EARTHQUAKE ENGINEERING RESEARCH CENTER

SHAKE

A COMPUTER PROGRAM FOR EARTHQUAKE RESPONSE ANALYSIS OF HORIZONTALLY LAYERED SITES

by

Per B. Schnabel
John Lysmer
H. Bolton Seed

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College of Engineering
University of California
Berkeley, California

TABLE OF CONTENTS

1. INTRODUCTION

Several methods for evaluating the effect of local soil conditions on ground response during earthquakes are presently available. Most of these methods are based on the assumption that the main responses in a soil deposit are caused by the upward propagation of shear waves from the underlying rock formation. Analytical procedures based on this concept incorporating nonlinear soil behavior, have been shown to give results in good agreement with field observations in a number of cases. Accordingly they are finding increasing use in earthquake engineering for predicting responses within soil deposits and the characteristics of ground surface motions.

The analytical procedure generally involves the following steps:

1. Determine the characteristics of the motions likely to develop in the rock formation underlying the site, and select an accelerogram with these characteristics for use in the analysis. The maximum acceleration, predominant period, and effective duration are the most important parameters of an earthquake motion. Empirical relationships between these parameters and the distance from the causative fault to the site have been established for different magnitude earthquakes (Gutenberg and Richter, 1956, Seed et al., 1969, Schnabel and Seed, 1972). A design motion with the desired characteristics can be selected from the strong motion accelerograms that have been recorded during previous earthquakes (Seed and Idriss, 1969) or from artificially generated accelerograms (Housner and Jennings, 1964).

2. Determine the dynamic properties of the soil deposit. Average relationships between the dynamic shear moduli and damping ratios of soils, as functions of shear strain and static properties, have been established for various soil types (Hardin and Drnevich, 1970, Seed and Idriss, 1970). Thus a relatively simple testing program to obtain the static properties for use in these relationships will often serve to establish the dynamic properties with a sufficient degree of accuracy. However more elaborate dynamic testing procedures are required for special problems and for cases involving soil types for which empirical relationships with static properties have not been established.
3. Compute the response of the soil deposit to the base-rock motions. A one-dimensional method of analysis can be used if the soil structure is essentially horizontal. Programs developed for performing this analysis are in general based on either the solution to the wave equation (Kanai, 1951; Matthiesen et al., 1964; Roesset and Whitman, 1969; Lysmer et al., 1971) or on a lumped mass simulation (Idriss and Seed, 1968). More irregular soil deposits may require a finite element analysis.

In the following sections the theory and use of a computer program based on the one-dimensional wave propagation method are described. The program can compute the responses for a design motion given anywhere in the system. Thus accelerograms obtained from instruments on soil deposits can be used to generate new rock motions which, in turn, can be used as design motion for other soil deposits, see Fig. 1 (Schnabel et al., 1971). The program also incorporates nonlinear soil behavior, the effect of the elasticity of the base rock and systems with variable damping.

2. THEORY

The theory considers the responses associated with vertical propagation of shear waves through the linear viscoelastic system shown in Fig. 2. The system consists of N horizontal layers which extend to infinity in the horizontal direction and has a halfspace as the bottom layer. Each layer is homogeneous and isotropic and is characterized by the thickness, h, mass density, ρ, shear modulus, G, and damping factor, β.

2.1 Propagation of harmonic shear waves in a one-dimensional system.

Vertical propagation of shear waves through the system shown in Fig. 2 will cause only horizontal displacements:

$$u = u(x,t) \tag{1}$$

which must satisfy the wave equation:

$$\rho \frac{\partial^2 u}{\partial t^2} = G \frac{\partial^2 u}{\partial x^2} + \eta \frac{\partial^3 u}{\partial x^2 \partial t} \tag{2}$$

Harmonic displacements with frequency ω can be written in the form:

$$u(x,t) = U(x) \cdot e^{i\omega t} \tag{3}$$

Substituting Eq. 3 into Eq. 2 results in an ordinary differential equation:

$$(G + i\omega\eta) \frac{d^2 U}{dx^2} = \rho\omega^2 U \tag{4}$$

which has the general solution

$$U(x) = Ee^{ikx} + Fe^{-ikx} \tag{5}$$

in which

$$k^2 = \frac{\rho\omega^2}{G + i\omega\eta} = \frac{\rho\omega^2}{G^*} \tag{6}$$

