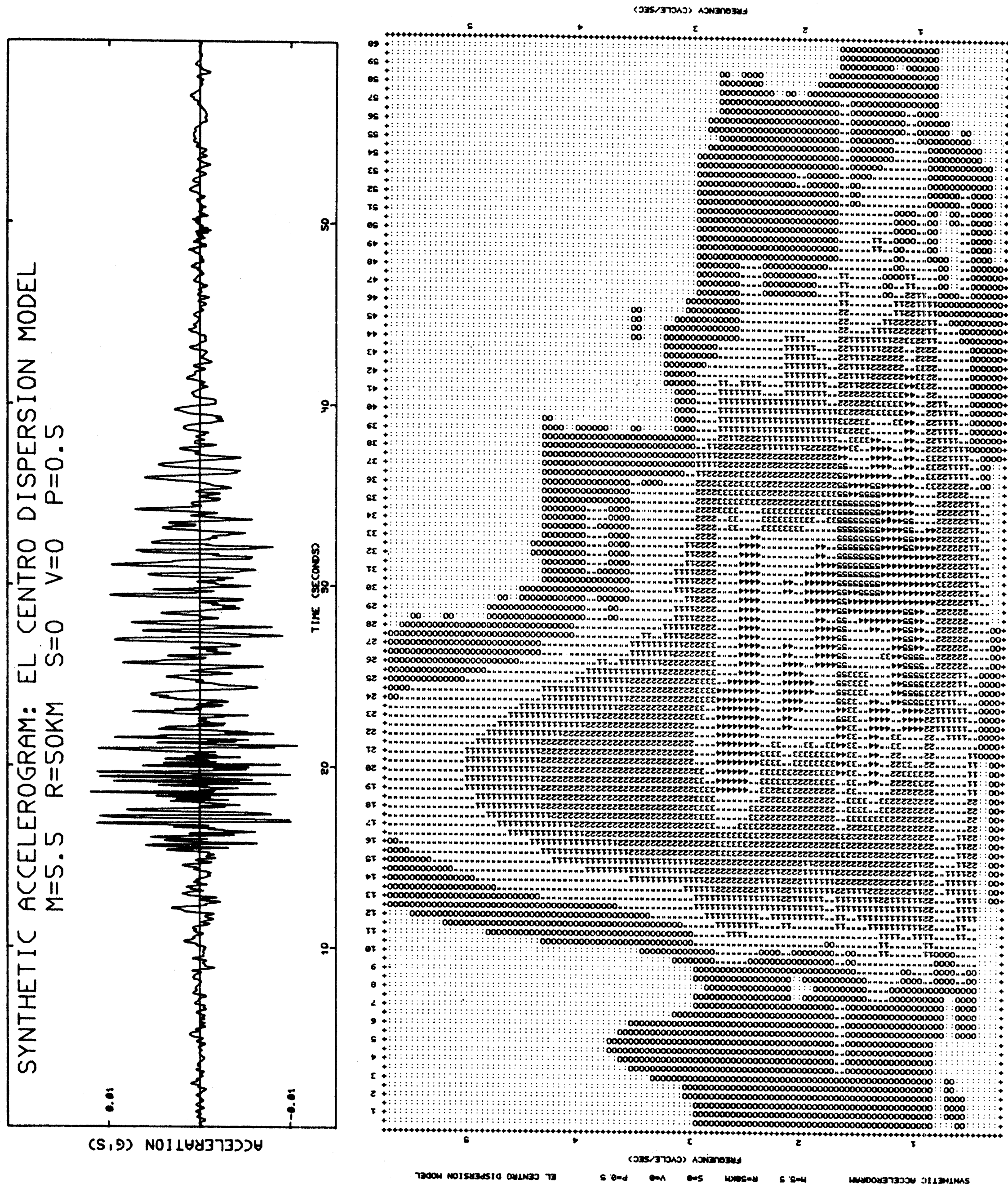
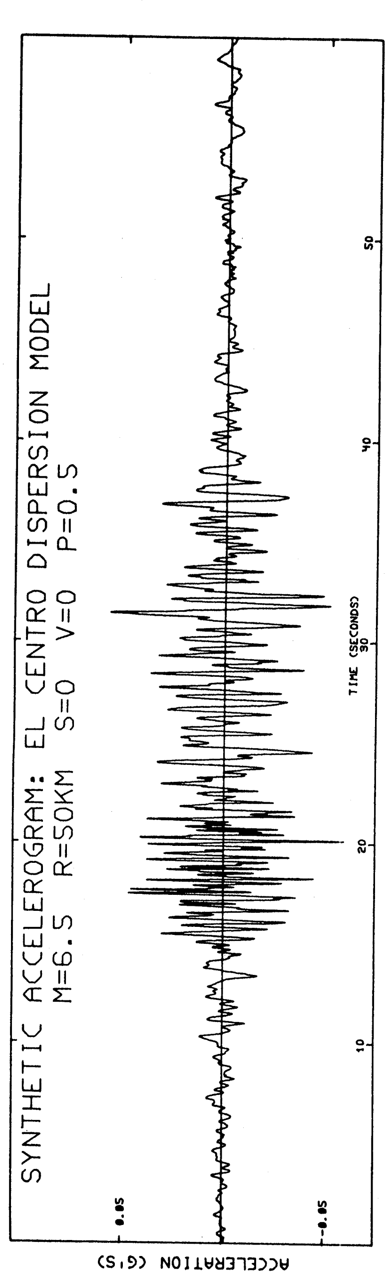

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=5.5 R=50KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
0.01
-0.01
10
20
30
40
50

Figure 12


SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=6.5 R=50KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
0.05
-0.05
10
20
30
40
50


FREQUENCY (CYCLE/SEC)
SYNTHETIC ACCELEROGRAM M=6.5 R=50KM S=0 V=0 P=0.5 EL CENTRO DISPERSION MODEL

Figure 13

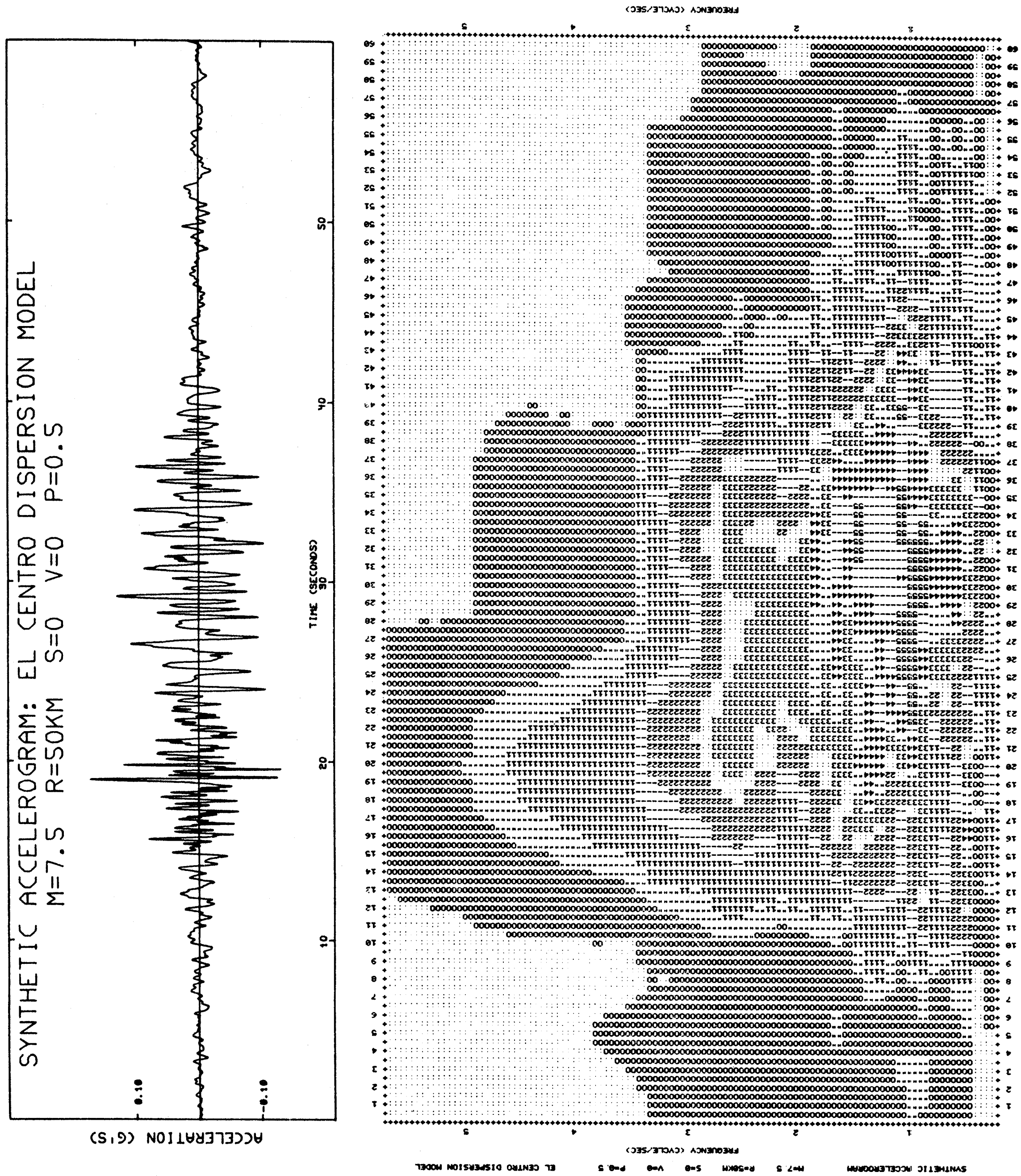

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=7.5 R=50KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 14

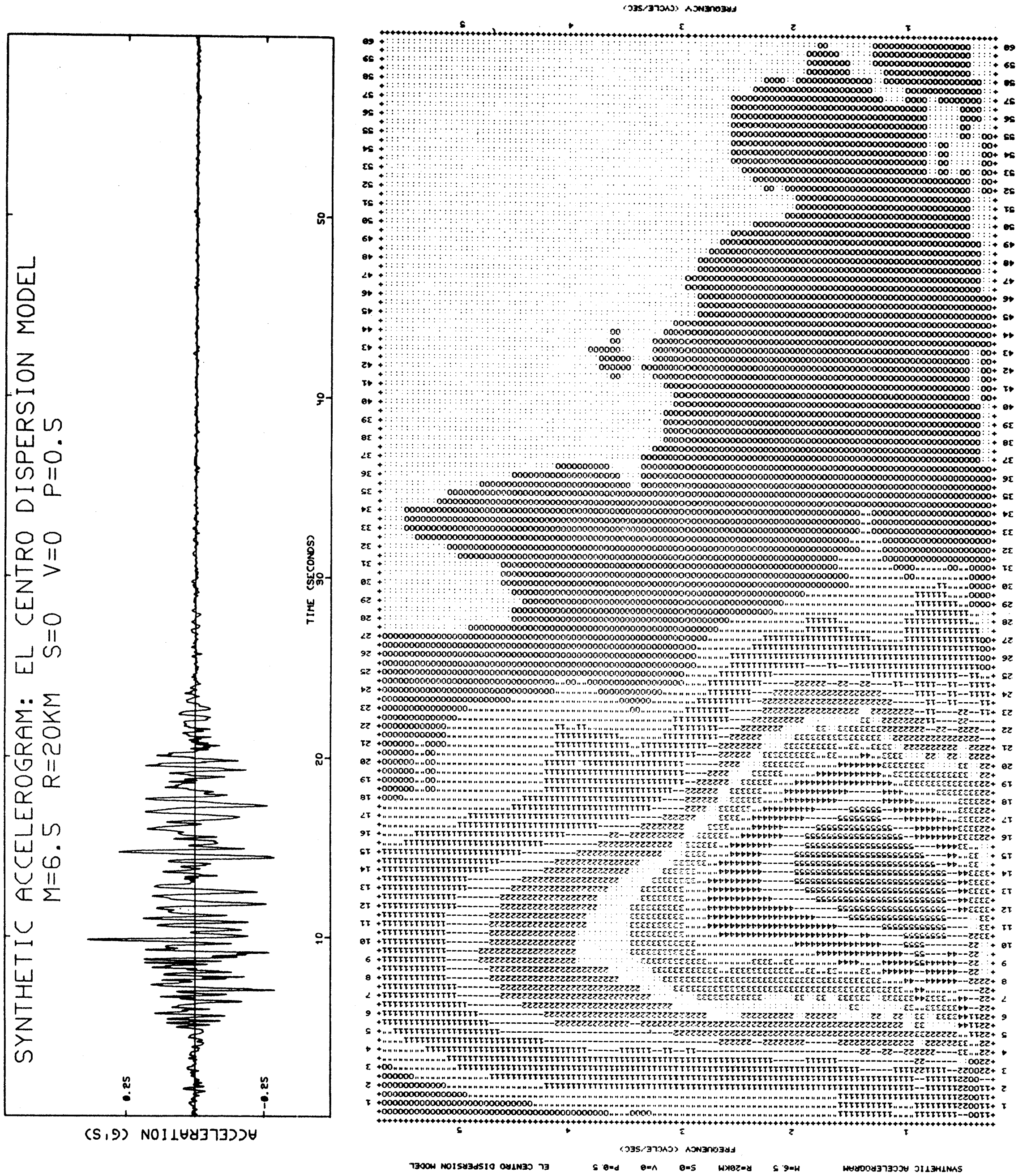
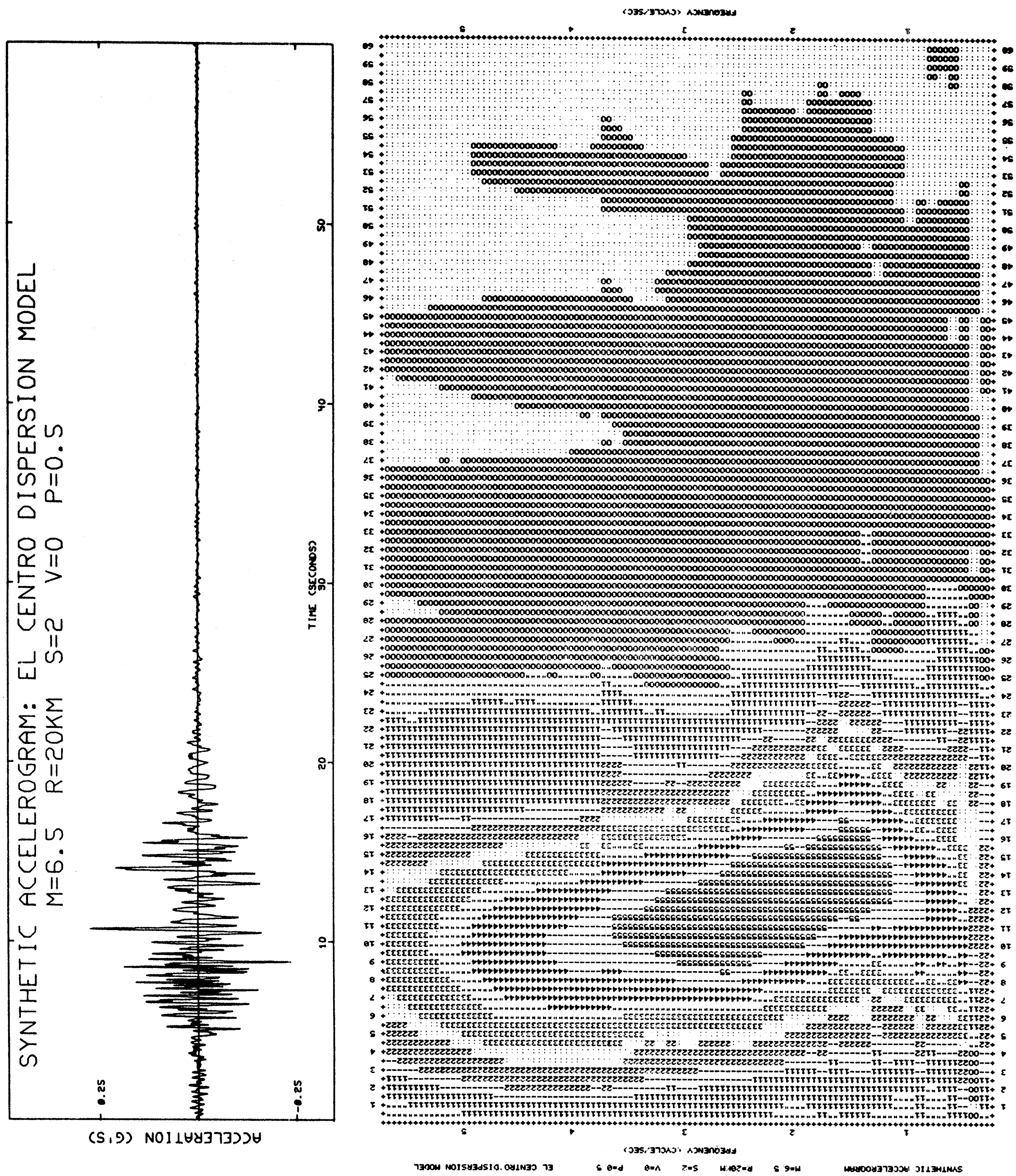

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=6.5 R=20KM S=0 V=0 P=0.5
ACCELERATION (G'S)
0.25
-0.25
TIME (SECONDS)
10
20
30
40
50
FREQUENCY (CYCLE/SEC)

Figure 15



SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=6.5 R=20KM S=2 V=0 P=0.5
ACCELERATION (G'S)
0.25
-0.25
TIME (SECONDS)
10
20
30
40
50
FREQUENCY (CYCLE/SEC)