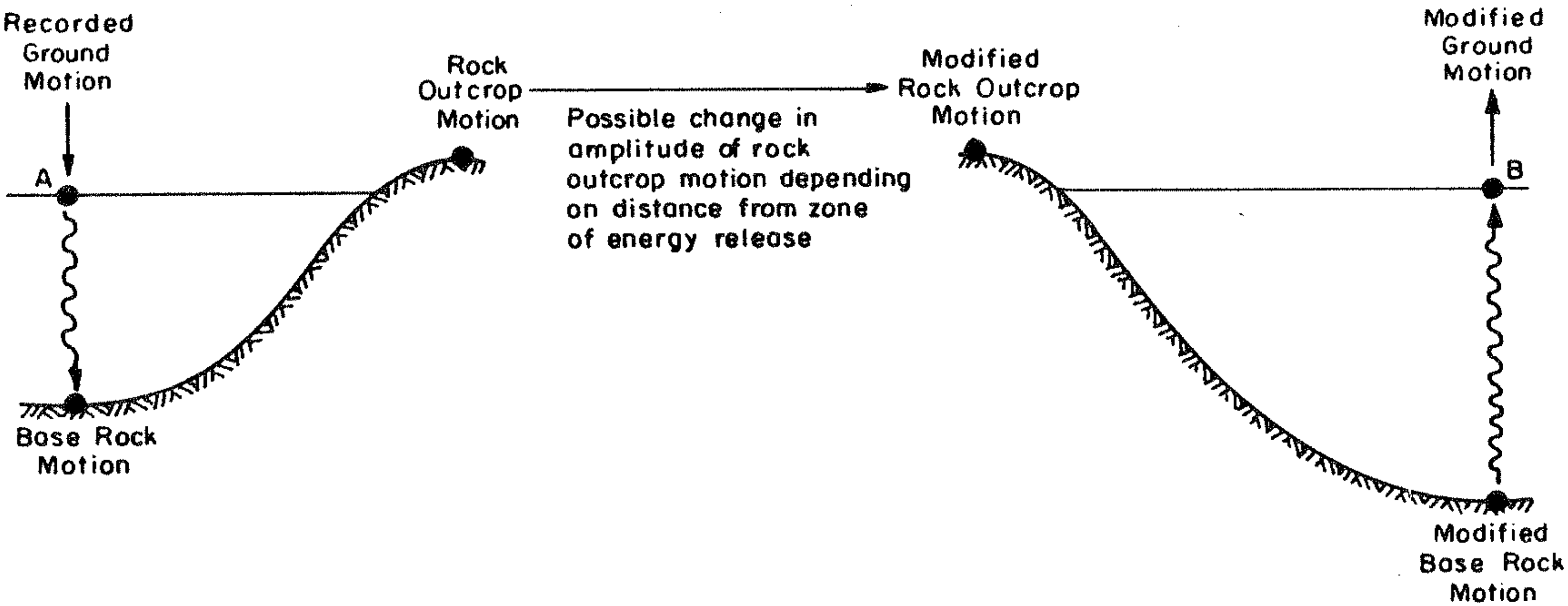


Fig. 1 SCHEMATIC REPRESENTATION OF PROCEDURE FOR COMPUTING EFFECTS OF LOCAL SOIL CONDITIONS ON GROUND MOTIONS

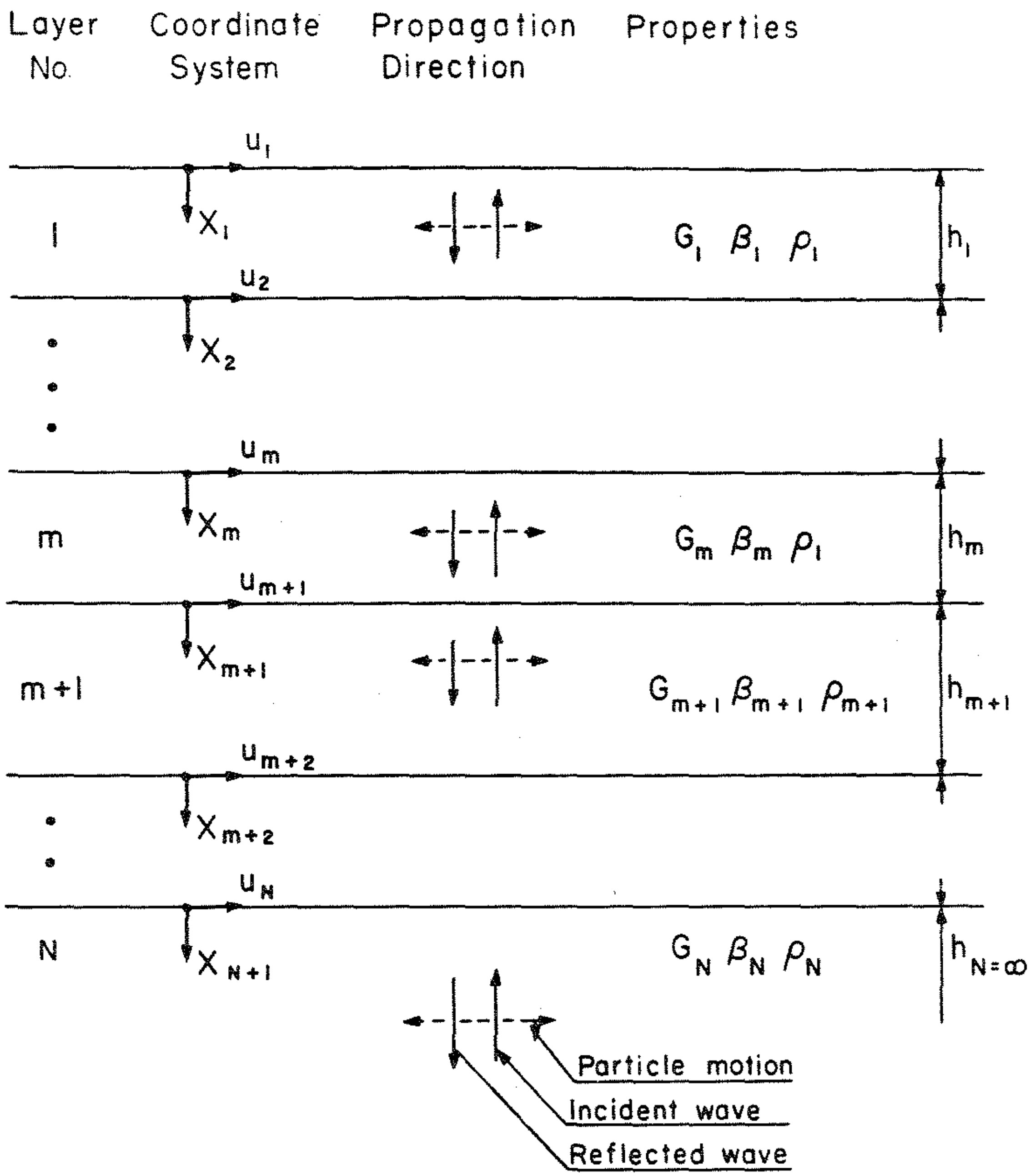


Fig. 2 ONE-DIMENSIONAL SYSTEM

where k is the complex wave number and G* is the complex shear modulus. The critical damping ratio, β, is related to the viscosity η by

$$\omega\eta = 2G\beta$$

Experiments on many soil materials indicate that G and β are nearly constant over the frequency range which is of main interest in the analysis. It is therefore convenient to express the complex shear modulus in terms of the critical damping ratio instead of the viscosity:

$$G^* = G + i\omega\eta = G(1+2i\beta) \qquad (7)$$

where G* can be assumed to be independent of frequency.

Equations 3 and 5 give the solution to the wave equation for a harmonic motion of frequency ω:

$$u(x,t) = Ee^{i(kx+\omega t)} + Fe^{-i(kx-\omega t)} \qquad (8)$$

where the first term represents the incident wave travelling in the negative x-direction (upwards) and the second term represents the reflected wave travelling in the positive x-direction (downwards).

Equation 8 is valid for each of the layers in Fig. 2. Introducing a local coordinate system X for each layer, the displacements at the top and bottom of layer m are:

$$u_m(X=0) = (E_m + F_m)e^{i\omega t} \qquad (9)$$

$$u_m(X=h_m) = (E_m \cdot e^{ik_m h_m} + F_m e^{-ik_m h_m}) \cdot e^{i\omega t} \qquad (10)$$

The shear stress on a horizontal plane is:

$$\tau(x,t) = G \cdot \frac{\partial u}{\partial x} + \eta \frac{\partial^2 u}{\partial x \partial t} = G^* \frac{\partial u}{\partial x} \qquad (11)$$

or by Eq. 8:

$$\tau(x,t) = ikG^*(Ee^{ikx} - Fe^{-ikx})e^{i\omega t} \tag{12}$$

and the shear stresses at the top and bottom of layer m are respectively:

$$\tau_m(X=0) = ik_m G_m^* \,(E_m - F_m)e^{i\omega t} \tag{13}$$

$$\tau_m(X=h_m) = ik_m G_m^* \,(Ee^{ik_m h_m} - F_m e^{-ik_m h_m})e^{i\omega t} \tag{14}$$