Figure 16

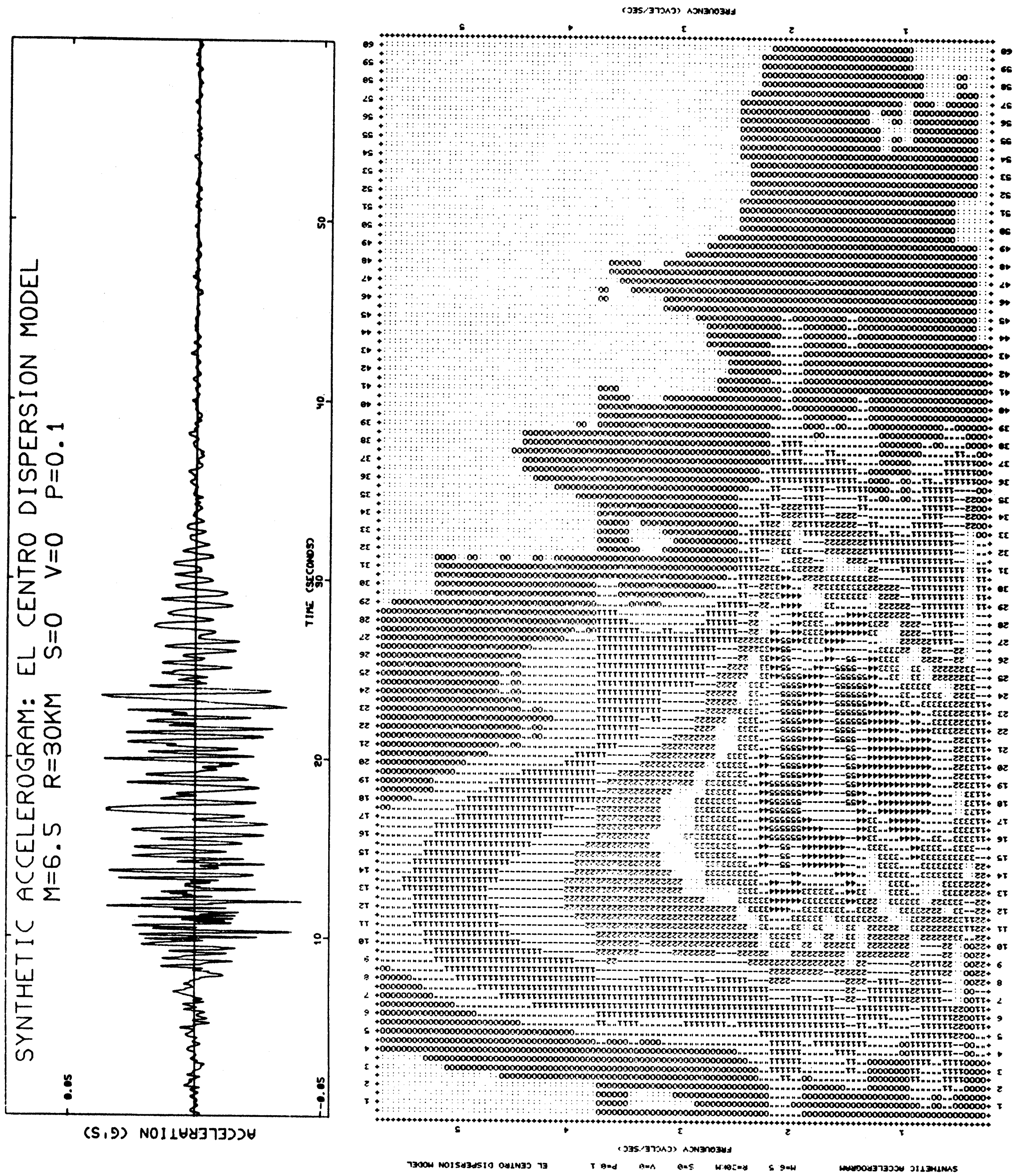

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=6.5 R=30KM S=0 V=0 P=0.1
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 17

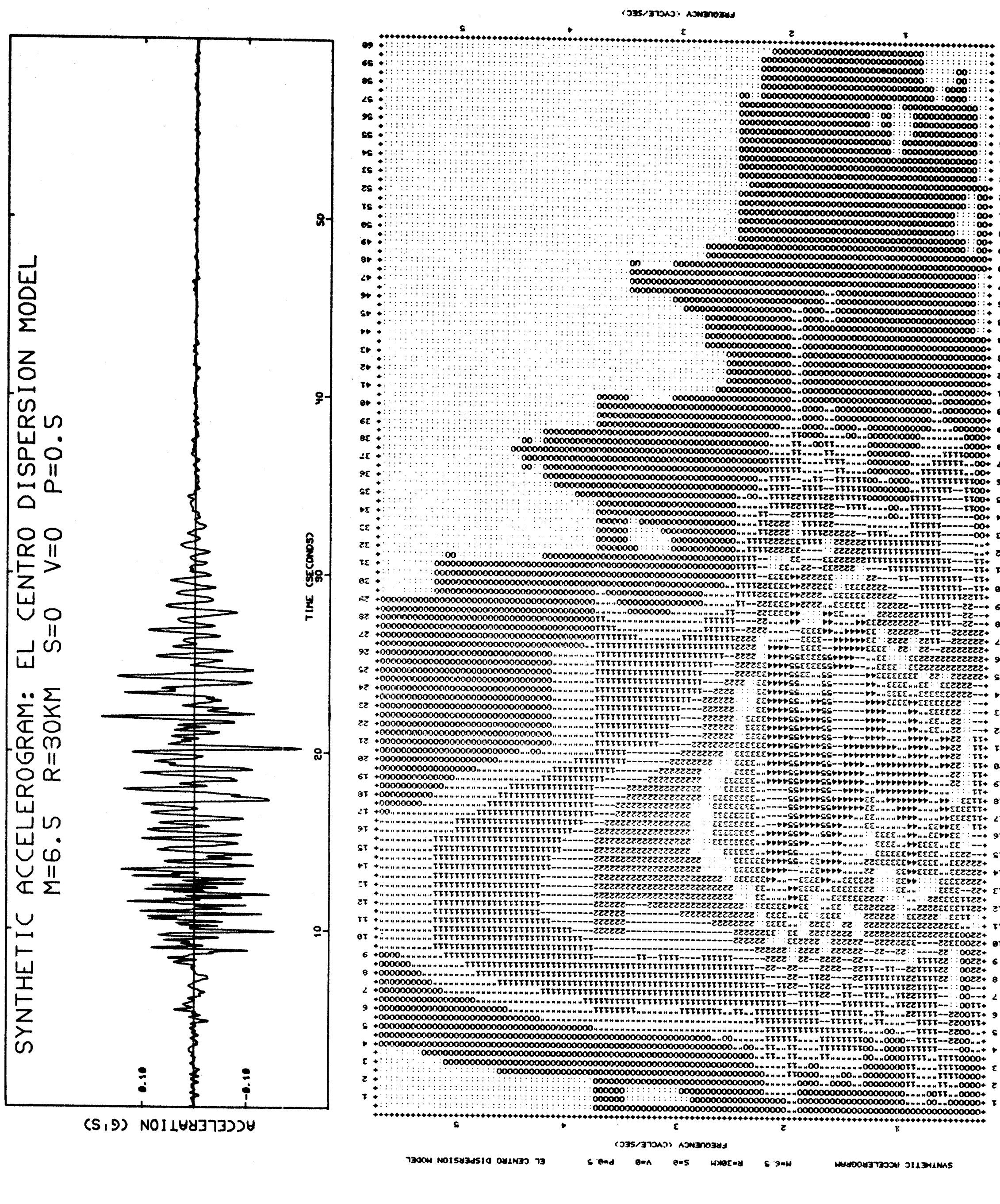

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=6.5 R=30KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 18

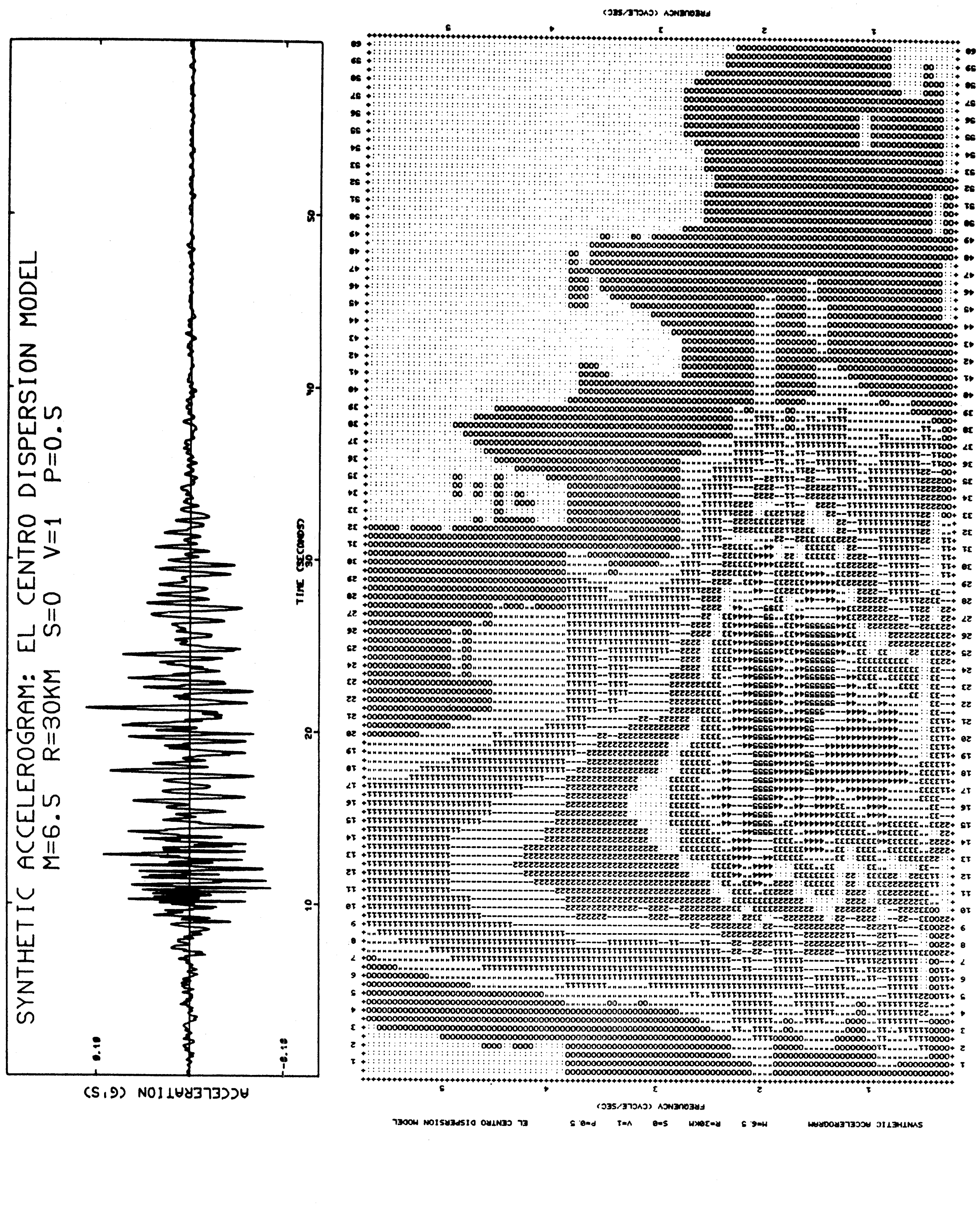

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
M=6.5 R=30KM S=0 V=1 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)

Figure 19

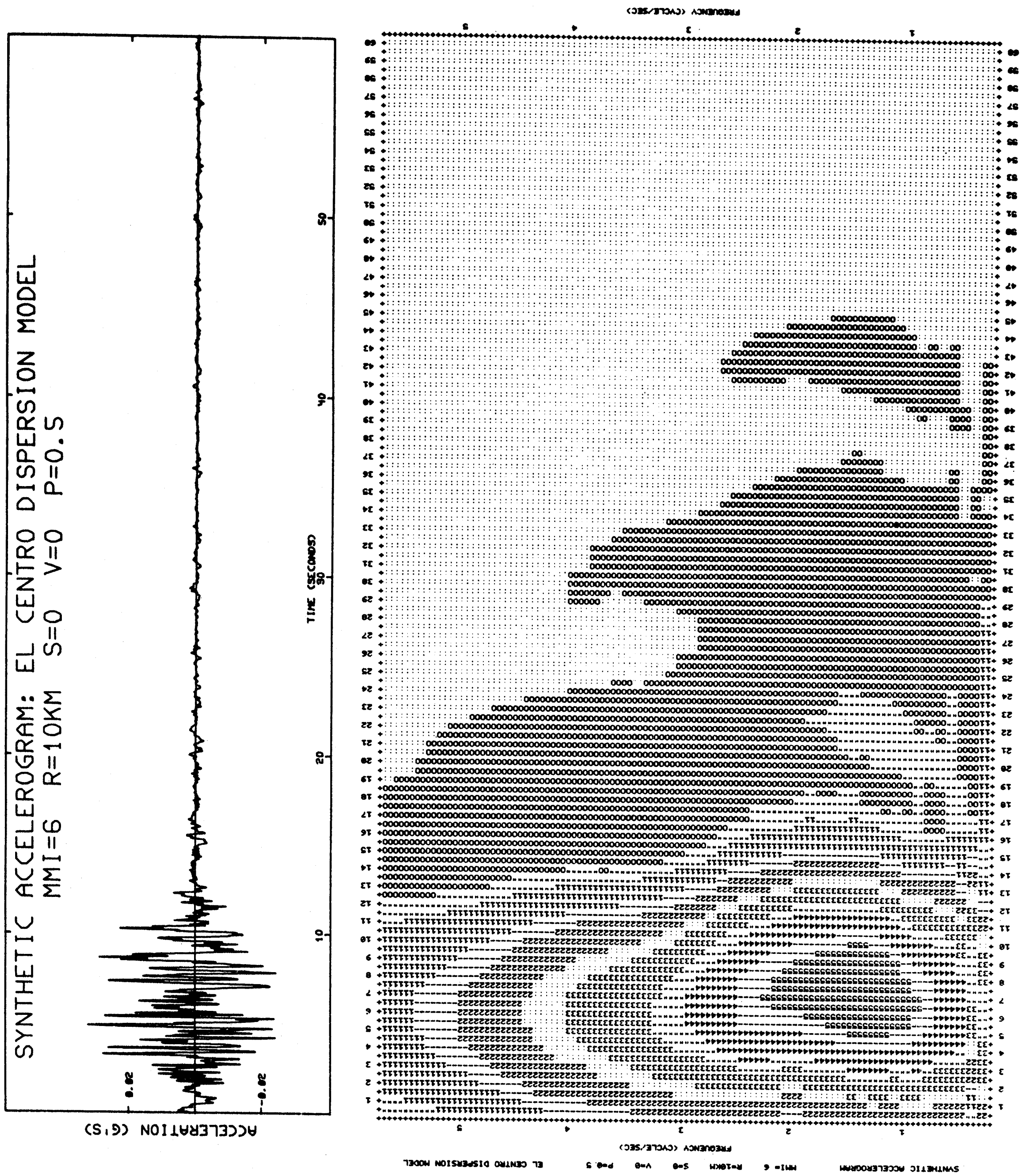

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
MMI=6 R=10KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)

Figure 20

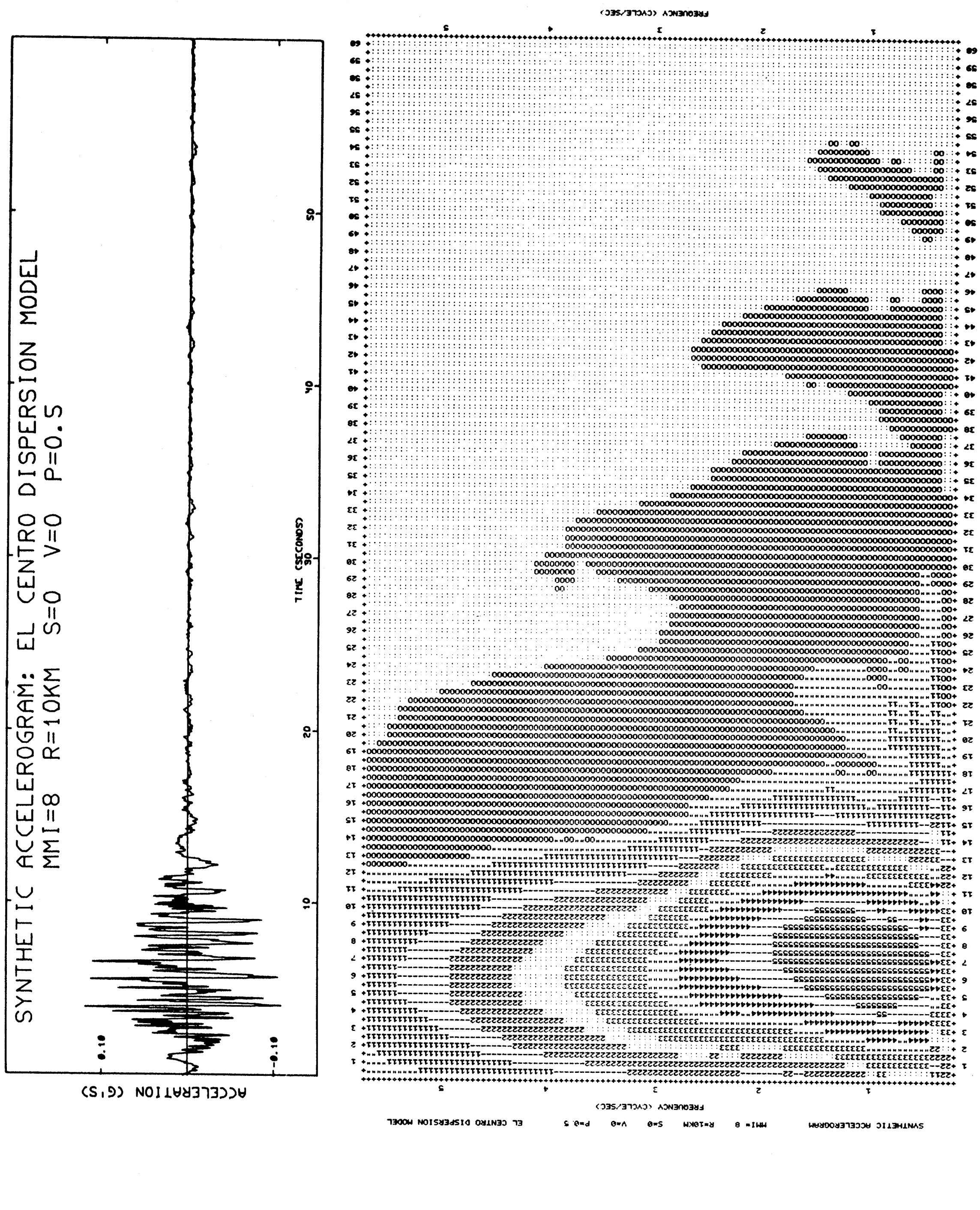
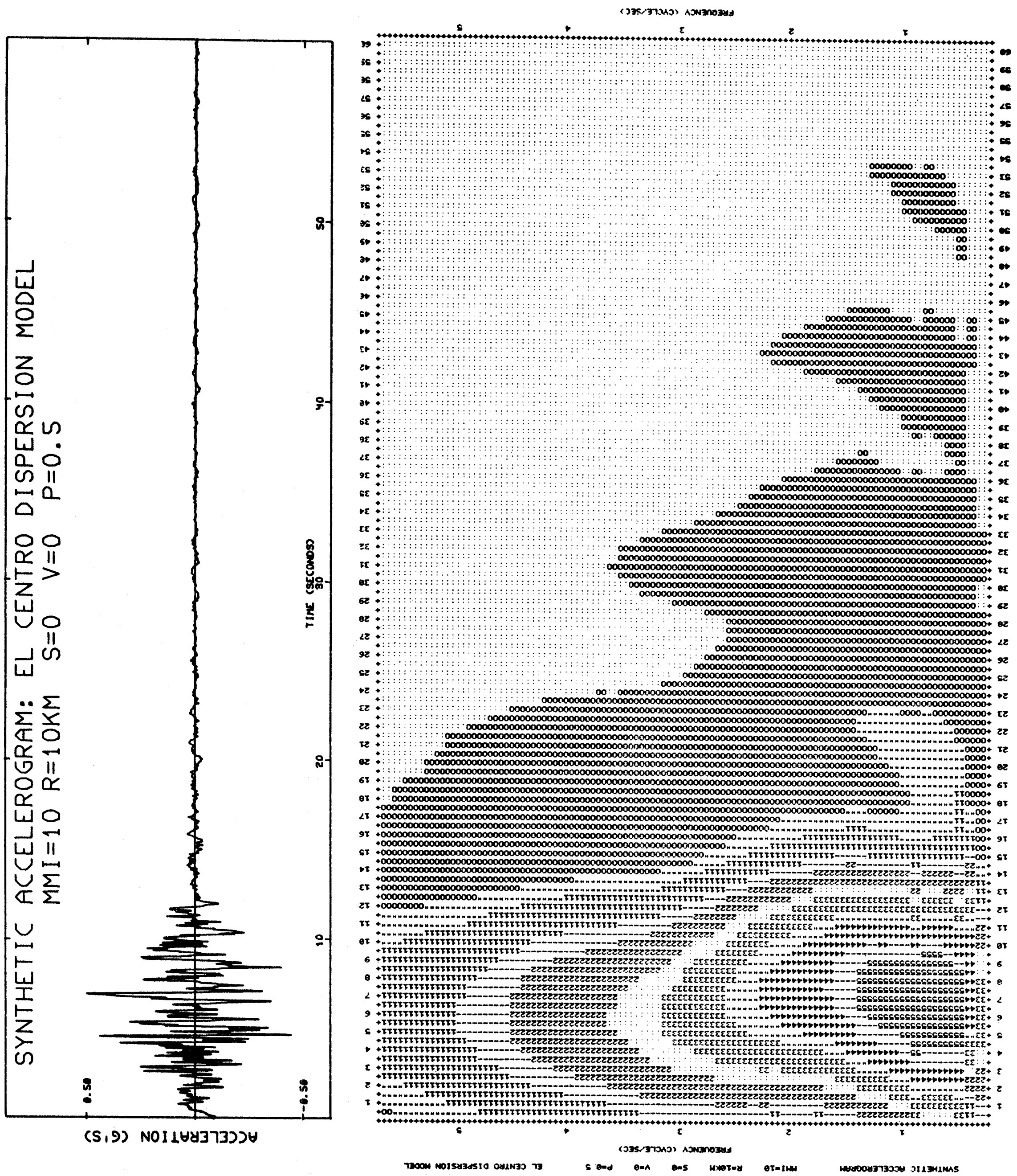

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
MMI=8 R=10KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 21



SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
MMI=10 R=10KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)

Figure 22

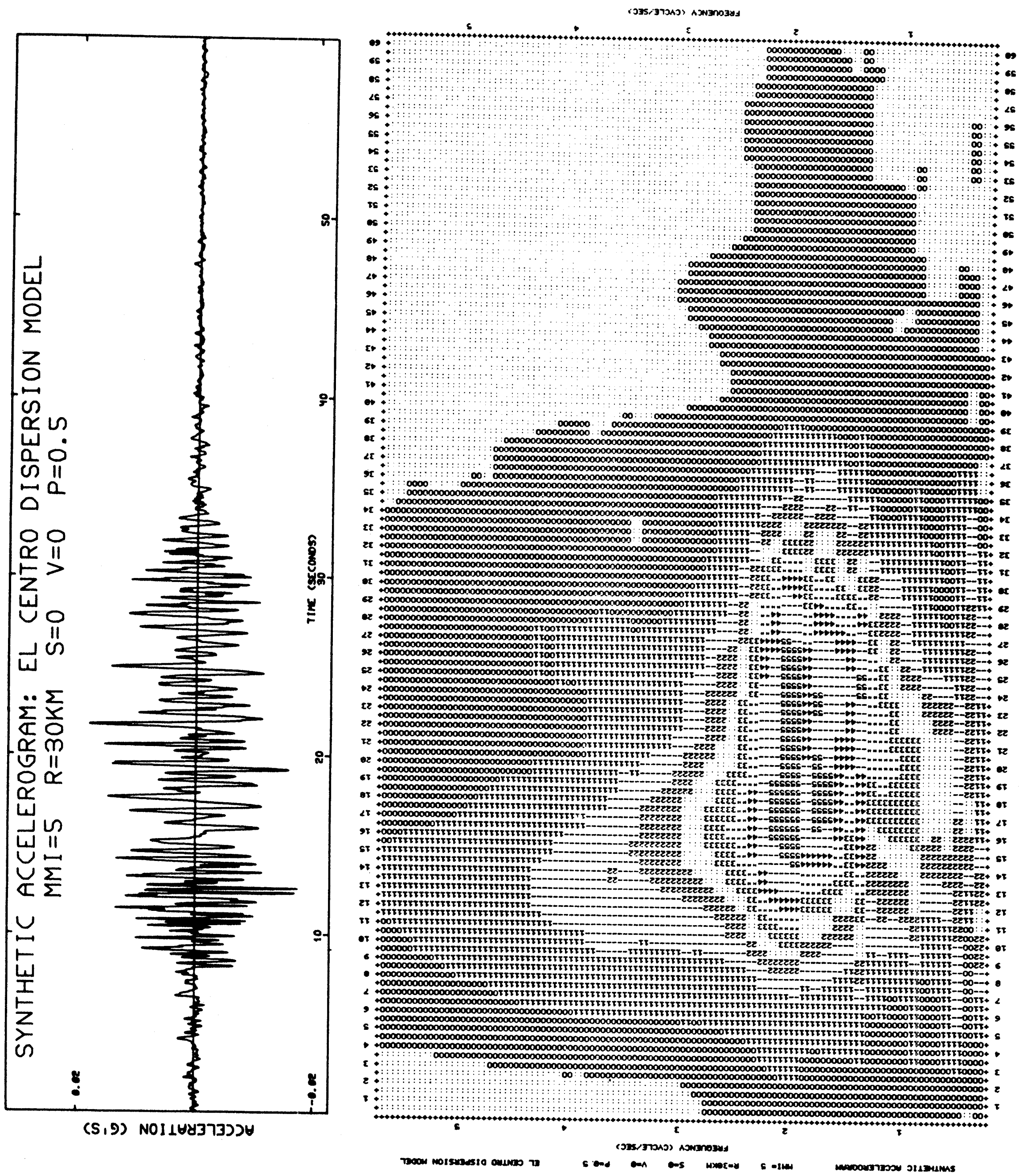

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
MMI=5 R=30KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 23

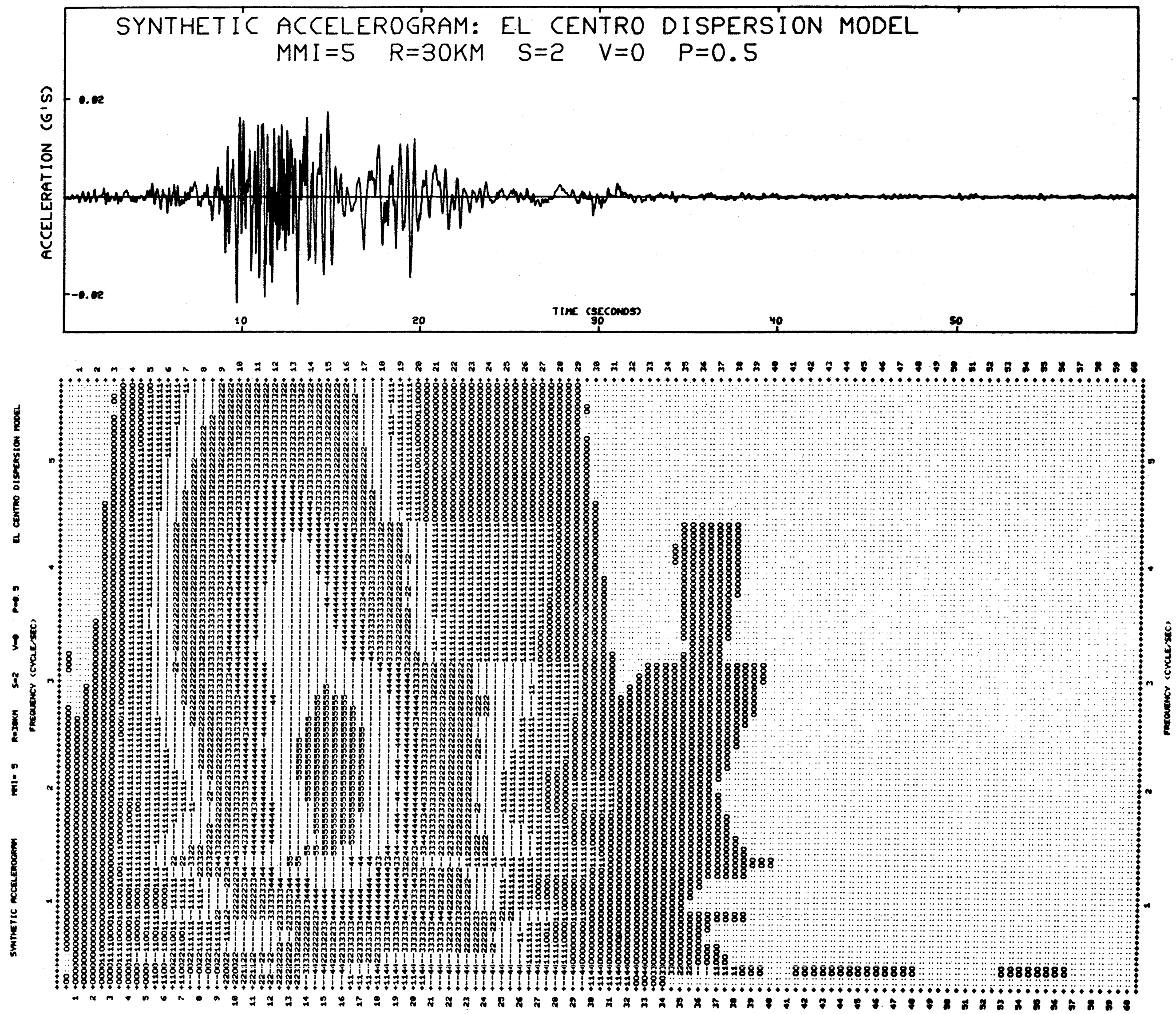

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
MMI=5 R=30KM S=2 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 24

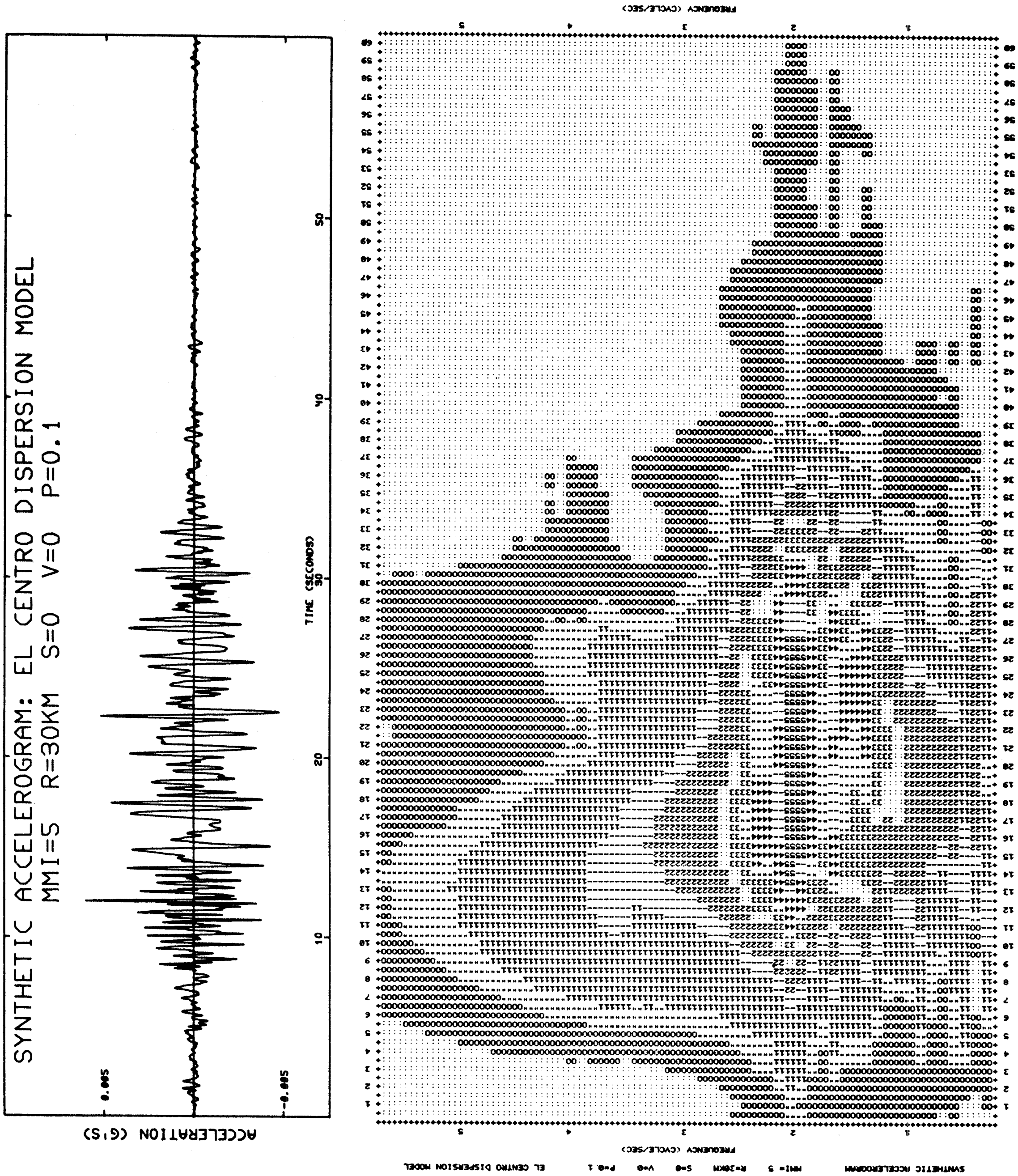

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
MMI=5 R=30KM S=0 V=0 P=0.1
ACCELERATION (G'S)
TIME (SECONDS)

Figure 25

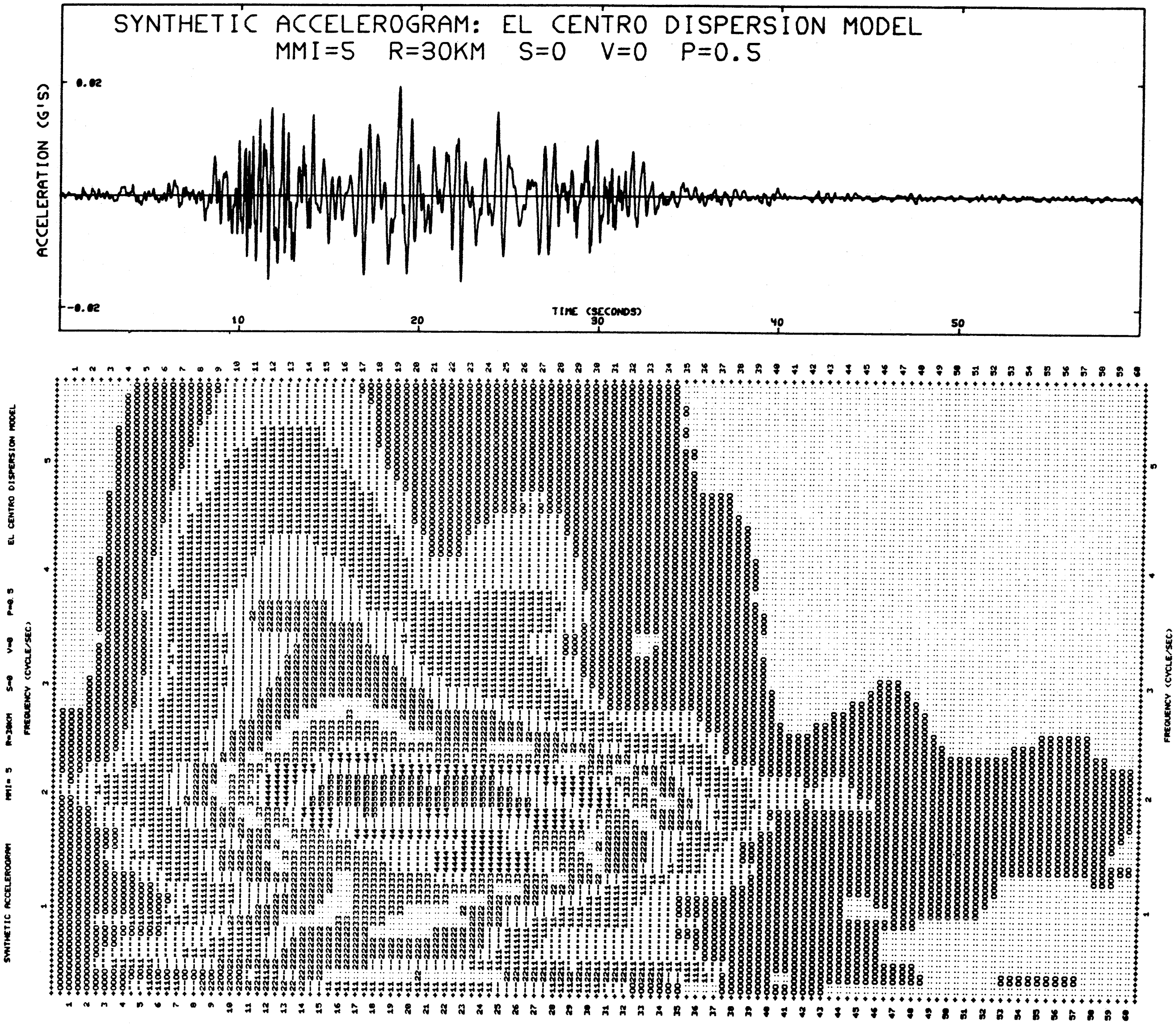

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
MMI=5 R=30KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 26