Stresses and displacements must be continuous at all interfaces. Hence, by Eq. 9, 10, 13 and 14:

$$E_{m+1} + F_{m+1} = E_m e^{ik_m h_m} + F_m e^{-ik_m h_m} \tag{15}$$

$$E_{m+1} - F_{m+1} = \frac{k_m G_m^*}{k_{m+1} G_{m+1}^*} \,(E_m e^{ik_m h_m} - F_m e^{-ik_m h_m}) \tag{16}$$

Subtraction and addition of Eqs. 15 and 16 yield the following recursion formulas for the amplitudes, E_{m+1} and F_{m+1}, of the incident and reflected wave in layer m+1, expressed in terms of the amplitudes in layer m:

$$E_{m+1} = \frac{1}{2}E_m(1+\alpha_m)e^{ik_m h_m} + \frac{1}{2}F_m(1-\alpha_m)e^{-ik_m h_m} \tag{17}$$

$$F_{m+1} = \frac{1}{2}E_m(1-\alpha_m)e^{ik_m h_m} + \frac{1}{2}F_m(1+\alpha_m)e^{-ik_m h_m} \tag{18}$$

where α_m is the complex impedance ratio

$$\alpha_m = \frac{k_m G_m^*}{k_{m+1} G_{m+1}^*} = \left(\frac{\rho_m G_m^*}{\rho_{m+1} G_{m+1}^*}\right)^{1/2} \tag{19}$$

which again is independent of frequency.

At the free surface, the shear stresses must be zero. In addition, Eq. 12 with τ_1 and X_1 equal to zero gives $E_1 = F_1$ --i.e., the amplitudes of the incident and reflected waves are always equal at a free surface. Beginning with the surface layer, repeated use of the recursion formulas Eqs. 17 and 18 leads to the following relationships between the amplitudes in layer m and those in the surface layer:

$$E_m = e_m(\omega)\ E_1 \tag{20}$$

$$F_m = f_m(\omega)\ E_1 \tag{21}$$

The transfer functions e_m and f_m are simply the amplitudes for the case $E_1 = F_1 = 1$, and can be determined by substituting this condition into the above recursion formulas.

Other transfer functions are easily obtained from the e_m and f_m functions. The transfer function $A_{n,m}$ between the displacements at level n and m is defined by

$$A_{n,m}(\omega) = u_m/u_n$$

and by substituting Eqs. 9, 20 and 21:

$$A_{n,m}(\omega) = \frac{e_m(\omega) + f_m(\omega)}{e_n(\omega) + f_n(\omega)} \tag{22}$$

Based on these equations the transfer function $A(\omega)$ can be found between any two layers in the system. Hence, if the motion is known in any one layer in the system, the motion can be computed in any other layer.

The amplitudes, E and F can thus be computed for all layers in the system, and the strains and accelerations can be derived from the displacement function. Accelerations are expressed by the equation:

$$\ddot{u}(x,t) = \frac{\partial^2 u}{\partial t^2} = -\omega^2(Ee^{i(kx+\omega t)} + Fe^{-i(kx-\omega t)}) \quad (23)$$

and strains by:

$$\gamma = \frac{\partial u}{\partial x} = ik(Ee^{i(kx+\omega t)} - Fe^{-i(kx-\omega t)}) \quad (24)$$

2.2 Ratio between rock outcrop motions and base rock motions.

If the amplitudes of the incident and reflected wave components, E_N and F_N, in the elastic halfspace, Fig. 3a, are known, the motions in the halfspace with the soil system removed, Fig. 3c, are easily computed. The shear stresses are zero at any free surface; thus $F_N = E_N$, and the incident wave is completely reflected with a resulting amplitude $2E_N$ at the free surface of the halfspace. The amplitude of the incident wave in the halfspace is independent of the properties of the system above it since the reflected wave is completely absorbed in the halfspace and does not contribute to the incident wave. The incident wave component, E_N, is therefore equal in all systems shown in Fig. 3.

The ratio between the base motion, u_N, and the motion, u'_N, at the free surface may be computed from the transfer function:

$$A'_N(\omega) = \frac{u_N}{u'_N} = \frac{e_N(\omega) + f_N(\omega)}{2e_N(\omega)} \quad (25)$$

The transfer function between the motion at the surface of the deposit, u_1, and the motion at the free surface of the halfspace is:

$$A'_{N,1}(\omega) = \frac{1}{e_N(\omega)} \quad (26)$$

If the halfspace is the rock formation underlying a soil deposit, Eq. 25 shows the ratio between the motion in the base rock and in the outcropping rock. The ratio between the amplitudes of the base rock motion