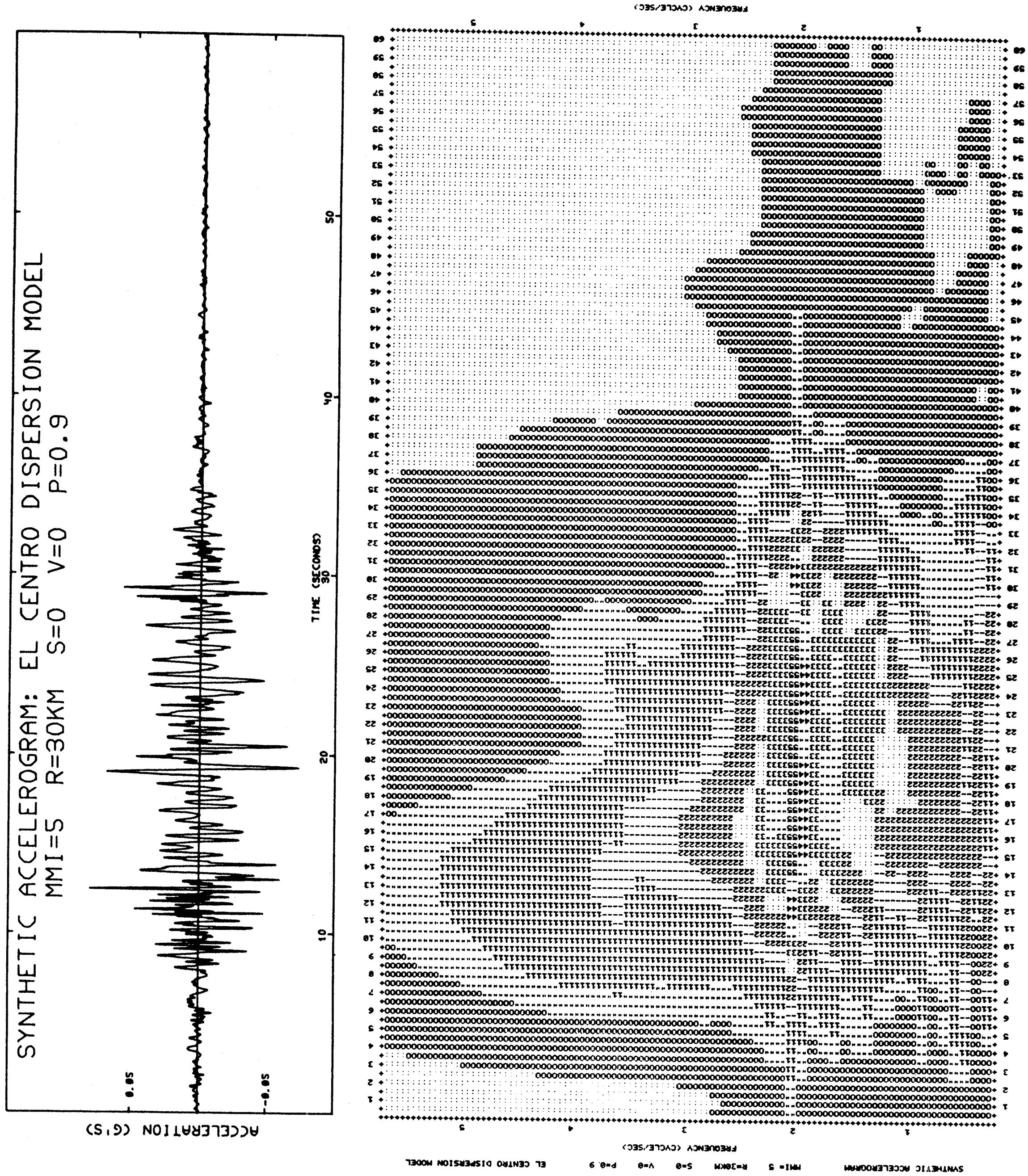

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
MMI=5 R=30KM S=0 V=0 P=0.9
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 27

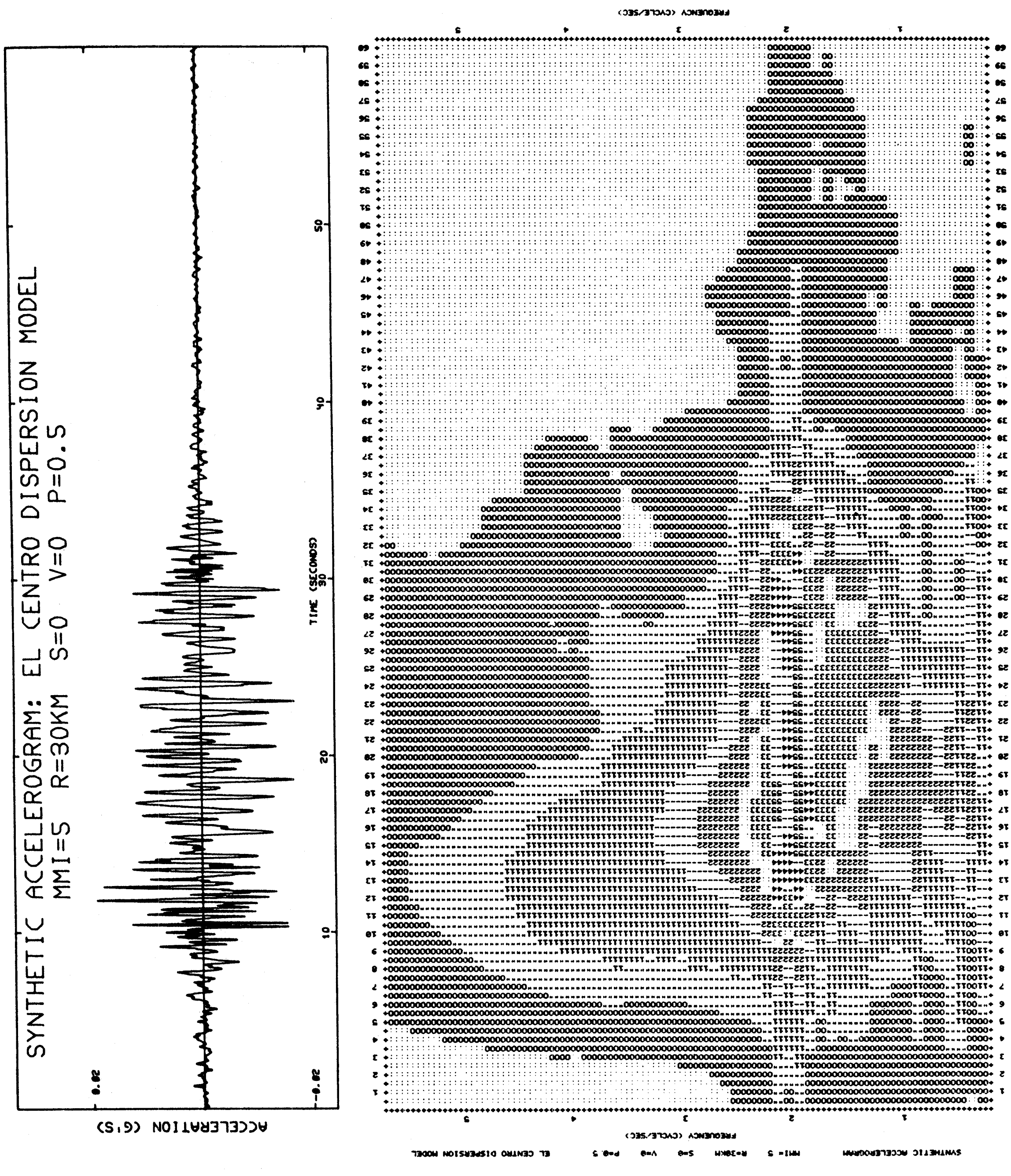

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
MMI=5 R=30KM S=0 V=0 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)
FREQUENCY (CYCLE/SEC)

Figure 28

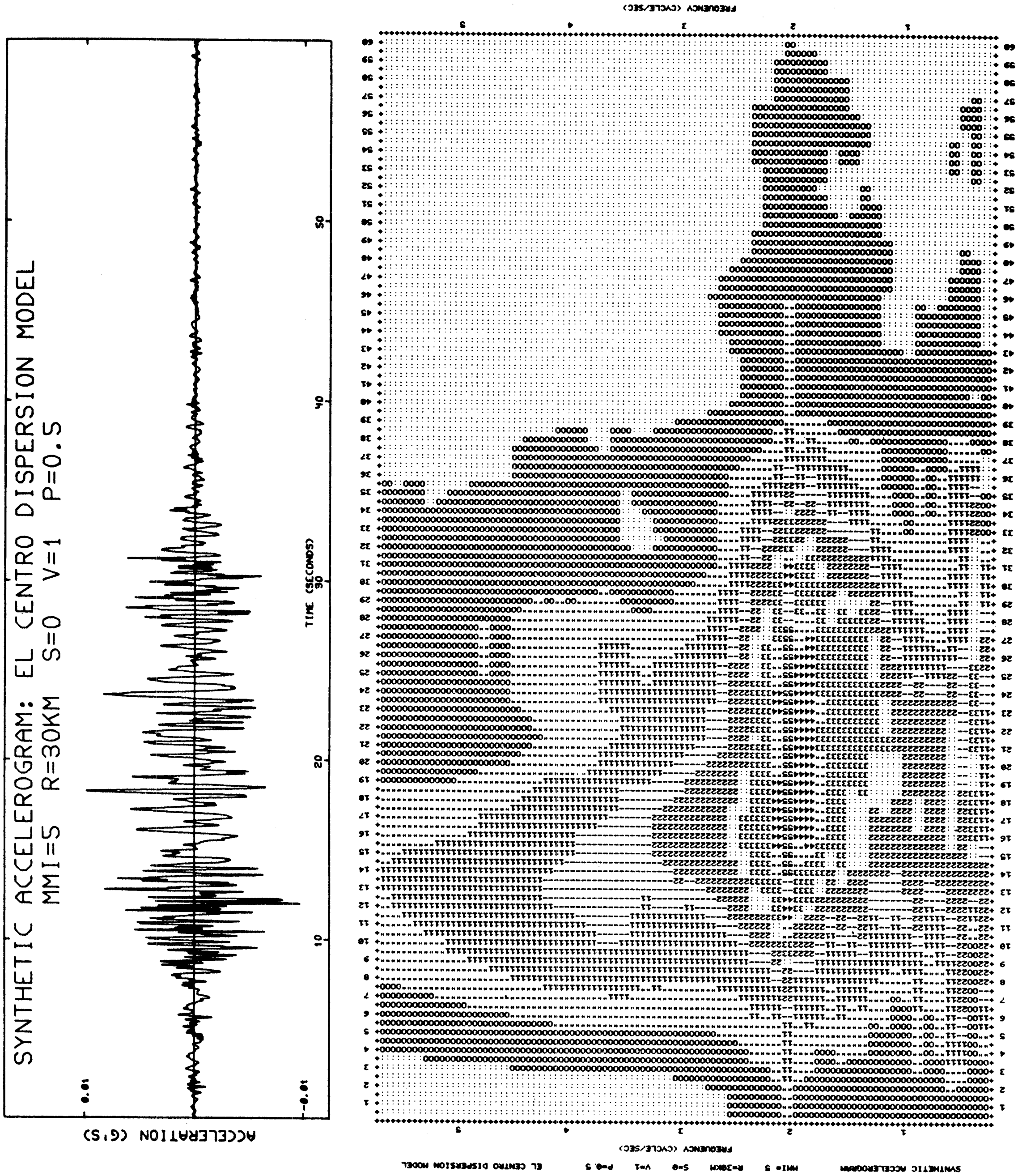

SYNTHETIC ACCELEROGRAM: EL CENTRO DISPERSION MODEL
MMI=5 R=30KM S=0 V=1 P=0.5
ACCELERATION (G'S)
TIME (SECONDS)

Figure 29

6.5 and 7.5) and for fixed R = 10 km, s=0 (alluvium), horizontal motions (v=0) and for p = 0.5 which approximates the average spectral amplitudes (Anderson and Trifunac, 1977). Figures 12, 13 and 14 present the same comparison but for R = 50 km.

The effect of different site conditions (s=2 for basement rock and s=0 for alluvium) is shown in Figures 15 and 16 for M = 6.5, R = 20 km, v=0 and p = 0.5. While the overall acceleration amplitudes are quite similar, for s=0 duration of strong shaking is longer that for s=2.

Figures 17 and 18 illustrate the effect of changing p; from 0.1 in Figure 17 to 0.5 in Figure 18. For other parameters fixed, it is seen that the overall amplitudes increase from p = 0.1 to p = 0.5. Thus, for the accelerogram in Figure 17 there is 90% chance that its amplitudes will be exceeded by strong shaking corresponding to M = 6.5, R = 30 km, s=0 and v=0. In Figure 18, this chance reduces to 50%.

Figures 18 and 19 show an example of the expected change between horizontal and vertical accelerations for M = 6.5, R = 30 km, s=0 and p = 0.5. It is seen that high frequency motion in the first part of strong motion is enhanced for v=1 relative to v=0.

Figures 20 through 29 present examples of synthetic accelerograms for scaling in terms of MMI scale at the site. Figures 20, 21 and 22 show the effect of MMI increasing from VI to X and for R = 10 km, s=0, v=0 and p = 0.5. Figures 23 and 24 present a comparison between s=0 and s=2 (alluvium and basement rock sites) and for MMI = V, R = 30 km, v=0 and p = 0.5.

Figures 25, 26 and 27 illustrate the effect of p increasing from

0.1 to 0.5 and 0.9. The examples for these three figures have been computed for MMI = V, R = 30 km, s=0 and v=0.

The last two figures illustrate the differences between horizontal (Figure 28) and vertical (Figure 29) accelerations, and for MMI = V, R = 30 km, s=0 and p = 0.5. As for accelerograms in Figures 18 and 19, it is seen here that vertical motions have higher high-frequency content in the first part of strong motion.

CONCLUSIONS

In this report, we have presented a method for synthesizing realistic strong motion accelerograms for use in engineering design. The advantages of this method are that the results have almost all known characteristics of strong shaking. In particular, these artificial accelerograms have nonstationary characteristics in time which are derived from known dispersive properties of earthquake waves guided through shallow low velocity layers of the earth's crust. These dispersive characteristics can be introduced directly as an input into the computer program (see Appendix A) and thus can portray directly the geologic environment of each specific site. Other scaling functionals required for synthesis of artificial accelerograms presented here are (1) Fourier amplitude spectrum, and (2) frequency dependent duration of strong shaking. These two functionals can be estimated either in terms of empirical scaling relations developed in terms of earthquake magnitude (Trifunac, 1976; Trifunac and Lee, 1978; Trifunac and Westermo, 1976a; Westermo and Trifunac, 1978) or in terms of Modified Mercalli Intensity (Trifunac, 1978; Trifunac and Lee, 1978; Trifunac and Westermo, 1976b; Westermo and Trifunac, 1979).

ACKNOWLEDGEMENTS

We thank J.G. Anderson and B.D. Westermo for critical reading of the manuscript and for useful suggestions.

This work was supported by a contract from the United States Nuclear Regulatory Commission.

REFERENCES

Anderson, J.G., and M.D. Trifunac (1977). On Uniform Risk Functionals which Describe Strong Earthquake Ground Motion: Definition, Numerical Estimation and an Application to the Fourier Amplitude of Acceleration, Report No. CE 77-02, U.S.C., Los Angeles.

Amin, M., and A.H. Ang (1966). A Nonstationary Stochastic Model for Strong Motion Earthquakes, Structural Research Series No. 306, Department of Civil Engineering, University of Illinois.

Bogdanoff, J.L., J.E. Goldberg, and M.C. Bernard (1961). Response of a Simple Structure to a Random Earthquake-like Disturbance, Bull. Seism. Soc. Am., 51, 293-310.

Bolotin, V.V. (1960). Statistical Theory of Asiesmic Design of Structures, Proc. Wrold Conference on Earthquake Engineering, 2nd, Japan, pp.1365-1374.

Bycroft, G.N. (1960). White-noise Representation of Earthquakes, J. Eng. Mech. Div., Am. Soc. Civil Engrs., 86, 1-16.

Cornell, C.A. (1964). Stochastic Process Models in Structural Engineering, Technical Report No. 34, Department of Civil Engineering, Stanford University.

Goodman, L.E., E. Rosenblueth, and N.M. Newmark (1955). Aseismic Design of Firmly Founded Elastic Structures, Transactions Am. Soc. Civil Engrs., 120, 782-802.

Goto, H., K. Toki, and T. Aiyoshi (1966). Generation of Artificial Earthquakes on Digital Computer for Asiesmic Design of Structures, Proc. Japan Earthquake Eng. Symp., pp 25-30.

Goto, H., and H. Kameda (1969). Statistical Inference on Future Earthquake Ground Motion, Proc. World Conf. Earthquake Eng., 4th, Santiago, Chile.

Goto, H., and K. Toki (1969). Structural Response to Nonstationary Random Excitation, Proc. World Conf. Earthquake Eng., 4th, Santiago, Chile.

Honda, H. (1957). The Mechanism of Earthquakes, Geophysics Institute, Tohoku University, 9, 5, 1-46.

Housner, G.W. (1947). Characteristics of Strong Motion Earthquakes, Bull. Seism. Soc. Am., 37, 19-31.

Housner, G.W. (1955). Properties of Strong Ground Motion Earthquakes, Bull. Seism. Soc. Am., 45, 187-218.

Housner, G.W., and P.C. Jennings (1964). Generation of Artificial Earthquakes, J. Eng. Mech. Div., Am. Soc. Civil Engrs., 90, pp. 113-150.

Hudson, D.E. (1956). Response Spectrum Techniques in Engineering Seismology, World Conference on Earthquake Engineering, Berkeley, California.

Hudson, D.E. (1976). Strong Motion Earthquake Accelerograms, Index Volume, Earthquake Eng. Res. Lab. EERL 76-02, Calif. Inst. of Tech., Pasadena.

Jennings, P.C., G.W. Housner, and N.C. Tsai (1968). Simulated Earthquake Motions, Earthquake Engineering Research Laboratory, California Institute of Technology, Pasadena, California.

Penzien, J., and S.C. Liu (1969). Nondeterministic Analysis of Nonlinear Structures Subjected to Earthquake Excitations, Proc. World Conf. Earthquake Eng., 4th, Santiago, Chile.

Rascon, O.A., and A.C. Cornell (1969). A Physically Based Model to Simulate Strong Earthquake Records on Firm Ground, Proc. World Conf. Earthquake Engr., 4th, Santiago, Chile.

Richter, C.F. (1958). Elementary Seismology, Freeman and Co., San Francisco.

Rosenblueth, E. (1956). Some Applications of Probability Theory on Aseismic Design, World Conference on Earthquake Engineering, Berkeley, California.

Rosenblueth, E., and J.E. Bustamante (1962). Distribution of Structural Response to Earthquakes, J. Eng. Mech. Div., Am. Soc. Civil Engrs., 88, 75-106.

Shinozuka, M., and Y. Sato (1967). Simulation of Nonstationary Random Processes, J. Eng. Mech. Div., Am. Soc. Civil Engrs., 93, 11-40.

Tajimi, H. (1960). A Statistical Method of Determining the Maximum Response of Building Structure During an Earthquake, Proc. World Conf. Earthquake Eng., 2nd, Japan.

Trifunac, M.D. (1971a). Response Envelope Spectrum and Interpretation of Strong Earthquake Ground Motion, Bull. Seism. Soc. Am., 61, 343-356.

Trifunac, M.D. (1971b). A Method for Synthesizing Realistic Strong Ground Motion, Bull. Seism. Soc. Amer., 61, 1739-1753.