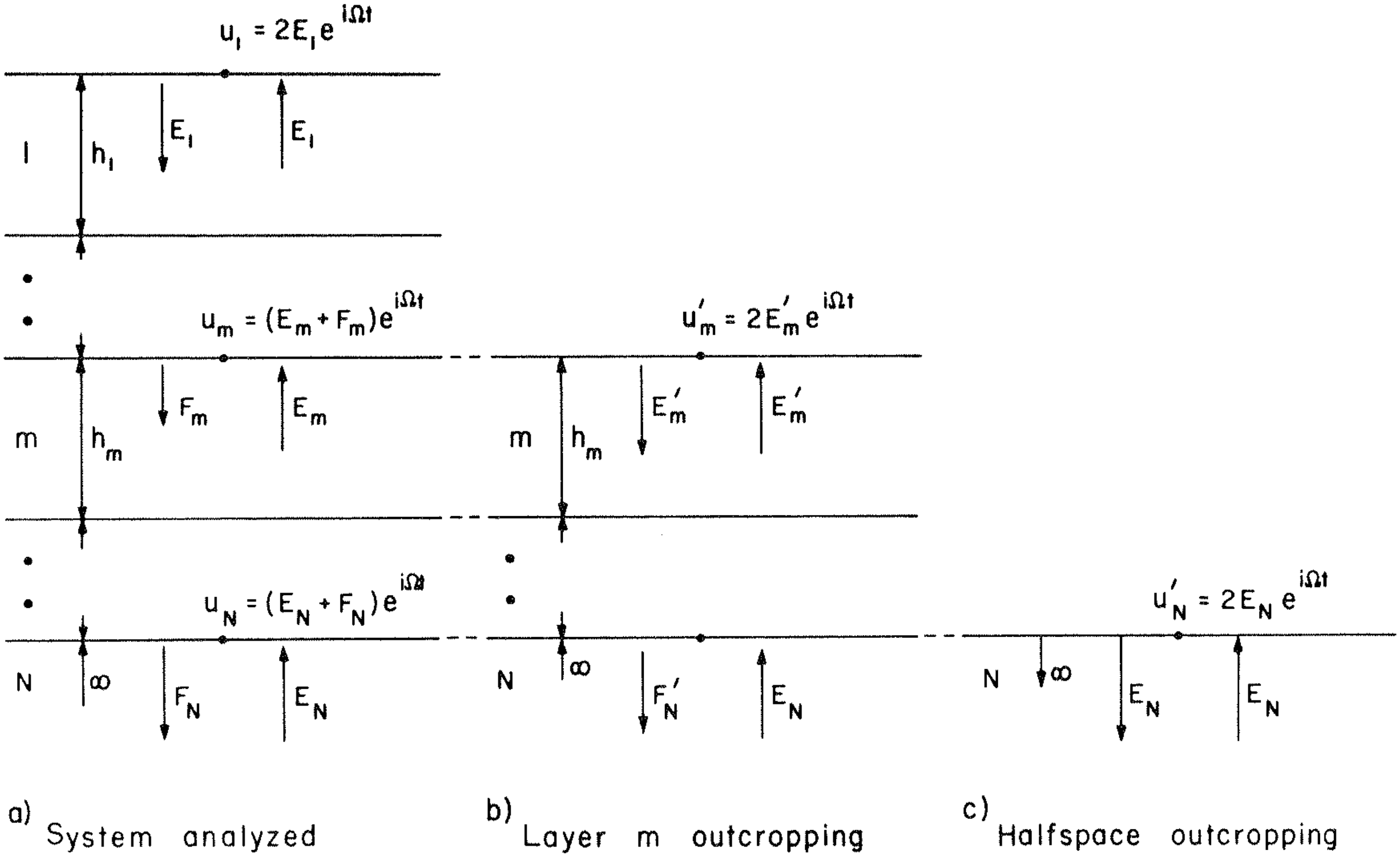


Fig. 3 ONE - DIMENSIONAL SYSTEM WITH OUTCROPPING LAYERS

and the outcropping rock motion is always less than 1, with minimum values at the resonance frequencies of the deposit. Transfer functions for the deposit used in the example, (Sect. 6), are shown in Fig. 4. The amplitude of the base rock motion is only 65% of the amplitude of the rock outcrop motion at the fundamental frequency of the deposit. This difference is a function of the impedance ratio between the deposit and the rock and of the damping in the deposit.

The differences in the computed responses resulting from the use of a rigid base, relative to the use of an elastic base, depend also on which frequencies are dominant in the rock motion. Rock motions with frequency dominance near the resonant frequencies of the deposit will be considerably more affected than motions with frequency dominance between the resonance frequencies, see Fig. 4. The effect of the elasticity of the base rock is, therefore, not only a function of the impedance ratio between deposit and rock and of the damping in the deposit, but also of the frequency distribution of the energy in the rock motion relative to the resonance frequencies of the deposit.

An approximation for the free surface motion for one of the layers in the system, Fig. 3b, may be obtained in the same way as for the halfspace, provided the incident wave component in the outcropping layer and in the layer within the system are equal--i.e. $E_m = E'_m$. This is approximately the case when the properties of layer m and all layers below are equal in the two systems and when the impedance, $\rho_m V_m$, is of the same order of magnitude as for the halfspace. This is the case for example, in sedimentary rock layers overlying a crystalline rock base. For a more accuate solution, the motion in outcropping layers must be computed in a separate system from the motion in the halfspace.

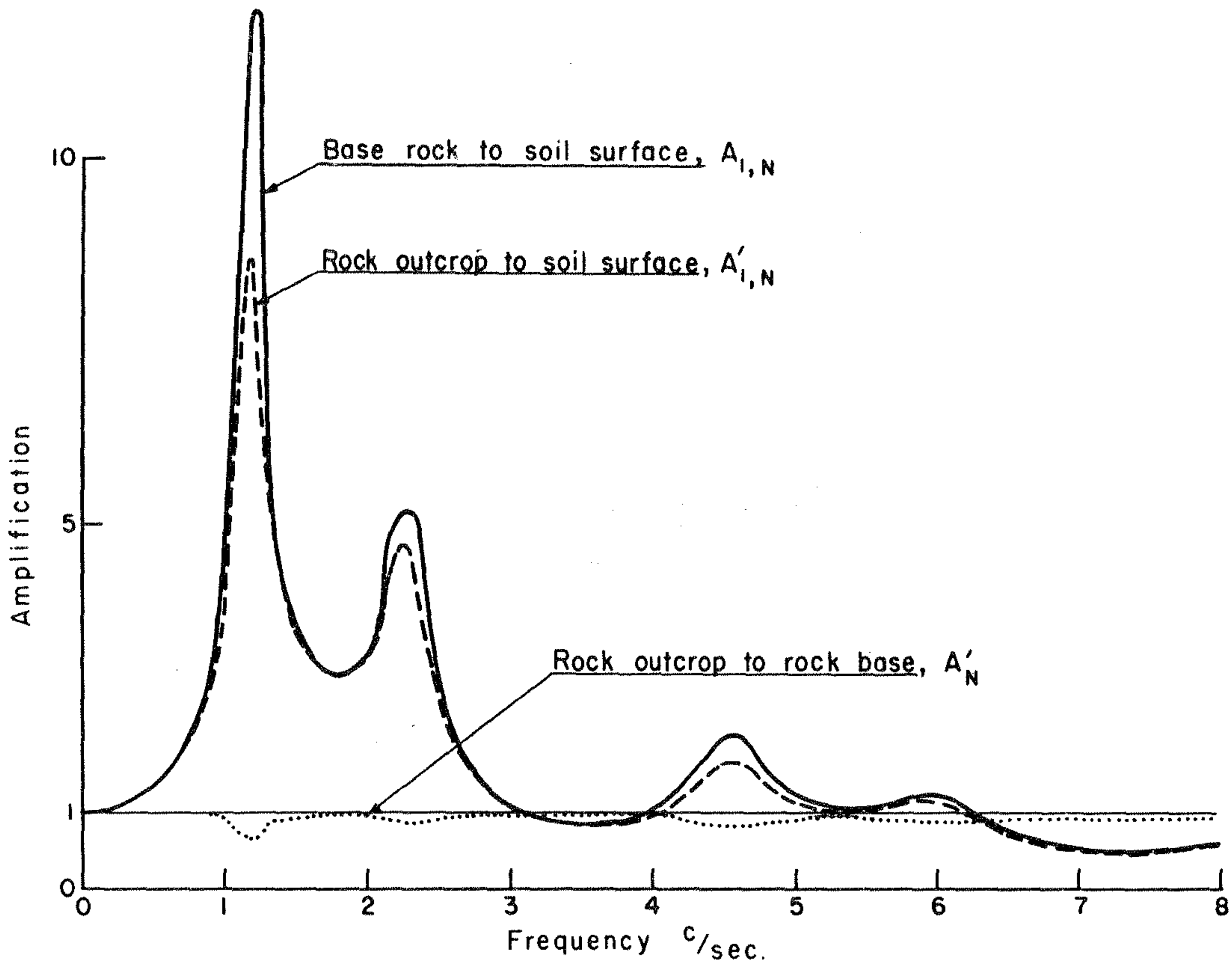


Fig. 4 TRANSFER FUNCTIONS

2.3 Transient motions

The expressions developed above are valid for steady state harmonic motions. The theory can be extended to transient motions through the use of Fourier transformation.