Trifunac, M.D. (1972a). Stress Estimates for San Fernando, California, Earthquake of 9 February 1971: Main Event and Thirteen Aftershocks, Bull. Seism. Soc. Amer., 62, 721-750.

Trifunac, M.D. (1972b). Tectonic Stress and Source Mechanism of the Imperial Valley, California, Earthquake of 1940, Bull. Seism. Soc. Amer., 62, 1283-1302.

Trifunac, M.D. (1973). Analysis of Strong Earthquake Ground Motion for Prediction of Response Spectra, Int. J. of Earthquake Eng. and Struct. Dyn., Vol. 2, No. 1, 59-69.

Trifunac, M.D. (1976). Preliminary Empirical Model for Scaling Fourier Amplitude Spectra of Strong Ground Acceleration in Terms of Earthquake Magnitude, Source to Station Distance and Recording Site Conditions, Bull. Seism. Soc. Am., 66, 1343-1373.

Trifunac, M.D., and A.G. Brady (1975). A Study on the Duration of Strong Earthquake Ground Motion, Bull. Seism. Soc. Amer., 65, 581-626.

Trifunac, M.D., and J.G. Anderson (1977). Preliminary Empirical Models for Scaling Absolute Acceleration Spectra, Dept. of Civil Engr., Report No. 77-03, U.S.C., Los Angeles.

Trifunac, M.D. (1978). Preliminary Empirical Model for Scaling Fourier Amplitude Spectra of Strong Motion Acceleration in Terms of Modified Mercalli Intensity and Geologic Site Conditions, Int. J. of Earthquake Eng. and Struct. Dyn. (in press).

Trifunac, M.D., and B.D. Westermo (1976a). Dependence of Duration of Strong Earthquake Ground Motion on Magnitude, Epicentral Distance, Geologic Conditions at the Recording Station and Frequency of Motion, Dept. of Civil Engr., Report No. 76-02, U.S.C., Los Angeles.

Trifunac, M.D., and B.D. Westermo (1976b). Correlations of Frequency Dependent Duration of Strong Earthquake Ground Motion with the Modified Mercalli Intensity and the Geologic Conditions at the Recording Stations, Dept. of Civil Engr., Report No. 77-03, U.S.C., Los Angeles.

Trifunac, M.D., and V.W. Lee (1978). Dependence of the Fourier Amplitude Spectra of Strong Motion Acceleration on the Depth of Sedimentary Deposits, Dept. of Civil Engr., Report No. 78-14, U.S.C., Los Angeles,

Westermo, B.D., and M.D. Trifunac (1978). Correlations of the Frequency Dependent Duration of Strong Earthquake Ground Motion with the Magnitude, Epicentral Distance and the Depth of Sediments at the Recording Site, Dept. of Civil Eng., Report No. 78-13, U.S.C., Los Angeles.

Westermo, B.D., and M.D. Trifunac (1979). Correlations of the Frequency Dependent Duration of Strong Ground Motion with the Modified Mercalli Intensity and the Depth of Sediments at the Recording Site, Report No. 79-01, U.S.C., (in press).

APPENDIX A

Program Description for "SYNACC"

By compiling the theory and data presented in this report, a computer program, "SYNACC," is made available for the generation of artificial accelerograms. This program is written in standard FORTRAN-IV and there are several features in this program that will allow easy applications.

1) The core space needed for this program is dynamically allocated so that only one dimension has to be changed if the input parameters demand more core than originally allowed. There are two locations in the programs (lines SYN01200 and SYN01260) where the core requirement is checked; the program will automatically stop if a larger dimension for the array ACC (line SYN00060) is needed. After increasing the dimension of ACC, the user must also increase the value of MBIG to the newly set dimension (line SYN00100).

2) The unit numbers of the peripheral devices are made variable because they may vary depending on the system used. NU1 should be set to the user's input device (e.g., a card reader), NU2 to the unit number of the line printer, and NU3 should be assigned to a permanent storage device such as a disk or a magnetic tape if the accelerogram generated is to be saved for future use. Currently, NU1, NU2, NU3 are 5, 6, and 7, respectively; for an IBM computer, 5 is a card reader, 6 is the line printer, and 7 is the card puncher.

3) Programmed into SYNACC are five options by which the synthetic accelerograms can be generated. The first four options use the correlation functionals developed by Lee, Trifunac and Westermo to calculate the Fourier amplitude spectrum and the duration, while the fifth option allows the users to specify their own. The scaling parameters required for the first four options are:

<u>Option #1</u>: Magnitude, M, distance, R, in kilometers, site condition, s, component direction, v, and confidence level, p_a.

<u>Option #2</u>: Modified Mercalli Intensity, I_{MM}, at the site, site condition, s, component direction, v, and confidence level, p_a.

<u>Option #3</u>: Magnitude, M, distance, R, in kilometers, depth of sediments in kilometers, component direction, v, and confidence level, p_a.

<u>Option #4</u>: Modified Mercalli Intensity, I_{MM}, at the site, depth of alluvium in kilometers, component direction, v, and confidence level, p_a.

For a more detailed description of these parameters, refer to Section 2 of the text.

<u>Input Data Format</u>

<u>1st DATA CARD</u> (Read by the main program, line SYN00190)

```
     READ(NU1,10)ICHOIC,IFDUR,IPUNCH,IGYZBE
 10  FORMAT(4I5)
```

ICHOIC - an integer from 1 to 5, specifying the option to be used to generate the synthetic accelerogram.

IFDUR - if IFDUR = 0, do not impose the empirical scaling durations;

with this option, the epicentral distance and the input dispersion curves will automatically produce desired duration.

if IFDUR = 1, impose the empirical duration scaling

IPUNCH - if IPUNCH = 0, do not output accelerogram through unit NU3;

if IPUNCH = 1, output accelerogram through unit NU3.

IGYZBE - an odd integer from 1 to 1023, used as a starter for the random number generator. There are a total of 512 different accelerograms that can be generated by using a different starting value of IGYZBE. The limit of 512 is only a restriction given by URAND, a subroutine written to accomodate computers with 16-bit integer words. For computers having integer words of 32 bits or more, a random number generator can be substituted to generate 2^{31} different accelerograms. In nearly all cases, this is not required.

<u>2nd DATA CARD</u> depends on the value of ICHOIC

ICHOIC = 1, otherwise, ignore this option (line SYN00320)

```
110  READ(NU1,120)DIST,AM,PR,IS,IV
120  FORMAT(F6.1,2F5.2,2I5)
```

DIST = epicentral distance in kilometers,

AM = magnitude M,

PR = confidence level p_a, from 0.05 to 0.95

IS = site condition s,

IS=0, alluvium
IS=1, intermediate
IS=2, hard rock

IV = component direction, v

IV=0, horizontal
IV=1, vertical

If ICHOIC = 2, otherwise, ignore this option (Line SYN00450)

```
210  READ(NU1,220)DIST,MMI,PR,IS,IV
220  FORMAT(F6.1,I5,F5.2,2I5)
```

DIST = epicentral distance in kilometers

MMI = an integer representing the Modified Mercalli Intensity at the site

PR = confidence level, p_a, from 0.05 to 0.95

IS = site condition s,

IS=0, alluvium
IS=1, intermediate
IS=2, hard rock

IV = component direction v,

IV=0, horizontal
IV=1, vertical

If ICHOIC = 3, otherwise, ignore this option (line SYN00580)

```
310  READ(NU1,320)DIST,AM,PR,DEPTH,IV
320  FORMAT(F6.1,3F5.2,I5)
```

DIST = epicentral distance in kilometers

AM = magnitude, M

PR = confidence level p_a, from 0.05 to 0.95

DEPTH = depth of sediments in kilometers

IV = component direction v,

IV=0, horizontal
IV=1, vertical

If ICHOIC = 4, otherwise, ignore this option (line SYN00710)

```
410  READ(NU1,420)DIST,MMI,PR,DEPTH,IV
420  FORMAT(F6.1,I5,2F5.2,I5)
```

DIST = epicentral distance in kilometers

MMI = an integer representing the Modified Mercalli Intensity at the site

PR = confidence level p_a, from 0.05 to 0.95

DEPTH = depth of sediments in kilometers

IV = component direction v,
IV=0, horizontal
IV=1, vertical

NOTE: The time increment $\Delta t = 0.02$ is automatically set for the first four options because no empirical data is available for frequencies higher than the Nyquist frequency of 25 cycle/sec.

If ICHOIC = 5, otherwise, ignore this option (line SYN00830)

```
510   READ(NU1,520)NTAB
520   FORMAT(I5)
      DO 540 IJ=1,NTAB
      READ(NU1,530)TU(IJ),AU(IJ)
530   FORMAT(2E10.3)
540   CONTINUE
      READ(NU1,550)DT
550   FORMAT(E10.3)
```

NTAB = number of points in the Fourier amplitude table to be read in by the user,

TU(IJ),AU(IJ) = the periods T and amplitudes FS, respectively. These must be read in as one pair per card in 2E10.3 format, and there should be a total of NTAB cards. The unit of TU is in seconds, and the unit of FS is in g-sec where g is the acceleration of gravity, either 9.81 m/sec^2 or 32.197 ft/sec^2

DT = the time increment, Δt in seconds.

<u>3rd DATA CARD</u> (Read by the main program, line SYN01030. Note, this is not the 3rd card for option ICHOIC = 5.)

```
610  READ(NU1,620)NWAVE
620  FORMAT(I5)
```

NWAVE = the total number of surface wave modes to be considered in the superposition of surface wave contributions.

THE FINAL DATA CARDS (Read by the subprogram READW, lines SYN01700 and SYN01770)

```
     DO 30 IW=1,NWAVE
     READ(NU1,10)MODNUM(IW),KPOINT(IW)
10   FORMAT(2I5)
     READ(N 1,20)(T(K),V(K),K=1,KPOINT(IW))
20   FORMAT(16F5.2)
30   CONTINUE
```

MODNUM(IW) = the mode number of the IWth mode, use a positive integer if it is Rayleigh wave, but use a negative integer if it is a Love wave. The sign is used for identification purposes only.

KPOINT(IW) = the number of points required to digitize the dispersion curve for this particular mode so that it can be interpolated linearly.

T(K),V(K) = the period in seconds, and the group velocity in km/sec for the dispersion curve. There is a total of KPOINT(IW) pairs of T and V, read in as 8 pairs per card in 16F5.2 format until all pairs are read.

EXAMPLE :

The following input data are designed for the parameters :

(1) I_{MM} = VII

(2) p_a = 0.5

(3) R = 30 km

(4) Effective depth of top layer = 0

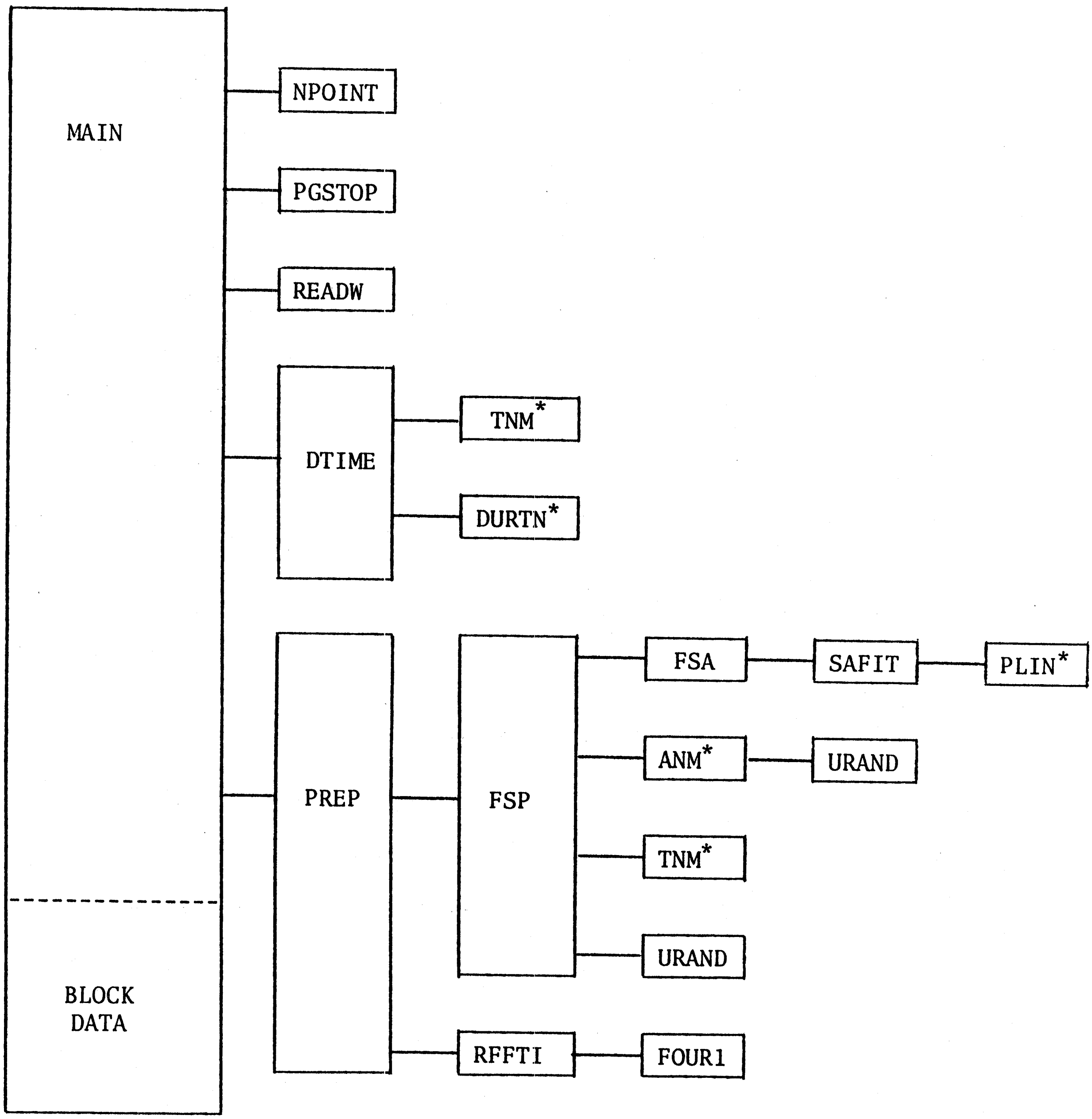
(5) component = horizontal

(6) total of 14 surface wave modes : 7 Love wave modes and 7 Rayleigh wave modes.

(7) an initial random number of 677.

The results of the calculation indicates a maximum acceleration of 8 % of gravity and the time of the maximum is 12.76 seconds from the beginning.

```
   4     1     0  677
 30.0     7 0.50 0.00     0
  14
   1    11
0.00 1.00 0.50 1.03 1.00 1.03 1.50 1.00 2.00 1.05 2.50 1.04 3.00 1.05 3.50 1.10
4.00 1.13 4.50 1.18 5.00 1.20
   2    13
0.00 1.00 0.30 1.00 0.39 1.09 0.60 0.96 0.80 1.18 1.10 1.30 1.55 1.30 2.50 1.74
3.20 1.88 3.50 2.20 3.75 2.50 4.40 3.73 4.60 3.75
   3    12
0.00 1.00 0.30 1.00 0.35 0.95 0.55 1.33 0.77 1.11 1.05 1.57 1.58 1.81 1.80 1.77
2.00 2.00 2.20 2.65 2.30 3.68 2.55 3.75
   4    14
0.00 1.00 0.26 1.00 0.30 1.35 0.38 1.38 0.52 1.18 0.70 1.43 0.82 1.38 1.00 2.05
1.09 2.10 1.21 1.98 1.45 1.99 1.55 2.80 1.60 3.55 1.71 3.75
   5     8
0.00 1.50 0.12 1.55 0.28 2.28 0.51 2.00 0.70 2.45 0.91 2.25 1.20 3.50 1.30 3.75
   6     6
0.00 2.35 0.20 2.76 0.32 2.82 0.55 2.80 0.71 2.92 0.95 3.75
   7     6
0.00 2.90 0.30 3.09 0.50 3.00 0.60 2.90 0.68 3.10 0.81 3.75
  -1     9
0.00 1.00 0.70 0.94 1.40 0.82 1.70 0.83 2.30 0.90 2.80 0.95 3.50 1.11 4.50 1.25
5.00 1.31
  -2    10
0.00 1.00 0.53 1.02 0.85 1.25 1.15 1.22 1.61 1.38 2.05 1.50 3.00 1.52 3.63 1.70
4.50 2.65 5.00 3.10
  -3    11
0.00 1.18 0.15 1.23 0.20 1.50 0.50 1.38 0.62 1.50 1.02 1.27 1.20 1.50 1.85 1.73
2.10 1.80 2.45 3.50 2.70 3.75
  -4    13
0.00 1.00 0.15 1.05 0.30 1.38 0.50 1.70 0.69 1.60 0.80 1.62 1.05 1.88 1.30 1.70
1.50 1.68 1.60 1.85 1.70 3.35 1.80 3.70 2.00 3.75
  -5    10
0.00 1.21 0.20 1.38 0.32 1.76 0.48 1.80 0.68 1.75 0.75 2.02 0.98 1.82 1.10 2.00
1.30 3.60 1.41 3.75
  -6     7
0.00 2.10 0.35 2.69 0.46 2.71 0.60 2.74 0.70 2.80 0.80 3.00 1.01 3.75
  -7     7
0.00 2.88 0.10 2.87 0.30 3.01 0.50 2.88 0.67 2.90 0.73 3.08 0.90 3.75
```



*Function Subroutines

Figure A.1 Program Organization for SYNACC

```
C***********************************************************************
C      "SYNACC" - A FORTRAN PROGRAM FOR THE GENERATION OF
C                 SYNTHETIC ACCELEROGRAMS.  BY HUNG LEUNG WONG.
C                 18 JULY 1978, UNIVERSITY OF SOUTHERN CALIFORNIA.
C***********************************************************************
      DIMENSION ACC(5500)
      COMMON/EARTHQ/DIST,AM,PR,IS,IV,MMI,DEPTH,NUM,AL0,ICHOIC,CONST
      COMMON/FSUSER/NTAB,TU(100),AU(100)
      COMMON/UNIT/NU1,NU2,NU3
      MBIG=5500
C-----------------------------------------------------------------------
C    UNIT NUMBERS FOR THE PERIPHERAL DEVICES:
C         NU1=INPUT DEVICE; NU2=PRINTER; NU3=PUNCH, TAPE, OR DISK.
C-----------------------------------------------------------------------
      NU1=5
      NU2=6
      NU3=7
C-----------------------------------------------------------------------
      READ (NU1,10) ICHOIC,IFDUR,IPUNCH,IGYZBE
   10 FORMAT(4I5)
      WRITE (NU2,20) ICHOIC,IFDUR,IPUNCH,IGYZBE
   20 FORMAT(2X,38HPARAMETERS USED FOR OPERATING SYNACC :,/2X/
     *  7X,20HCHOICE OPTION NUMBER,I2/2X/
     *  7X,27HDURATION PARAMETER : IFDUR=,I1/2X/
     *  7X,36HPERMANENT OUTPUT PARAMETER : IPUNCH=,I1/2X/
     *  7X,23HINITIAL RANDOM NUMBER :,I5/2X/)
      GO TO (110,210,310,410,510),ICHOIC
C-----------------------------------------------------------------------
C    ICHOIC=1: INPUT DISTANCE, MAGNITUDE, CONFIDENCE LEVEL,
C              SITE CONDITION AND COMPONENT SPECIFICATION.
C-----------------------------------------------------------------------
  110 READ (NU1,120) DIST,AM,PR,IS,IV
  120 FORMAT(F6.1,2F5.2,2I5)
      WRITE (NU2,130) ICHOIC,DIST,AM,PR,IS,IV
  130 FORMAT(2X,45HSTATISTICAL PARAMETERS USED FOR OPTION NUMBER,I2/2X/
     *  7X,9HDISTANCE=,F6.1,3H KM/7X,10HMAGNITUDE=,F5.2/
     *  7X,17HCONFIDENCE LEVEL=,F5.2/7X,15HSITE CONDITION=,I2/
     *  7X,26HCOMPONENT DESCRIPTOR : IV=,I1/2X)
      DT=0.02
      GO TO 610
C-----------------------------------------------------------------------
C    ICHOIC=2: INPUT DISTANCE, MM INTENSITY, CONFIDENCE LEVEL,
C              SITE CONDITION AND COMPONENT SPECIFICATION.
C-----------------------------------------------------------------------
  210 READ (NU1,220) DIST,MMI,PR,IS,IV
  220 FORMAT(F6.1,I5,F5.2,2I5)
      WRITE (NU2,230) ICHOIC,DIST,MMI,PR,IS,IV
  230 FORMAT(2X,45HSTATISTICAL PARAMETERS USED FOR OPTION NUMBER,I2/2X/
     *  7X,9HDISTANCE=,F6.1,3H KM,/7X,15HM.M. INTENSITY=,I3/
     *  7X,17HCONFIDENCE LEVEL=,F5.2/7X,15HSITE CONDITION=,I2/
     *  7X,26HCOMPONENT DESCRIPTOR : IV=,I1/2X)
      DT=0.02
      GO TO 610
C-----------------------------------------------------------------------
C    ICHOIC=3: INPUT DISTANCE, MAGNITUDE, CONFIDENCE LEVEL,
C              DEPTH AND COMPONENT SPECIFICATION.
C-----------------------------------------------------------------------
  310 READ (NU1,320) DIST,AM,PR,DEPTH,IV
  320 FORMAT(F6.1,3F5.2,I5)
      WRITE (NU2,330) ICHOIC,DIST,AM,PR,DEPTH,IV
```

```
 330 FORMAT(2X,45HSTATISTICAL PARAMETERS USED FOR OPTION NUMBER,I2/2X/
    *  7X,9HDISTANCE=,F6.1,3H KM,/7X,10HMAGNITUDE=,F5.2/
    *  7X,17HCONFIDENCE LEVEL=,F5.2/7X,28HEFFECTIVE DEPTH OF LAYERING=,
    *  F5.2,3H KM/7X,26HCOMPONENT DESCRIPTOR : IV=,I1/2X)
     DT=0.02
     GO TO 610
C-----------------------------------------------------------------------
C    ICHOIC=4: INPUT DISTANCE, MM INTENSITY, CONFIDENCE LEVEL,
C              DEPTH AND COMPONENT SPECIFICATION.
C-----------------------------------------------------------------------
 410 READ (NU1,420) DIST,MMI,PR,DEPTH,IV
 420 FORMAT(F6.1,I5,2F5.2,I5)
     WRITE (NU2,430) ICHOIC,DIST,MMI,PR,DEPTH,IV
 430 FORMAT(2X,45HSTATISTICAL PARAMETERS USED FOR OPTION NUMBER,I2/2X/
    *  7X,9HDISTANCE=,F6.1,3H KM,/7X,15HM.M. INTENSITY=,I3/
    *  7X,17HCONFIDENCE LEVEL=,F5.2/7X,28HEFFECTIVE DEPTH OF LAYERING=,
    *  F5.2,3H KM,/7X,26HCOMPONENT DESCRIPTOR : IV=,I1/2X)
     DT=0.02
     GO TO 610
C-----------------------------------------------------------------------
C    ICHOIC=5: INPUT USER'S FOURIER SPECTRUM, TOTAL OF NTAB POINTS.
C-----------------------------------------------------------------------
 510 READ (NU1,520) NTAB
 520 FORMAT(I5)
     DO 540 IJ=1,NTAB
     READ (NU1,530) TU(IJ),AU(IJ)
 530 FORMAT(2E10.3)
 540 CONTINUE
     READ (NU1,550) DT
 550 FORMAT(E10.3)
     WRITE (NU2,560) ICHOIC,DT
 560 FORMAT(2X,45HSTATISTICAL PARAMETERS USED FOR OPTION NUMBER,I2/2X/
    *  7X,18HTIME INCREMENT DT=,F7.4/2X/
    *  7X,32HUSER SUPPLIED FOURIER SPECTRUM :/7X,32(1H-)/2X)
     DO 580 IJ=1,NTAB
     WRITE (NU2,570) TU(IJ),AU(IJ)
 570 FORMAT((4X,2E16.3))
 580 CONTINUE
C-----------------------------------------------------------------------
C    INPUT THE DISPERSION CURVES FOR SURFACE WAVES, THE TOTAL
C    NUMBER OF CURVES IS NWAVE.
C-----------------------------------------------------------------------
 610 READ (NU1,620) NWAVE
 620 FORMAT(I5)
     CALL NPOINT(NUM1,DT,IN,ICHOIC)
     IF(DIST.GT.60.0)NUM1=NUM1*2
     NUM2=NUM1*2
     CONST=2./((NUM2-2)*DT)
     NWT=NWAVE+2
     MG1=NUM2+3
     MG2=MG1+NWT
     MG3=MG2+NWT
     MG4=MG3+NWAVE
     MG5=MG4+NWAVE
     MTG=MBIG-MG5
C-----------------------------------------------------------------------
C    CORE CHECKING LOCATION NUMBER 1
C-----------------------------------------------------------------------
     IF(MTG.LE.0)CALL PGSTOP(-MTG,1)
     CALL READW(ACC(MG3),ACC(MG4),ACC(MG5),NWAVE,NTOT)
```

```
      MG6=MG5+NTOT
      MTG=MBIG+1-MG6
C-----------------------------------------------------------------------
C    CORE CHECKING LOCATION NUMBER 2
C-----------------------------------------------------------------------
      IF(MTG.LT.0)CALL PGSTOP(-MTG,2)
      NTOT=NTOT/2
      CALL DTIME(ACC(MG3),ACC(MG4),ACC(MG5),NTOT,NWAVE,ICHOIC,
     *  IFDUR,DIST)
      IGYZBE=(IGYZBE/2)*2+1
      CALL PREP(ACC(1),NUM2+2,DT,IGYZBE,NWAVE,NWT,NTOT,IPUNCH,IN,
     *  ACC(MG1),ACC(MG2),ACC(MG3),ACC(MG4),ACC(MG5))
      STOP
      END
C***********************************************************************
      SUBROUTINE NPOINT(NUM1,DT,IN,ICHOIC)
      IF(DT.LE.0.02)GO TO 10
      NUM1=2048
      IN=2
      RETURN
   10 FACT=0.0201/DT
      NUM1=2048
      IF(FACT.GT.1.3)NUM1=4096
      IF(FACT.GT.2.6)NUM1=8192
      IN=2
      IF(ICHOIC.EQ.3) IN=NUM1/2048
      RETURN
      END
C***********************************************************************
      SUBROUTINE PGSTOP(II,IK)
      COMMON/UNIT/NU1,NU2,NU3
      IF(IK.EQ.2)GO TO 20
      WRITE (NU2,10) II
   10 FORMAT(45H  CHECK LOCATION #1: PROGRAM NEEDS MORE CORE.,
     *14H ADD AT LEAST ,I6,16H + 2*NTOT WORDS.,/
     *61H  WHERE NTOT IS THE NUMBER OF POINTS IN THE DISPERSION CURVE.)
      GO TO 40
   20 WRITE (NU2,30) II
   30 FORMAT(1X,50H CHECK LOCATION NUMBER 2: PROGRAM NEEDS MORE CORE.,
     *13H ADD AT LEAST,I6,7H WORDS.)
   40 STOP
      END
C***********************************************************************
      SUBROUTINE READW(MODNUM,KPOINT,TV,NWAVE,NNN)
      DIMENSION MODNUM(NWAVE),KPOINT(NWAVE),TV(1)
      COMMON/UNIT/NU1,NU2,NU3
      NNN=0
      WRITE (NU2,40) NWAVE
      DO 30 IW=1,NWAVE
      READ (NU1,10) MODNUM(IW),KPOINT(IW)
   10 FORMAT(2I5)
      K=IABS(MODNUM(IW))
      IF(MODNUM(IW).GT.0)WRITE (NU2,50) K
      IF(MODNUM(IW).LT.0)WRITE (NU2,60) K
      N1=NNN+1
      N2=NNN+2*KPOINT(IW)
      READ (NU1,20) (TV(K),K=N1,N2)
   20 FORMAT(16F5.2)
      WRITE (NU2,70) (TV(K),K=N1,N2)
      NNN=N2
```

```
   30 CONTINUE
   40 FORMAT(2X,30HTHIS DISPERSION MODEL CONTAINS,I3,7H MODES./)
   50 FORMAT(/3X,25HRAYLEIGH WAVE MODE NUMBER,I3/
     *  5X,29HPERIOD(SEC)   VELOCITY(KM/SEC))
   60 FORMAT(/3X,21HLOVE WAVE MODE NUMBER,I3/
     *  5X,29HPERIOD(SEC)   VELOCITY(KM/SEC))
   70 FORMAT(8X,F5.2,10X,F5.2)
      RETURN
      END
C***********************************************************************
      SUBROUTINE DTIME(MODNUM,KPOINT,TV,NTOT,NWAVE,ICHOIC,IFDUR,DIST)
      EXTERNAL TNM
      DIMENSION TV(2,NTOT),MODNUM(NWAVE),KPOINT(NWAVE)
      COMMON/DURN/IAS(6),TADD(3,6)
      COMMON/WAY2/WE(7),WCC(6)
      IF(ICHOIC.NE.5.AND.IFDUR.NE.0)GO TO 20
      DO 10 J=1,6
   10 IAS(J)=0
      RETURN
   20 CONTINUE
      DO 30 J=1,6
      TADD(1,J)=10000.0
   30 TADD(2,J)=0.0
      NTOTT=1
      DO 70 LC=1,NWAVE
      KP=KPOINT(LC)
      DO 60 J=1,6
      DDW=(WE(J+1)-WE(J))/20.
      WC=WE(J)
      DO 50 JW=1,21
      TD=TNM(DIST,WC,KP,TV(1,NTOTT))
      IF(TD.LT.0.0)GO TO 40
      IF(TD.LT.TADD(1,J))TADD(1,J)=TD
      IF(TD.GT.TADD(2,J))TADD(2,J)=TD
   40 WC=WC+DDW
   50 CONTINUE
      IF(TADD(1,J).GT.1000.)TADD(1,J)=0.0
   60 CONTINUE
      NTOTT=NTOTT+KP
   70 CONTINUE
      DO 120 J=1,6
      IB=J
      CALL DURTN(DUR,STD,IB)
      IF(DUR.LT.0.0)GO TO 80
      IF(TADD(2,J).LT.0.05 .OR.  STD.LT.0.01)GO TO 80
      TE1=TADD(1,J)+DUR-STD
      TE2=TADD(1,J)+DUR+STD
      IF(TADD(2,J).LT.TE1)GO TO 90
      IF(TADD(2,J).GT.TE2)GO TO 110
   80 IAS(IB)=0
      GO TO 120
   90 IAS(IB)=1
      TE2=TADD(1,J)+DUR
      TE1=TE2-TADD(2,J)
      IF(TE1.GT.(20.-2.5*IB))IAS(IB)=2
      NINT=IAS(IB)+1
      TE1=TE1/FLOAT(NINT)
      TE2=TADD(2,J)
      NTOTT=IAS(IB)
      DO 100 JW=1,NTOTT
```

```
  100 TADD(JW, J)=TE2+TE1*JW
      TADD(NINT, J)=TE1
      GO TO 120
  110 IAS(IB)=-1
      TADD(1, J)=TADD(1, J)+DUR+STD
  120 CONTINUE
      RETURN
      END
C***********************************************************************
      FUNCTION TNM(DIST, W, KP, TV)
      DIMENSION TV(2, KP)
      TT=6.2832/W
      DO 10 J=1, KP
      IF(TT.LE.TV(1, J))GO TO 20
   10 CONTINUE
      TNM=-1.0
      RETURN
   20 FACT=(TT-TV(1, J-1))/(TV(1, J)-TV(1, J-1))
      TNM=DIST/(TV(2, J-1)+FACT*(TV(2, J)-TV(2, J-1)))
      RETURN
      END
C***********************************************************************
      SUBROUTINE DURTN(DUR, STD, IB)
      COMMON/EARTHQ/DIST, AM, PR, IS, IV, MMI, DEPTH, NUM, AL0, ICHOIC, CONST
      COMMON/DURMAG/ADM(6, 2), BDM(6, 2), CDM(6, 2), DDM(6, 2), SDM(6, 2)
      COMMON/DURI/DVI(6, 3, 8), DHI(6, 3, 8), SVI(6, 3, 8), SHI(6, 3, 8)
      COMMON/DURMGH/ADMH(6, 2), BDMH(6, 2), CDMH(6, 2), DDMH(6, 2),
     *  AGDMH(6, 2), BGDMH(6, 2), CGDMH(6, 2), DGDMH(6, 2), UPMH(6, 2), DNMH(6, 2)
      COMMON/DURIH/ADIH(6, 2), BDIH(6, 2), CDIH(6, 2), AGDIH(6, 2),
     *  BGDIH(6, 2), CGDIH(6, 2), DGDIH(6, 2), UPIH(6, 2), DNIH(6, 2)
      IVV=IV+1
      GO TO (10, 20, 110, 120), ICHOIC
C-----------------------------------------------------------------------
C     DURATION BASED ON SITE CLASSFICATIONS.
C-----------------------------------------------------------------------
   10 DUR=ADM(IB, IVV)*IS+BDM(IB, IVV)*AM+CDM(IB, IVV)*DIST
     *  +DDM(IB, IVV)
      STD=SDM(IB, IVV)
      RETURN
   20 GO TO (60, 60, 30, 30, 30, 30, 30, 30, 30, 30, 60, 60), MMI
   30 GO TO (40, 50), IVV
   40 DUR=DHI(IB, IS+1, MMI-2)
      STD=SHI(IB, IS+1, MMI-2)
      RETURN
   50 DUR=DVI(IB, IS+1, MMI-2)
      STD=SVI(IB, IS+1, MMI-2)
      RETURN
   60 DUR=-1.0
      STD=0.0
      RETURN
C-----------------------------------------------------------------------
C     DURATION BASED ON DEPTHS.
C-----------------------------------------------------------------------
  110 X1=UPMH(IB, IVV)
      X2=DNMH(IB, IVV)
      A1=AGDMH(IB, IVV)
      B1=BGDMH(IB, IVV)
      A2=CGDMH(IB, IVV)
      B2=DGDMH(IB, IVV)
      GO TO 130
```

```
  120 X1=UPIH(IB,IVV)
      X2=DNIH(IB,IVV)
      A1=AGDIH(IB,IVV)
      B1=BGDIH(IB,IVV)
      A2=CGDIH(IB,IVV)
      B2=DGDIH(IB,IVV)
  130 F1=PR-1.-A1*EXP(B1*X1)-A2*EXP(B2*X1)
      DO 160 J=1,20
      Z=(X1+X2)/2.
      F2=PR-1.-A1*EXP(B1*Z)-A2*EXP(B2*Z)
      IF(F1*F2)140,170,150
  140 X2=Z
      GO TO 160
  150 X1=Z
      F1=F2
  160 CONTINUE
  170 EPS=Z
      PP=1.+A1*EXP(B1*EPS)+A2*EXP(B2*EPS)
      IF(ICHOIC.EQ.4)GO TO 180
      DUR=ADMH(IB,IVV)+BDMH(IB,IVV)*AM+CDMH(IB,IVV)*DIST
     *  +DDMH(IB,IVV)*DEPTH+EPS
      STD=1.0
      RETURN
  180 DUR=ADIH(IB,IVV)+BDIH(IB,IVV)*MMI+CDIH(IB,IVV)*DEPTH+EPS
      STD=1.0
      RETURN
      END
C***********************************************************************
      SUBROUTINE PREP(ACC,NUM2,DT,IGYZBE,NWAVE,NWT,NTOT,
     *  IPUNCH,IN,TD,AANM,MODNUM,KPOINT,TV)
      COMMON/WAY1/NPB(6),NB(73),IBB(9),IBC(9)
      COMMON/UNIT/NU1,NU2,NU3
      DIMENSION MODNUM(NWAVE),KPOINT(NWAVE),TV(2,NTOT)
      DIMENSION ACC(NUM2),TD(NWT),AANM(NWT)
      COMMON/EARTHQ/DIST,AM,PR,IS,IV,MMI,DEPTH,NUM,AL0,ICHOIC,CONST
      COMMON/RICHT/X0(71),Y0(71)
      NUM=NUM2-2
      DW=2.*3.141592654/(NUM*DT)
C-----------------------------------------------------------------------
C     CALCULATING THE RICHTER ATTENUATION FACTOR.
C-----------------------------------------------------------------------
      DO 10 I=1,70
      IF(DIST.LT.X0(I+1) .AND.  DIST.GE.X0(I))GO TO 20
   10 CONTINUE
   20 AL0=Y0(I)+((Y0(I+1)-Y0(I))/(X0(I+1)-X0(I)))*(DIST-X0(I))
      AL0=-AL0
      IF(DIST.LT.X0(1))AL0=-Y0(1)
C-----------------------------------------------------------------------
C     SETTING UP THE NB'S.
C-----------------------------------------------------------------------
      ID=0
      DO 30 I1=1,9
      IC=ID+1
      ID=ID+IBC(I1)
      DO 30 I2=IC,ID
      NB(I2)=IBB(I1)*IN
   30 CONTINUE
C-----------------------------------------------------------------------
C     SETTING UP THE FOURIER TRANSFORM.