A digitized seismogram with n equidistant acceleration values, $\ddot{u}_j(j\cdot\Delta t)$, $j = 0,\ldots,n-1$, can be represented by a finite sum of harmonic motions:

$$\ddot{u}(t) = \sum_{s=0}^{n/2} (a_s e^{i\omega_s t} + b_s e^{-i\omega_s t}) \quad (27)$$

where ω_s, $s=0,\ldots,n/2$ are the equidistant frequencies:

$$\omega_s = \frac{2\pi}{n\cdot\Delta t}\cdot s \quad (28)$$

a_s and b_s designates the complex Fourier coefficients:

$$a_s = \frac{1}{n}\sum_{j=0}^{n-1} \ddot{u}(t)e^{-i\omega_s t},\quad b_s = \frac{1}{n}\sum_{j=0}^{n-1} \ddot{u}(t)e^{i\omega_s t} \quad (29)$$

and each term in Eq. 27 is a harmonic motion oscillating with frequency ω_s.

If the series in Eq. 27 represent the motion in a layer m, a new series representing the motion in any other layer n, is obtained by applying the appropriate amplification factor from Eq. 22 to each term in the series:

$$\ddot{u}_n(t) = \sum_{s=0}^{n/2} A_{m,n}(\omega_s)\cdot(a_{m,s}e^{i\omega_s t} + b_{m,s}e^{-i\omega_s t}) \quad (30)$$

The representation of a discrete motion with its Fourier transform gives an exact representation of the motion at the discrete points $t = j\cdot\Delta t$, $j = 0,\ldots,n-1$. Cyclic repetition of the motion with the period $T = n\cdot\Delta t$

is implied in the solution. The solution applies, therefore, to an infinite train of identical accelerograms rather than the given single accelerogram. For systems with damping this is not of any significant consequence since the individual accelerograms can be separated by a quiet zone of zeros causing the responses from one cycle to damp out before the beginning of the next cycle.

The Fourier Transformation can be performed in several ways. The SHAKE program utilizes the Fast Fourier Transform algorithm developed by Cooley and Tukey (1965), which is faster by a factor n/logn over the conventional method. This technique computes all values in the series simultaneously. The method requires that the number of terms in the series be some power of 2. A typical analysis using an acceleration record of 800 terms with time-step Δt = .02 sec. will use 1024 values in the Fast Fourier Transform, with all values between 800 and 1024 set equal to 0. This will satisfy both the requirements of a quiet zone after the acceleration record and that the total number of terms must be a power of two.

3. DESCRIPTION OF PROGRAM SHAKE

Program SHAKE computes the responses in a system of homogeneous, visco-elastic layers of infinite horizontal extent subjected to vertically travelling shear waves. The system is shown in Fig. 2. The program is based on the continuous solution to the wave-equation (Kanai, 1951) adapted for use with transient motions through the Fast Fourier Transform algorithm (Cooley and Tukey, 1965). The nonlinearity of the shear modulus and damping is accounted for by the use of equivalent linear soil properties (Idriss and Seed, 1968, Seed and Idriss, 1970) using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer.

The following assumptions are implied in the analysis:

1. The soil system extends infinitely in the horizontal direction.
2. Each layer in the system is completely defined by its value of shear modulus, critical damping ratio, density, and thickness. These values are independent of frequency.
3. The responses in the system are caused by the upward propagation of shear waves from the underlying rock formation.
4. The shear waves are given as acceleration values of equally spaced time intervals. Cyclic repetition of the acceleration time history is implied in the solution.
5. The strain dependence of modulus and damping is accounted for by an equivalent linear procedure based on an average effective strain level computed for each layer.

The program is able to handle systems with variation in both moduli and damping and takes into account the effect of the elastic base. The motion used as a basis for the analysis, the object motion, can be given in any one layer in the system and new motions can be computed in any other layer.

The following set of operations can be performed by the program:

1. Read the input motion, find the maximum acceleration, scale the values up or down, and compute the predominant period.
2. Read data for the soil deposit and compute the fundamental period of the deposit.
3. Compute the maximum stresses and strains in the middle of each sub-layer and obtain new values for modulus and damping compatible with a specified percentage of the maximum strain.

4. Compute new motions at the top of any sublayer inside the system or outcropping from the system.
5. Print, plot and punch the motions developed at the top of any sublayer.
6. Plot Fourier Spectra for the motions.
7. Compute, print and plot response spectra for motions.
8. Compute print and plot the amplification function between any two sublayers.
9. Increase or decrease the time interval without changing the predominant period or duration of the record.
10. Set a computed motion as a new object motion. Change the acceleration level and predominant period of the object motion.
11. Compute, print and plot the stress or strain time-history in the middle of any sublayer.

These operations are performed by exercising the various available options in the program. A list of these options is given in Section 5, Required Input Data.

4. SYSTEM AND OPERATION DOCUMENTATION

4.1 Computer equipment

The program has been developed on a CDC 6400 computer using FORTRAN IV language. The CDC 6400 has a 131 k core memory and uses a 60 bit words. The program has been run without modifications on CDC 6600, 7600 and UNIVAC 1108 computers, and with minor modifications on IBM 360 and 370 computers.

4.2 Storage requirements

The program requires approximately 50,000 octal words of storage excluding the blank common X. The additional storage is a function of the maximum number of terms used in the Fourier Transform as shown in Table 1.

Table 1. Storage Requirements

Number of terms	Length of array X	Field length octal
0	0	50,000
512	3220	57,000
1024	6420	65,000
2048	12820	102,000
4096	25620	134,000
8192	51220	220,000

4.3 Runtime

The runtime is a function of the number of terms, n, used in the Fourier Transformation and of the number of sublayers in the deposit. The time involved in the Fast Fourier Transformation is proportional to $n \cdot \log n$; all other operations are approximately proportional to n. In the computation of strain compatible soil properties, the time will also increase in proportion to the number of sublayers.

For the example run, Sect. 6, the approximate run times on the CDC 6400 are shown in Table 2.

Table 2. Runtimes.

Number of terms	Time interval, sec.	Run time sec.
512	.04	45
1024	.02	80
2048	.01	170

5. REQUIRED INPUT DATA

5.1 Organization of input data.

Following is a description of the operations performed by the different options, the required format for the input data, and explanations of some of the input parameters. The input format is also described at the beginning of the main program, see listing sect. 8.3.

The various options can be executed and repeated in any logical sequence. The operations in an option will be performed on the data given or computed in the program when the option is called, and the data may be changed at any time during the execution by repeating the option with new data.