C-----------------------------------------------------------------------
```

```
      NI1=(IN*6+1)
      NI2=NI1*2
      DO 40 I1=1,NUM2
   40 ACC(I1)=0.0
      ID=0
      DO 60 IB=1,6
      IBD=IB
      IC=ID+1
      ID=ID+NPB(IB)
      NA=0
      DO 50 I1=IC,ID
   50 NA=NA+NB(I1)
      N=NPB(IB)
      CALL FSP(ACC,N,DW,NB(IC),IBD,NWT,NI1,IGYZBE,NWAVE,NTOT,
     *  MODNUM,KPOINT,TV,TD,AANM)
      NI1=NI1+NA
   60 CONTINUE
      NUM3=NUM/2
      CALL RFFTI(ACC,NUM)
      AMAX=0.
      DO 70 IBM=1,NUM3
      IF(ABS(ACC(IBM)).LT.AMAX)GO TO 70
      AMAX=ABS(ACC(IBM))
      IIBM=IBM
   70 CONTINUE
      TPEAK=IIBM*DT
      WRITE (NU2,80) AMAX
   80 FORMAT(5X,20HMAXIMUM AMPLITUDE IS,F10.4,2H G/)
      WRITE (NU2,90) TPEAK
   90 FORMAT(5X,29HTHE TIME OF THE MAXIMUM IS AT,F10.3,
     *  8H SECONDS/)
      WRITE (NU2,100)
  100 FORMAT(4X,61H THE SYNTHETIC ACCELEROGRAM IN 8E10.3 FORMAT, THE UNI
     *T IS G'S//)
      WRITE (NU2,110) (ACC(I),I=1,NUM3)
  110 FORMAT(7X,8E10.3)
      IF(IPUNCH.NE.0)WRITE (NU3,120) (ACC(I),I=1,NUM3)
  120 FORMAT(8E10.3)
      RETURN
      END
C************************************************************************
      SUBROUTINE FSP(FS,N,DW,NB,IBB,NWT,NI1,IGYZBE,NWAVE,NTOT,
     *  MODNUM,KPOINT,TV,TD,AANM)
      COMMON/EARTHQ/DIST,AM,PR,IS,IV,MMI,DEPTH,NUM,AL0,ICHOIC,CONST
      DIMENSION NB(N),TD(NWT),AANM(NWT)
      DIMENSION MODNUM(NWAVE),KPOINT(NWAVE),TV(2,NTOT)
      COMPLEX FS(1)
      EXTERNAL FSA,ANM,TNM
      COMMON/WAY2/WE(7),WCC(6)
      COMMON/DURN/IAS(6),TADD(3,6)
      IASS=IAS(IBB)+2
      PI2=3.141592654*2.
      LA2=NI1-1
      DO 100 N1=1,N
      LA1=LA2+1
      LA2=LA1+NB(N1)-1
      WCEN=((LA2+LA1+1)/2.-0.5-1.0)*DW
      IF(IASS.NE.1)GO TO 20
      IBBB=IBB+1
      IF(WCEN.LT.WCC(IBB))IBBB=IBB-1
```

```
      IF(IBBB.LT.1 .OR.  IBBB.GT.6)IBBB=IBB
      IF(IAS(IBBB).GE.0)IBBB=IBB
      IF(IBBB.EQ.IBB)GO TO 10
      TCUT=(WCEN-WCC(IBBB))/(WCC(IBB)-WCC(IBBB))
      TCUT=TADD(1,IBBB)+TCUT*(TADD(1,IBB)-TADD(1,IBBB))
      GO TO 20
   10 TCUT=TADD(1,IBB)
   20 NTOTT=1
      DO 40 LC=1,NWAVE
      KP=KPOINT(LC)
      TD(LC)=TNM(DIST,WCEN,KP,TV(1,NTOTT))
      NTOTT=NTOTT+KP
      LD=IABS(MODNUM(LC))
      AANM(LC)=ANM(WCEN,LD,IGYZBE)
      GO TO (30,40,40,40),IASS
   30 IF(TD(LC).GT.TCUT)AANM(LC)=AANM(LC)*0.1
   40 CONTINUE
      NWTT=NWAVE
      IF(IAS(IBB).LT.1)GO TO 60
      NTOTT=IAS(IBB)
      DO 50 LC=1,NTOTT
      LX=IGYZBE
      CALL URAND(LX,IGYZBE,YFL)
      TD(LC+NWAVE)=TADD(LC,IBB)+(YFL-0.5)*TADD(NTOTT+1,IBB)
      LX=IGYZBE
      CALL URAND(LX,IGYZBE,YFL)
      AANM(LC+NWAVE)=0.20*YFL
   50 CONTINUE
      NWTT=NWAVE+NTOTT
   60 LX=IGYZBE
      CALL URAND(LX,IGYZBE,YFL)
      PHIR=(YFL-0.5)*PI2
      F1=0.
      DO 80 LB=LA1,LA2
      WW=(LB-1)*DW
      WWS=WW-WCEN
      DO 70 LC=1,NWTT
      IF(TD(LC).LT.0.0)GO TO 70
      C1=-WWS*(TD(LC))+PHIR
      FS(LB)=FS(LB)+AANM(LC)*(COS(C1)+(0.,1.)*SIN(C1))
   70 CONTINUE
      TEMM=CABS(FS(LB))
      IF(TEMM.EQ.0.0)GO TO 80
      F1=F1+ALOG10(TEMM)
   80 CONTINUE
      F1=F1/FLOAT(LA2-LA1+1)
      F1=10.**F1
      FSEE=FSA(WCEN,ICHOIC)
      ALPHA=FSEE*CONST/F1
      IF(F1.LT.0.000001)ALPHA=0.
      DO 90 LB=LA1,LA2
   90 FS(LB)=FS(LB)*ALPHA
  100 CONTINUE
      RETURN
      END
C***********************************************************************
      FUNCTION FSA(W,ICHOIC)
      COMMON/FSMAG/TM(11),AM(11,9)
      COMMON/FSI/TI(11),AI(11,7)
      COMMON/FSMGH/TMH(11),AMH(11,9)
```

```
      COMMON/FSIH/TIH(11),AIH(11,7)
      COMMON/FSUSER/NTAB,TU(100),AU(100)
      DIMENSION AF(9)
      IF(ICHOIC.EQ.5)GO TO 510
      TT=ALOG10(6.2832/W)
      GO TO (110,210,310,410),ICHOIC
C ---------------------------------------------------------------------
C   USING MAGNITUDE AND SITE STATISTICS FOR FOURIER SPECTRUM.
C ---------------------------------------------------------------------
  110 IF(TT.LT.TM(1))GO TO 130
      DO 120 J=2,11
      IF(TT.LE.TM(J))GO TO 140
  120 CONTINUE
  130 FSA=0.0
      RETURN
  140 FACT=(TT-TM(J-1))/(TM(J)-TM(J-1))
      DO 150 JKL=1,9
      AF(JKL)=AM(J-1,JKL)+FACT*(AM(J,JKL)-AM(J-1,JKL))
  150 CONTINUE
      GO TO 460
C ---------------------------------------------------------------------
C   USING M.M.I. AND SITE STATISTICS FOR FOURIER SPECTRUM.
C ---------------------------------------------------------------------
  210 IF(TT.LT.TI(1))GO TO 230
      DO 220 J=2,11
      IF(TT.LE.TI(J))GO TO 240
  220 CONTINUE
  230 FSA=0.0
      RETURN
  240 FACT=(TT-TI(J-1))/(TI(J)-TI(J-1))
      DO 250 JKL=1,7
  250 AF(JKL)=AI(J-1,JKL)+FACT*(AI(J,JKL)-AI(J-1,JKL))
      GO TO 460
C----------------------------------------------------------------------
C   USING MAGNITUDE AND DEPTH STATISTICS FOR FOURIER SPECTRUM.
C----------------------------------------------------------------------
  310 IF(TT.LT.TMH(1))GO TO 330
      DO 320 J=2,11
      IF(TT.LE.TMH(J))GO TO 340
  320 CONTINUE
  330 FSA=0.0
      RETURN
  340 FACT=(TT-TMH(J-1))/(TMH(J)-TMH(J-1))
      DO 350 JKL=1,9
  350 AF(JKL)=AMH(J-1,JKL)+FACT*(AMH(J,JKL)-AMH(J-1,JKL))
      GO TO 460
C----------------------------------------------------------------------
C   USING M.M.I. AND DEPTH STATISTICS FOR FOURIER SPECTRUM
C----------------------------------------------------------------------
  410 IF(TT.LT.TIH(1))GO TO 430
      DO 420 J=2,11
      IF(TT.LE.TIH(J))GO TO 440
  420 CONTINUE
  430 FSA=0.0
      RETURN
  440 FACT=(TT-TIH(J-1))/(TIH(J)-TIH(J-1))
      DO 450 JKL=1,7
  450 AF(JKL)=AIH(J-1,JKL)+FACT*(AIH(J,JKL)-AIH(J-1,JKL))
  460 CALL SAFIT(AF,PSV)
      FSA=PSV/384.0
```

```
      RETURN
C -----------------------------------------------------------------------
C   USER SUPPLIED FOURIER SPECTRUM.
C -----------------------------------------------------------------------
  510 TT=6.2832/W
      IF(TT.LT.TU(1))GO TO 530
      DO 520 J=2,NTAB
      IF(TT.LE.TU(J))GO TO 540
  520 CONTINUE
  530 FSA=0.0
      RETURN
  540 FACT=(TT-TU(J-1))/(TU(J)-TU(J-1))
      FSA=AU(J-1)+FACT*(AU(J)-AU(J-1))
      RETURN
      END
C***********************************************************************
      SUBROUTINE SAFIT(AF,PSV)
      EXTERNAL PLIN
      COMMON/EARTHQ/DIST,AM,PR,IS,IV,MMI,DEPTH,NUM,AL0,ICHOIC,CONST
      DIMENSION AF(9)
      PACT=PR
      GO TO (10,20,10,20),ICHOIC
C-----------------------------------------------------------------------
C    FOURIER AMPLITUDE BASED ON MAGNITUDES.
C-----------------------------------------------------------------------
   10 PLINR=PLIN(PACT,AF(8),AF(9))
      AM1=AM
      AMMIN=-AF(2)/(2*AF(6))
      IF(AM1.LE.AMMIN)AM1=AMMIN
      ALPSV=AM+AL0-AF(1)*PLINR - AF(2)*AM1 - AF(3) -AF(5)*IV
     *  -AF(6)*AM1*AM1 -AF(7)*DIST
      IF(ICHOIC.EQ.1)ALPSV=ALPSV-AF(4)*IS
      IF(ICHOIC.EQ.3)ALPSV=ALPSV-AF(4)*DEPTH
      AMAX=(1.-AF(2))/(2.*AF(6))
      IF(AM.GT.AMAX)ALPSV=ALPSV+AF(6)*(AM-AMAX)**2
      PSV=10.0**ALPSV
      RETURN
C-----------------------------------------------------------------------
C    FOURIER AMPLITUDE BASED ON MMI'S.
C-----------------------------------------------------------------------
   20 PLINR=PLIN(PACT,AF(6),AF(7))
      ALPSV=AF(1)*PLINR+AF(2)*MMI+AF(3)+AF(5)*IV
      IF(ICHOIC.EQ.2)ALPSV=ALPSV+AF(4)*IS
      IF(ICHOIC.EQ.4)ALPSV=ALPSV+AF(4)*DEPTH
      PSV=10.00**ALPSV
      RETURN
      END
C***********************************************************************
      FUNCTION PLIN(PACT,SIG,AVE)
      COMMON/WAY3/C0,C1,C2,D1,D2,D3
      IF(PACT.GT.0.5)GO TO 10
      T=SQRT(-2.*ALOG(PACT))
      XP=T-(C0+T*(C1+C2*T))/(1.+T*(D1+T*(D2+D3*T)))
      PLIN=-XP*SIG+AVE
      RETURN
   10 T=SQRT(-2.*ALOG(1.-PACT))
      XP=T-(C0+T*(C1+C2*T))/(1.+T*(D1+T*(D2+D3*T)))
      PLIN=XP*SIG+AVE
      RETURN
      END
```

```
C**********************************************************************
      FUNCTION ANM(WW,M,IGYZBE)
      COMMON/MPF/B0(7),BR(7),WP(7),WB(7),C0(7),M0(7)
      CR=0.2
      M1=M
      IF(M.GT.7)M1=7
      P=(WW-WP(M1))**2/(2.*WB(M1)**2)
      IF(P.GT.10.)GO TO 10
      P=EXP(-P)
      GO TO 20
   10 P=0.
   20 CONTINUE
      LX=IGYZBE
      CALL URAND(LX,IGYZBE,XRN)
      G1=B0(M1)*P+BR(M1)*XRN
      LX=IGYZBE
      CALL URAND(LX,IGYZBE,XRM)
      G2=EXP(-(M1-M0(M1))**2/(2.*C0(M1)**2)) + CR*XRM
      ANM=ABS(G1*G2)
      RETURN
      END
C**********************************************************************
      SUBROUTINE URAND(IX,IY,YFL)
      IXX=IX*19
      IY=MOD(IXX,1024)
      YFL=IY/1023.
      RETURN
      END
C**********************************************************************
      SUBROUTINE RFFTI(X,N)
      REAL X(1)
      NN=N/2
      S=X(1)
      X(1)=.5*(X(1)+X(N+1))
      X(2)=.5*(S-X(N+1))
      X(NN+2)=-X(NN+2)
      IS=-1
      NM=NN/2
      FN=N
      EX=6.2831852/FN
      J=NN
      WR=1.
      WI=0.
      WWR=COS(EX)
      WWI=-SIN(EX)
      DO 10 I=2,NM
      WRR=WR*WWR-WI*WWI
      WI=WR*WWI+WI*WWR
      WR=WRR
      K1J=2*J-1
      K1I=2*I-1
      K2J=2*J
      K2I=2*I
      A1=.5*(X(K1I)+X(K1J))
      A2=.5*(X(K2I)-X(K2J))
      B1=.5*(-X(K1I)+X(K1J))
      B2=.5*(-X(K2I)-X(K2J))
      S=B1
      B1=B1*WR+B2*WI
      B2=B2*WR-S*WI
```

```
      X(K1I)=A1-B2
      X(K2I)=-A2-B1
      X(K1J)=A1+B2
      X(K2J)=A2-B1
   10 J=J-1
      CALL FOUR1(X,NN,IS)
      RETURN
      END
C*********************************************************************
      SUBROUTINE FOUR1(DAT,N,ISIG)
      DIMENSION DAT(1)
      IP0=2
      IP3=IP0*N
      I3REV=1
      DO 50 I3=1,IP3,IP0
      IF(I3-I3REV)10,20,20
   10 TEMPR=DAT(I3)
      TEMPI=DAT(I3+1)
      DAT(I3)=DAT(I3REV)
      DAT(I3+1)=DAT(I3REV+1)
      DAT(I3REV)=TEMPR
      DAT(I3REV+1)=TEMPI
   20 IP1=IP3/2
   30 IF(I3REV-IP1)50,50,40
   40 I3REV=I3REV-IP1
      IP1=IP1/2
      IF(IP1-IP0)50,30,30
   50 I3REV=I3REV+IP1
      IP1=IP0
   60 IF(IP1-IP3)70,100,100
   70 IP2=IP1*2
      THETA=6.283185307/FLOAT(ISIG*IP2/IP0)
      SINTH=SIN(THETA/2.)
      WSTPR=-2.*SINTH*SINTH
      WSTPI=SIN(THETA)
      WR=1.
      WI=0.
      DO 90 I1=1,IP1,IP0
      DO 80 I3=I1,IP3,IP2
      I2A=I3
      I2B=I2A+IP1
      TEMPR=WR*DAT(I2B)-WI*DAT(I2B+1)
      TEMPI=WR*DAT(I2B+1)+WI*DAT(I2B)
      DAT(I2B)=DAT(I2A)-TEMPR
      DAT(I2B+1)=DAT(I2A+1)-TEMPI
      DAT(I2A)=DAT(I2A)+TEMPR
   80 DAT(I2A+1)=DAT(I2A+1)+TEMPI
      TEMPR=WR
      WR=WR*WSTPR-WI*WSTPI+WR
   90 WI=WI*WSTPR+TEMPR*WSTPI+WI
      IP1=IP2
      GO TO 60
  100 RETURN
      END
C*********************************************************************
      BLOCK DATA
      COMMON/RICHT/X0(71),Y0(71)
      COMMON/FSMAG/TM(11),AM(11),BM(11),CM(11),DM(11),EM(11),
     *  FM(11),GM(11),SFSM(11),AFSM(11)
      COMMON/FSI/TI(11),AI(11),BI(11),CI(11),DI(11),EI(11),
```

```
     *   SFSI(11), AFSI(11)
      COMMON/FSMGH/TMH(11), AMH(11), BMH(11), CMH(11), DMH(11), EMH(11),
     *   FMH(11), GMH(11), SFSMH(11), AFSMH(11)
      COMMON/FSIH/TIH(11), AIH(11), BIH(11), CIH(11), DIH(11), EIH(11),
     *   SFSIH(11), AFSIH(11)
      COMMON/DURMAG/ADM(6, 2), BDM(6, 2), CDM(6, 2), DDM(6, 2), SDM(6, 2)
      COMMON/DURI/DVI(6, 3, 8), DHI(6, 3, 8), SVI(6, 3, 8), SHI(6, 3, 8)
      COMMON/DURMGH/ADMH(6, 2), BDMH(6, 2), CDMH(6, 2), DDMH(6, 2),
     *   AGDMH(6, 2), BGDMH(6, 2), CGDMH(6, 2), DGDMH(6, 2), UPMH(6, 2), DNMH(6, 2)
      COMMON/DURIH/ADIH(6, 2), BDIH(6, 2), CDIH(6, 2), AGDIH(6, 2),
     *   BGDIH(6, 2), CGDIH(6, 2), DGDIH(6, 2), UPIH(6, 2), DNIH(6, 2)
      COMMON/MPF/B0(7), BR(7), WP(7), WB(7), C0(7), M0(7)
      COMMON/WAY1/NPB(6), NB(73), IBB(9), IBC(9)
      COMMON/WAY2/WE(7), WCC(6)
      COMMON/WAY3/C0P, C1P, C2P, D1P, D2P, D3P
C-----------------------------------------------------------------------
C    RICHTER'S ATTENUATION COEFFICIENTS.
C-----------------------------------------------------------------------
        DATA X0/0. 001, 5. 0, 10. 0, 15. 0, 20. 0, 25. 0, 30. 0,
     X  35. 0, 40. 0, 45. 0, 50. 0, 55. 0, 60. 0, 65. 0,
     X  70. 0, 80. 0, 85. 0, 90. 0, 95. 0, 100. 0, 110. 0,
     X  120. 0, 130. 0, 140. 0, 150. 0, 160. 0, 170. 0, 180. 0,
     X  190. 0, 200. 0, 210. 0, 220. 0, 230. 0, 240. 0, 250. 0,
     X  260. 0, 270. 0, 280. 0, 290. 0, 300. 0, 310. 0, 320. 0,
     X  330. 0, 340. 0, 350. 0, 360. 0, 370. 0, 380. 0, 390. 0,
     X  400. 0, 410. 0, 420. 0, 430. 0, 440. 0, 450. 0, 460. 0,
     X  470. 0, 480. 0, 490. 0, 500. 0, 510. 0, 520. 0, 530. 0,
     X  540. 0, 550. 0, 560. 0, 570. 0, 580. 0, 590. 0, 600. 0,
     X  1000. 0/
        DATA Y0/1. 400, 1. 500, 1. 605, 1. 716, 1. 833, 1. 955, 2. 078,
     Y  2. 199, 2. 314, 2. 421, 2. 517, 2. 603, 2. 679, 2. 746,
     Y  2. 805, 2. 920, 2. 958, 2. 989, 3. 020, 3. 044, 3. 089,
     Y  3. 135, 3. 182, 3. 230, 3. 279, 3. 328, 3. 378, 3. 429,
     Y  3. 480, 3. 530, 3. 581, 3. 631, 3. 680, 3. 729, 3. 779,
     Y  3. 828, 3. 877, 3. 926, 3. 975, 4. 024, 4. 072, 4. 119,
     Y  4. 164, 4. 209, 4. 253, 4. 295, 4. 336, 4. 376, 4. 414,
     Y  4. 451, 4. 485, 4. 518, 4. 549, 4. 579, 4. 607, 4. 634,
     Y  4. 660, 4. 685, 4. 709, 4. 732, 4. 755, 4. 776, 4. 797,
     Y  4. 817, 4. 835, 4. 853, 4. 869, 4. 885, 4. 900, 4. 900,
     Y  5. 700/
C-----------------------------------------------------------------------
C     COEFFICIENTS FOR FOURIER SPECTRUM, BASED ON MAGNITUDES AND SITES.
C-----------------------------------------------------------------------
        DATA TM/-1. 398, -1. 150, -0. 903, -0. 655, -0. 407, -0. 159,