For example, in order to compute new motions in a soil deposit, (Option 5) object motion (Option 1), soil profile data (Option 2), specification of location of object motion (Option 3), dynamic soil property-strain relation (Option 8), and strain iterations (Option 4--if strain compatible properties are desired), must precede Option 5. Soil responses for a new (additional) soil deposit may be obtained by repeating Options 2, 3, 4, and 5. The last-read soil deposit may be subjected to a new earthquake by repeating Options 1, 4, and 5.

5.2 Initialization card (I5,F10.0)

Cols.	1-5	MAMAX	Maximum number of terms to be used in the Fourier Transformation in any of the problems to be run. Must be a power of 2 such as 512, 1024, 2048, etc.
	6-15	SKO	Coefficient of earth pressure at rest for sand layers. If blank the value is set equal to 0.45. May be left blank if all layers are clay.

After the initialization card follows one run option card.

5.3 Run option card (I5)

Cols. 1-5 KK Run of option

0 - stop, no more data
1 - read input motion, and set as object motion
2 - read soil profile data
3 - assign the object motion to a specified sublayer
4 - iterate to obtain strain—compatible soil properties
5 - compute new motions at the top of specified sublayers, print maximum accelerations and punch acceleration time history
6 - print or punch acceleration time history of object motion or any specified computed motion
7 - modify object motion or set the motion in any specified sublayer as new object motion
8 - read relations between dynamic soil properties and strain
9 - compute response spectra for any specified motion
10 - increase time interval in motions
11 - decrease time interval in motions
12 - plot Fourier Spectrum of object motion
13 - compute and plot Fourier Spectrum of motion in any specified sublayer
14 - plot acceleration time history of object motion or any specified computed motion
15 - compute and plot amplification function between any two specified sublayers
16 - compute and plot stress or strain history in the middle of any specified sublayer.

After the run option card follows the data set for the selected option:

5.4 Data cards and explanatory notes for the various options

Option 1. Read Input Motion.

Operations performed

(1) Acceleration values are read from cards.

(2) The sequence of the cards is checked.

(3) The maximum acceleration value in the record is found.

(4) The acceleration values may be scaled either by a specified factor or to a specified maximum acceleration.

(5) Trailing zeros are added to the record to obtain sufficient length on the quiet zone [(a)] and a total number of values which are a power of 2.

(6) The higher frequencies in the record are removed and the maximum acceleration in the modified record is found--optional.

(7) The motion is set as the new object motion.

Data Cards

1st Card (2I5,F10.0,5A6)

Cols.	1-5	NV	Number of acceleration values to be read from cards.
	6-10	MA[(a)]	Number of values to be used in Fourier transform. Must be a power of 2.
	11-20	DT[(b)]	Time interval between acceleration values (sec.)
	22-50	TITLE(I)	Identification for earthquake.

2nd Card (3F10.0)

Cols.	1-10	XF	Multiplication factor for acceleration values. Used only if XMAX is 0, left blank otherwise.
	11-20	XMAX	Maximum acceleration value to be used. The acceleration values in the record will be scaled to give maximum acceleration = XMAX , unless XF is left blank.
	21-30	FMAX[(c)]	Maximum frequency to be used in the calculations. Acceleration amplitudes at all frequencies greater than FMAX are set equal to 0.

3rd and consecutive cards. Acceleration record. (8F9.6,I7)

Cols.	1-72	X(I)	8 acceleration values. (g's)
	73-79	K	Card number. Warning will be given for cards not in sequence.

Explanatory notes for Option 1.

(a) The acceleration values between NV and MA are set equal to 0. in the program. Cyclic repetition of the motion is implied in the Fourier transform and a quiet zone of 0.'s or low values are necessary to avoid interference between the cycles. For most problems a quiet zone of 2-4 seconds is adequate with longer time required for profiles deeper than about 250 ft and/or damping values less than about 5 percent.

(b) The predominant period of the earthquake record can be changed by altering the time interval Δt from that originally assigned to the acceleration record. If the original record has time interval Δt, and corresponding predominant period T_1, a new predominant period T_2 is obtained by changing the time interval to

$$\Delta t_2 = \frac{T_2}{T_1} \Delta t_1$$

(c) Frequencies above 10-15 c/sec carry a relatively small amount of the energy in earthquake motions, and the amplitudes of these frequencies can often be set equal to 0 without causing any significant change in the responses within a soil system. Table 3 shows the maximum accelerations and strains in the soil system used in the example run, sect. 6, computed for the Pasadena motion with time interval 0.02 sec and a maximum frequency of 25 c/sec. Results are also shown for the same motion with all amplitudes above 5 c/sec set equal to 0. The difference in maximum accelerations was less than 6.5% and in maximum strains less than 0.7% in the two cases. The difference in response spectral values was less than 1% for periods above 0.2 sec and less than 10% for periods from .0 to 0.2 sec.

Table 3. Effect of the Higher Frequencies on the Maximum Accelerations and Strains.

Depth	Maximum acceleration, g's		Difference %	Maximum strain, %		Difference %
	f_{max} = 25 c/sec	5 c/sec		f_{max} = 25 c/sec	5 c/sec	
0	.0971	.0962	.9			
				.00725	.00724	.1
7	.0958	.0949	.3			
				.1292	.1283	.7
20	.0600	.0599	.1			
				.0391	.0390	.3
30	.0553	.0556	.6			
				.0287	.0287	-
42	.0508	.0507	.2			
				.00982	.00989	.7
62	.0470	.0469	.2			
				.0505	.0504	.2
80	.0319	.0299	6.3			
				.0349	.0348	.3
100	.0239	.0235	1.7			
				.0320	.0319	.3
120	.0178	.0189	6.2			

In the computation of responses in deep soil systems from a motion given near the surface of the deposit, errors in the higher frequencies will be amplified and may cause erroneous results. To avoid this source of error, the amplitudes of all frequencies above 10-20 c/sec. may be set equal to 0., since these frequencies generally are of little interest and do not affect the response. Several runs should be performed with different amounts of the higher frequencies removed to investigate the effect on the response and to ensure a stable solution.

Removal of the higher frequencies in a motion has a smoothening effect on the acceleration time history as shown in Fig. 5 for a segment of the Pasadena motion. In this case the maximum acceleration for the modified and original motion were approximately equal, but the maximum accelerations may decrease or increase with the removal of the higher frequencies depending on the shape of the acceleration curve near the maximum value.

Option 2. Read Data for Soil Deposit.

Operations performed

(1) The properties of the soil deposit are read from cards.

(2) The sequence of the layer cards is checked.

(3) The layers are subdivided into sublayers--optional.

(4) Effective pressures in the middle of each sublayer are computed.

(5) The fundamental period of the deposit is computed.