     T          0. 088,  0. 336,  0. 584,  0. 831,  1. 079/
        DATA AM/-1. 688, -1. 620, -1. 517, -1. 445, -1. 460, -1. 514,
     A         -1. 549, -1. 570, -1. 601, -1. 630, -1. 633/
        DATA BM/-1. 086, -1. 380, -1. 418, -1. 216, -1. 053, -1. 129,
     B         -1. 499, -2. 592, -4. 042, -4. 699, -4. 872/
        DATA CM/ 7. 615,  7. 892,  7. 344,  6. 249,  5. 587,  5. 913,
     C           7. 328, 11. 230, 16. 381, 18. 875, 19. 715/
        DATA DM/-0. 018, -0. 080, -0. 068,  0. 011,  0. 102,  0. 163,
     D           0. 189,  0. 197,  0. 200,  0. 204,  0. 203/
        DATA EM/-0. 098, -0. 026,  0. 094,  0. 229,  0. 304,  0. 319,
     E           0. 309,  0. 288,  0. 281,  0. 292,  0. 297/
        DATA FM/0. 132, 0. 1527, 0. 1542, 0. 1364, 0. 1206, 0. 1227,
     F          0. 1469, 0. 2250, 0. 3300, 0. 3775, 0. 3900/
        DATA GM/-0. 000441, -0. 000869, -0. 001052, -0. 000940, -0. 000709,
     G      -0. 000610, -0. 000753, -0. 001033, -0. 001258, -0. 001352, -0. 001375/
        DATA SFSM/0. 301, 0. 300, 0. 299, 0. 289, 0. 281, 0. 280,
```

```
     S              0.287,0.301,0.312,0.302,0.289/
      DATA AFSM/0.492,0.502,0.500,0.488,0.479,0.479,
     M              0.488,0.511,0.532,0.522,0.492/
C-----------------------------------------------------------------------
C     COEFFICIENTS FOR FOURIER SPECTRUM, BASED ON MMI AND SITES.
C-----------------------------------------------------------------------
      DATA TI/-1.398,-1.141,-0.883,-0.626,-0.368,-0.111,
     T             0.146,0.404,0.661,0.919,1.176/
      DATA AI/1.707,1.688,1.559,1.387,1.294,1.316,
     A            1.413,1.516,1.537,1.485,1.473/
      DATA BI/0.341,0.312,0.285,0.272,0.272,0.286,
     B            0.312,0.320,0.280,0.216,0.174/
      DATA CI/-4.295,-3.467,-2.523,-1.886,-1.626,-1.667,
     C            -1.937,-2.097,-1.947,-1.793,-1.983/
      DATA DI/0.159,0.222,0.178,0.092,0.023,-0.016,
     D            -0.039,-0.079,-0.102,-0.063,-0.032/
      DATA EI/0.011,0.025,-0.104,-0.264,-0.335,-0.338,
     E            -0.277,-0.207,-0.234,-0.214,-0.014/
      DATA SFSI/0.321,0.326,0.326,0.315,0.308,0.307,
     S              0.314,0.333,0.342,0.329,0.318/
      DATA AFSI/0.476,0.496,0.506,0.501,0.496,0.497,
     M              0.508,0.519,0.522,0.530,0.541/
C-----------------------------------------------------------------------
C     COEFFICIENTS FOR FOURIER SPECTRUM, BASED ON MAGNITUDES AND DEPTHS.
C-----------------------------------------------------------------------
      DATA TMH/-1.398,-1.141,-0.883,-0.626,-0.368,-0.111,
     T             0.146,0.404,0.661,0.919,1.176/
      DATA AMH/11*-1.0/
      DATA BMH/-1.190,-1.360,-1.350,-0.869,-0.465,-0.422,
     B             -0.662,-1.020,-1.020,-0.192,0.199/
      DATA CMH/7.050,7.050,6.250,4.410,3.120,3.150,
     C             4.270,5.680,5.610,2.880,1.780/
      DATA DMH/0.00446,0.00823,0.00908,-0.00564,-0.03050,-0.04930,
     D            -0.06210,-0.07970,-0.08750,-0.07020,-0.02620/
      DATA EMH/-0.047,-0.014,0.115,0.273,0.327,0.326,
     E             0.289,0.231,0.250,0.195,-0.030/
      DATA FMH/0.137,0.150,0.149,0.111,0.0787,0.0725,
     F             0.0849,0.111,0.117,0.0598,0.0328/
      DATA GMH/-0.00041,-0.000514,-0.00115,-0.00244,-0.00374,-0.00447,
     G            -0.00453,-0.00486,-0.00578,-0.0062,-0.00519/
      DATA SFSMH/0.492,0.479,0.435,0.390,0.379,0.389,
     S               0.406,0.450,0.481,0.469,0.501/
      DATA AFSMH/0.003,0.015,0.018,0.006,-0.001,-0.000,
     M               0.024,0.072,0.088,0.037,-0.001/
C-----------------------------------------------------------------------
C     COEFFICIENTS FOR FOURIER SPECTRUM, BASED ON MMI AND DEPTHS.
C-----------------------------------------------------------------------
      DATA TIH/-1.398,-1.141,-0.883,-0.626,-0.368,-0.111,
     T             0.146,0.404,0.661,0.919,1.176/
      DATA AIH/11*1.0/
      DATA BIH/0.340,0.312,0.278,0.269,0.266,0.276,
     B             0.308,0.322,0.277,0.203,0.175/
      DATA CIH/-3.200,-2.460,-1.490,-1.080,-0.951,-1.030,
     C            -1.360,-1.590,-1.400,-1.120,-1.320/
      DATA DIH/-0.03370,-0.02920,-0.01980,-0.00038,0.02090,0.04230,
     D             0.06730,0.09720,0.10500,0.07460,0.04400/
      DATA EIH/0.039,0.008,-0.124,-0.281,-0.343,-0.347,
     E             -0.287,-0.204,-0.237,-0.226,-0.004/
      DATA SFSIH/0.581,0.574,0.523,0.442,0.400,0.401,
     S               0.426,0.475,0.496,0.467,0.500/
```

```
      DATA AFSIH/-0.069,-0.046,-0.024,-0.020,-0.016,-0.012,             SYN08410
     M           -0.002,0.010,0.012,-0.010,-0.044/                      SYN08420
C-----------------------------------------------------------------------SYN08430
C     COEFFICIENTS FOR DURATION, BASED ON MAGNITUDES AND SITES.         SYN08440
C-----------------------------------------------------------------------SYN08450
      DATA ADM/-3.02,-4.82,-4.09,-2.75,-1.38,-1.66,                     SYN08460
     A          -4.45,-6.80,-5.83,-3.30,-1.23,-1.04/                    SYN08470
      DATA BDM/-0.43, 1.68,-0.36, 1.28, 1.32, 0.64,                     SYN08480
     B          -1.09,-0.47, 0.51, 2.12, 1.38, 0.34/                    SYN08490
      DATA CDM/0.09,0.07,0.08,0.09,0.08,0.13,                           SYN08500
     C          0.08,0.06,0.08,0.08,0.08,0.12/                          SYN08510
      DATA DDM/22.00,11.82,16.41, 1.42,-0.77, 1.88,                     SYN08520
     D          30.62,29.57,16.16,-0.95,-0.57, 3.43/                    SYN08530
      DATA SDM/12.01,10.75, 7.41, 5.57, 5.10, 5.89,                     SYN08540
     S          12.44,11.65, 8.86, 5.93, 4.59, 5.34/                    SYN08550
C-----------------------------------------------------------------------SYN08560
C     COEFFICIENTS FOR DURATION, BASED ON MMI AND SITES.                SYN08570
C-----------------------------------------------------------------------SYN08580
      DATA DHI/42.5,35.6,24.6,17.6,13.4,25.6,12*-1.0,                   SYN08590
     1 40.2,35.9,32.2,33.3,28.2,42.7,34.9,35.9,26.0,18.2,12.2,15.5,     SYN08600
     2 6*-1.0,30.9,29.6,21.9,16.5,15.1,18.4,                            SYN08610
     3 25.0,22.6,17.9,12.3,11.9,12.1,17.1,14.7, 8.6, 9.8,8.25,8.75,     SYN08620
     4 29.3,29.4,23.8,18.2,13.4,15.8,33.3,30.2,18.6,10.2,7.59,9.24,     SYN08630
     5 22.3,14.9,8.69,9.10,9.87,7.87,20.2,22.4,14.9,11.4,10.7,11.2,     SYN08640
     6 11.4,14.9,10.2,8.12,7.80,8.88,12.6,11.5,8.18,4.92,4.98,6.36,     SYN08650
     7 25.6,28.5,18.6,15.8,14.0,13.5, 42*-1.0,                          SYN08660
     8 10.4,6.40,5.70,6.30,7.10,6.20/                                   SYN08670
      DATA SHI/24*0.0,9.71,3.68,4.40,2.06,4.23,3.03,6*0.0,              SYN08680
     1 13.8,13.5,10.2,9.20,8.23,12.0,12.4,13.1,8.98,6.14,7.19,6.98,     SYN08690
     2 9.24,6.95,1.56,1.98,0.67,1.92,12.6,12.7,9.26,8.30,7.13,10.6,     SYN08700
     3 12.6,12.3,9.41,4.99,3.99,7.16,9.88,7.48,5.22,4.83,3.59,3.61,     SYN08710
     4 11.0,8.12,5.28,4.93,6.01,6.20,4.00,5.20,2.90,2.35,2.65,3.14,     SYN08720
     5 3.22,3.47,3.24,2.50,2.86,3.62,12.9,12.9,8.25,9.41,7.62,8.25,     SYN08730
     6 48*0.0/                                                          SYN08740
      DATA DVI/47.4,44.7,28.0,25.8,20.6,35.8,12*-1.0,                   SYN08750
     1 43.2,41.5,54.2,49.4,34.8,53.8,33.2,38.8,30.9,18.4,17.4,27.0,     SYN08760
     2 6*-1.0,37.1,31.5,27.1,17.8,15.9,16.8,                            SYN08770
     3  25.9,25.2,18.9,13.9,12.6,11.3,15.1,14.9,15.2,10.9,7.10,8.60,    SYN08780
     4  32.4,34.0,28.0,19.9,14.5,14.3,35.4,34.5,21.1,12.3,9.42,11.0,    SYN08790
     5  23.4,14.4,10.1,10.1,11.3,8.60,24.7,25.5,20.1,14.4,11.3,11.1,    SYN08800
     6  17.3,16.1,13.4,10.9,9.04,8.81,14.2,11.6,10.1,7.16,5.72,6.16,    SYN08810
     7  25.5,35.0,25.3,20.1,13.7,11.7,42*-1.0,                          SYN08820
     8  11.4,5.20,6.60,6.00,7.00,8.00/                                  SYN08830
      DATA SVI/36*0.0,16.2,13.9,12.5,9.94,7.21,10.6,                    SYN08840
     1  11.6,14.5,9.60,4.97,7.21,6.46,8.70,7.70,6.80,1.90,0.50,0.80,    SYN08850
     2  11.3,12.5,11.0,8.22,7.15,9.73,13.4,13.1,9.20,4.55,3.68,6.94,    SYN08860
     3  10.3,7.56,4.20,5.35,4.88,2.56,11.3,8.34,6.28,5.58,5.14,4.49,    SYN08870
     4  7.01,4.04,3.91,3.17,2.64,1.84,4.58,5.14,3.05,2.68,2.98,3.37,    SYN08880
     5  17.1,13.1,11.7,10.7,7.74,6.69,48*0.0/                           SYN08890
C-----------------------------------------------------------------------SYN08900
C     COEFFICIENTS FOR DURATION, BASED ON MAGNITUDES AND DEPTHS.        SYN08910
C-----------------------------------------------------------------------SYN08920
      DATA ADMH/38.66,16.78,15.74,3.356,-1.244,1.823,                   SYN08930
     A           42.63,25.80,18.47,1.196,-1.078,3.20/                   SYN08940
      DATA BDMH/-3.46,0.05671,-0.9797,0.3984,1.174,0.3172,              SYN08950
     B           -3.598,-1.351,-1.021,1.099,1.216,0.06996/              SYN08960
      DATA CDMH/0.08655,0.07625,0.08873,0.09375,0.07612,0.1331,         SYN08970
     C           0.09096,0.07324,0.09009,0.08515,0.08176,0.1262/        SYN08980
      DATA DDMH/1.129,1.342,1.411,1.12,0.4121,0.5356,                   SYN08990
     D           1.363,2.198,2.174,1.525,0.4850,0.5919/                 SYN09000
```

```
      DATA AGDMH/1.25,0.8887,0.8905,0.0427,1.152,1.037,
     A          1.241,0.8902,0.8869,0.3961,1.139,1.034/
      DATA BGDMH/-0.1039,-0.1361,-0.1816,-0.4474,-0.3893,-0.3221,
     B          -0.09813,-0.1274,-0.1678,-0.3137,-0.4254,-0.3753/
      DATA CGDMH/-1.651,-1.320,-1.315,-0.4602,-1.55,-1.464,
     C          -1.66,-1.315,-1.311,-0.821,-1.563,-1.469/
      DATA DGDMH/-0.09556,-0.1181,-0.1586,-0.2019,-0.3518,-0.2849,
     D          -0.08886,-0.1111,-0.1463,-0.2415,-0.3797,-0.3308/
      DATA UPMH/30.,24.,18.1,10.5,7.1,8.2,27.,23.,17.,11.,8.,9.4/
      DATA DNMH/-14.3,-14.,-10.9,-6.3,-5.1,-5.9,
     D          -20.,-15.4,-11.5,-6.4,-4.3,-4.9/
C-----------------------------------------------------------------------
C     COEFFICIENTS FOR DURATION, BASED ON MMI AND DEPTHS.
C-----------------------------------------------------------------------
      DATA ADIH/53.62,42.81,36.44,25.63,20.27,27.19,
     A          55.31,45.76,33.13,22.61,17.62,24.58/
      DATA BDIH/-4.686,-3.458,-3.340,-2.325,-1.676,-2.755,
     B          -5.290,-3.946,-3.008,-1.968,-1.348,-2.295/
      DATA CDIH/1.230,2.080,2.112,1.770,0.8818,1.095,
     C          1.422,1.679,1.734,1.579,0.9085,1.211/
      DATA AGDIH/0.3130,0.3053,1.381,0.9628,0.1083,1.145,
     A          1.397,0.07219,1.248,0.8869,0.4386,1.160/
      DATA BGDIH/-0.1147,-0.1511,-0.1631,-0.2614,-0.4539,-0.3111,
     B          -0.1027,-0.1946,-0.1601,-0.2881,-0.3852,-0.319/
      DATA CGDIH/-0.6643,-0.695,-1.723,-1.290,-0.4288,-1.508,
     C          -1.914,-0.5669,-1.863,-1.473,-0.9064,-1.485/
      DATA DGDIH/-0.09206,-0.1142,-0.1522,-0.2386,-0.2987,-0.2841,
     D          -0.09075,-0.08922,-0.1332,-0.2304,-0.2935,-0.2954/
      DATA UPIH/33.,28.,24.,14.,9.2,8.,25.,21.,16.,10.,7.,9./
      DATA DNIH/-17.5,-14.6,-13.8,-8.7,-6.1,-6.7,
     D          -15.9,-12.,-7.9,-4.8,-4.8,-7.1/
C-----------------------------------------------------------------------
C     MODE PARTICIPATION FACTORS FOR SURFACE WAVES.
C-----------------------------------------------------------------------
      DATA B0/1.5,1.5,1.5,2.0,2.0,3.0,1.5/
      DATA BR/0.1,0.1,0.1,0.1,0.1,0.3,0.25/
      DATA WP/10.,10.,10.,25.,25.,30.,30./
      DATA WB/5.,5.,5.,15.,15.,10.,5./
      DATA C0/3.,3.,3.,3.,3.,6.,7./
      DATA M0/5,5,5,5,5,6,7/
C-----------------------------------------------------------------------
C     CONFIGURATIONS OF THE FREQUENCY BANDS CHOSEN
C     TO BE COMPATIBLE WITH DURATION CALCULATIONS.
C-----------------------------------------------------------------------
C        BAND     NPOINTS          NPB      NB
C        0        6                XX       XXXXX
C        1        8                2        2(4)
C        2        16               4        4(4)
C        3        34               5        3(6),2(8)
C        4        102              11       4(8),7(10)
C        5        246              18       7(12),7(14),4(16)
C        6        612              29       5(16),14(18),14(20)
C-----------------------------------------------------------------------
      DATA NPB/2,4,5,11,18,33/
      DATA IBB/4,6,8,10,12,14,16,18,20/
      DATA IBC/6,3,6,7,7,7,9,14,14/
C-----------------------------------------------------------------------
C     THE CUTOFF FREQUENCIES FOR THE SIX BANDS USED FOR DURATION.
C-----------------------------------------------------------------------
      DATA WE/0.917,2.149,4.6,9.82,25.47,63.21,157.08/
```

```
      DATA WCC/1.533,3.375,7.21,17.65,44.34,110.15/                    SYN09610
C-----------------------------------------------------------------------SYN09620
C     CONSTANTS TO BE USED IN FUNCTION PLIN.                            SYN09630
C-----------------------------------------------------------------------SYN09640
      DATA C0P,C1P,C2P/2.515517,0.802853,0.010328/                      SYN09650
      DATA D1P,D2P,D3P/1.432788,0.189269,0.001308/                      SYN09660
      END                                                               SYN09670
```