Data Cards

1st Card (3I5,6A6)

Cols.	1-5	MSOIL	Soil deposit number. Can be left blank.
	6-10	ML[a]	Number of layer cards to be read including card for halfspace. There is one card for each layer whose properties are individually specified.[b]

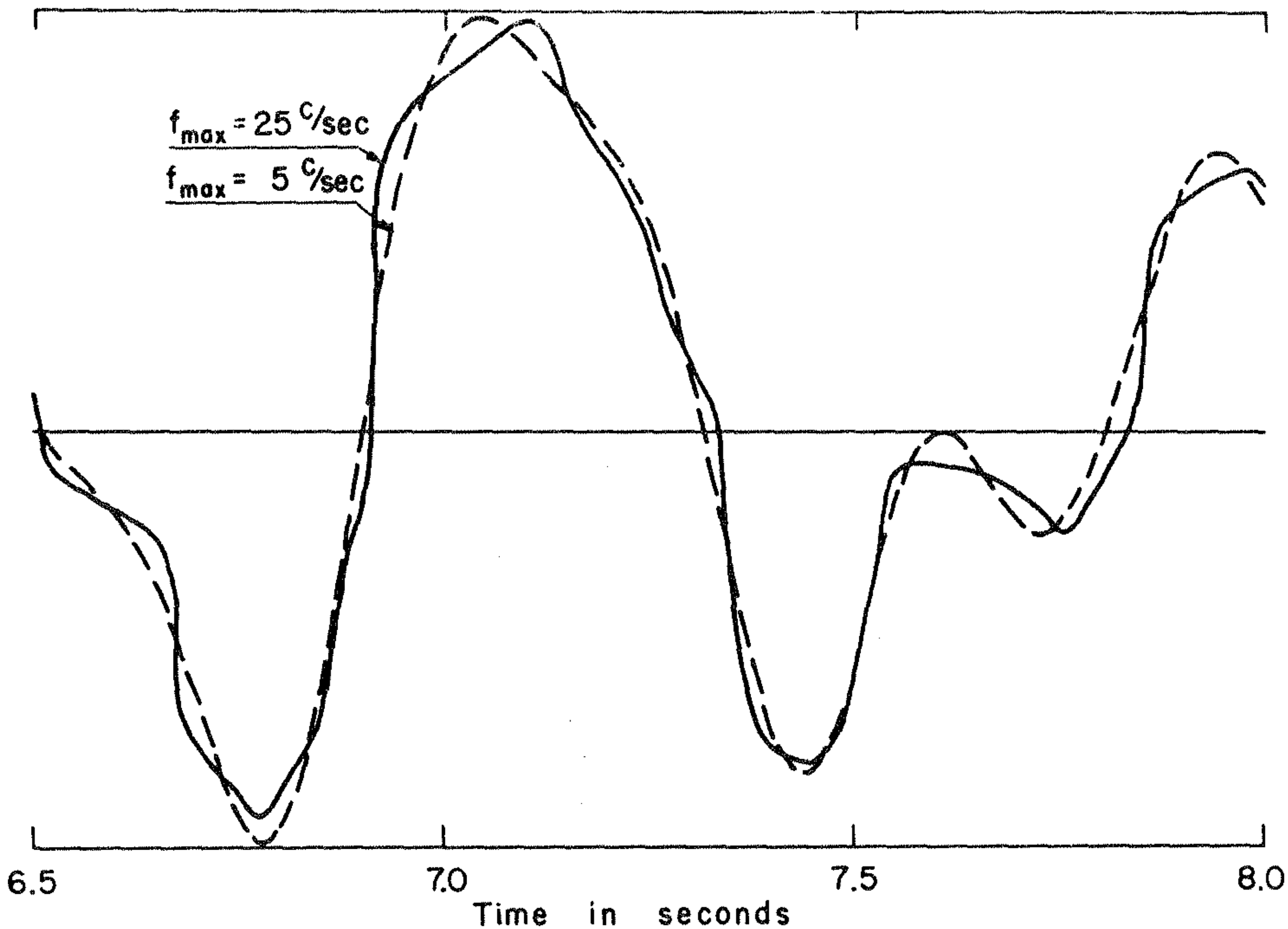


Fig. 5 EFFECT OF THE HIGHER FREQUENCIES ON THE ACCELERATION TIME-HISTORY

Cols. 11-15	MWL	Number of first submerged sublayer [b]. [If no ground water table present, put groundwater table at top of halfspace.]
17-51	IDNT(I)	Identification for soil profile.

2nd and consecutive cards. One card for each layer including halfspace. (3I5,6F10.0,F5.0)

Cols. 1-5	K	Layer number. The layer cards must be in sequence with the surface layer as layer 1. Note that the number of layers may be $\leq$ the number of sublayers [b].
10	TYPE [c]	Soil type 1 - clay 2 - sand 3 - rock
11-15	NLN [a,b]	Number of sublayers in layer K. The K^{th} layer will be divided into NLN sublayers of thickness = HL/NLN.*
16-25	HL [a]	Layer thickness (ft.)
26-35	GMOD [d]	Initial estimate of shear modulus (kips/sq.ft.) Not necessary if VS is given.
36-45	B [d]	Initial estimate of critical damping ratio (decimal).
46-55	W	Unit weight (kips/cu. ft.).
56-65	VS [d]	Initial estimate of shear wave velocity (ft/sec). Not necessary if GMOD is given.
66-75	FACTOR [c]	Factor for shear modulus Clay - F_c = undrained shear strength (kips/sq. ft.) Sand - F_s = factor modifying the average curve read in under Option 8. Set F_s = 1. for no change. Rock - F_R = Shear wave velocity for low strain values—in thousands of ft./sec.
76-80	BFAC	Factor modifying the standard damping curve read in under Option 8. For example, a factor of 1.2 increases each and every value by 20 percent.

For the elastic half space, soil layer card number ML, it is sufficient to give values for K, GMOD or VS and W.

---

*Maximum total number of sublayers including the base is 20.

Explanatory notes for Option 2.

(a) With the wave propagation method the responses can be computed in a homogeneous layer of any thickness. A soil deposit will, however, have varying properties not only due to the variation in the soil itself but also due to the differences in the strain-level induced during shaking. Since the soil deposit must be represented by a set of homogeneous layers, each with a constant value of modulus and damping, the thickness of each layer must be limited based on the variation in the soil properties. For a fairly uniform deposit, a sublayer thickness increasing from about 5' at the surface to 50-200' below 100' depth should give sufficient accuracy. Accuracy may be checked by making a trial run and comparing results with a subsequent run where more layers and/or sublayers are used.

(b) The division of a layer into sublayers is for convenience to avoid punching of several cards with the same properties, and all sublayers are treated as separate layers in the following computations. The sublayers are numbered consecutively starting at the top of the soil deposit and the halfspace is counted as the last layer and the last sublayer in the deposit.

(c) Computations of shear moduli for the different soil types are based on the following expressions:

Clay $G_c = K_c \cdot F_c$

Sand $G_s = K_s \cdot 1000 \cdot (\sigma'_m)^{1/2} \cdot F_s$

Rock $G_R = K_R \cdot \rho \cdot (1000 \cdot F_R)^2/2000.$

where

K = strain function given in Option 8.

F = factor given as input (FACTOR)

ρ = mass density in kips/cu. ft.

σ'_m = mean effective pressure (psf).

The strain function for clays, K_c, gives the average relationship between G/S_u and strain for saturated clays. While the undrained shear strength of the clay, S_u, is normally used in this modulus-strain relation, the factor for clay, F_c, should be given a value which gives the correct modulus-strain relation; thus F_c is not necessarily equal to S_u. If the modulus of the clay is found from seismic investigations, the value of F_c should be set to G_c/K_c where K_c is the value for 10^{-4} percent strain in the curve given in Option 8.

(d) The modulus and damping are in general used as initial values on the first iteration for the computation of strain-compatible properties, but they can also be used directly to compute the responses for the values given, by omitting Option 4. Typical values of the modulus for strong shaking are of the order of 500 kips/sq. ft. near the surface increasing to 3000 kips/sq. ft. at 100-200' depth for sand, 500-2000 kips/sq.ft. for clay with values as low as 50-100 kips/sq. ft. for soft clay. Usually 3-5 iterations are sufficient to obtain strain compatible values within a 5-10% error limit.

The results are not highly sensitive to errors in the damping ratio and values selected between 0.05 to 0.15 will usually give strain-compatible values with 2 to 3 iterations.

Option 3. Assign Object Motion to a Specified Sublayer.

Operations performed

The object motion is assigned to the top of one sublayer in the soil deposit.

Data Cards

1st Card (2I5)

Cols.	1-5	IN	Number of sublayer where object motion is assigned.
	6-10	INT	Type of sublayer 0 - Outcropping[(a)] sublayer 1 - sublayer within profile

Explanatory notes to Option 3.

[(a)] See Section 2.2.

Option 4. Obtain Strain Compatible Soil Properties.

Operations performed

(1) Parameters for the iterations are read from card.

(2) Maximum strains, stresses and times for the maxima are computed in the middle of each sublayer.

(3) Effective strains are obtained from the maximum strains and used to compute new soil properties.

(4) The operation is repeated until strain-compatible soil properties are obtained within a given error limit or until a specified maximum number of iterations is reached.

(5) The fundamental period of the deposit is computed after the final iteration.

(6) A set of soil data cards with the new strain compatible properties is punched--optional.

Data Cards

1st Card (2I5,2F10.0)

Cols.	Field	Description
1-5	KS[(a)]	Set equal to 1 for punched set of soil data cards with the soil properties after final iteration. Leave blank if punched cards are not wanted.
6-10	ITMAX[(b)]	Maximum number of iterations.
11-20	ERR[(b)]	Maximum acceptable difference between the last-used modulus and damping values and the strain-compatible values (percent).
21-30	PRMUL[(c)]	Ratio between effective strain and maximum strain (decimal).

Explanatory notes for Option 4.

(a) The most time consuming part of the computations is to obtain strain compatible soil properties. A set of soil data cards with strain-compatible properties may save computer or punching time if additional computer runs are to be made subsequently.

(b) The iterations stop when the specified maximum number of iterations (ITMAX) is reached or when the difference between the modulus and damping used and the strain-compatible modulus and damping values is less than the acceptable difference (ERR). Usually 3-5 iterations are sufficient to obtain an error of less than 5-10%. The values given as "new values" in the final iteration are used in all computations following Option 4, and the actual error is less than the error values given in the final iteration.

(c) The effective strain is used to compute new soil properties. The ratio between the effective and the maximum strain has been empirically found to be between 0.5 and 0.7. The responses, however, are not highly sensitive to this value and an estimate between 0.55 to 0.65 is usually adequate, with the higher value appropriate for giving more uniform strain histories.

Option 5. Compute Motion in Specified Layers.

Operations performed

(1) The acceleration time history is computed at the top of specified sublayers.

(2) The maximum acceleration and times for maxima are printed for the computed motions.

(3) The computed acceleration time histories may be punched--optional.

(4) The acceleration time histories may also be printed or plotted (Option 6, 7 and 14)[a].

Data Cards

1st Card (15I5)

Cols.	1-75	LL5(I)	Array showing the numbers of the sublayers at the top of which the motion is to be computed. Maximum of 15 locations.

2nd Card (15I5)

Cols.	1-75	LT5(I)	Array specifying types[b] of above sublayers. 0 - outcropping sublayer 1 - sublayer within profile

3rd Card (15I5)

Cols.	1-75	LP5(I)[a]	Array with mode of output for the computed motions. 0 - max. acceleration value only printed. 1 - punched cards giving acceleration time history in addition to the printed maximum acceleration value.

Explanatory notes for Option 5

(a) The acceleration time histories can be printed or plotted through the use of Option 7 where a specified motion is set as the new object motion. Subsequent use of Options 6 and 14 give respectively a printed and a plotted output of the acceleration time history of the motion.

(b) See section 2.2.

Option 6. Print or Punch Object Motion.

Operations performed

(1) Maximum acceleration and time at which maximum occurs are found.

(2) The object motion is printed--optional.

(3) The object motion is punched on cards--optional.

Data Cards

1st Card (I5)

Col. 5 K2 Selects mode of output.

K2 = 0 Max. acc. only
1 Punched output
2 Printed and punched output.

Option 7. Change Object Motion.

Operations performed

(1) A motion at the top of a specified sublayer can be set as the new object motion and printed or punched (Option 6) or plotted (Option or used for subsequent computations--optional.

(2) The time step in the object motion can be changed--optional.

(3) The acceleration level in the object motion can be changed--optional.

Data Cards

1st Card (2I5,2F10.0)

Cols. 1-5 LL1 Number of sublayer. Use 0 if object motion originally assigned is to be retained[a].

6-10 LT1 Type of above sublayer
0 - outcropping [c] sublayer
1 - sublayer within profile

11-20 XF Multiplication factor for acceleration values--1. for no change.

21-30 DTNEW New timestep[b].

Explanatory notes for Option 7

(a) The acceleration level and timestep can be changed either on the motion originally set as the object motion, or on the computed motion which is set as the new object motion through Option 7.

(b) A change in time interval will change the predominant period of the motion. If the time interval and predominant period of the original motion are Δt_1 and T_1, respectively, a new predominant period T_2 is obtained by changing the time interval to

$$\Delta t_2 = \frac{T_2}{T_1} \Delta t_1$$

(c) See section 2.2.

Option 8. Read the relation between the Effective Strain and the Dynamic Properties

Operations performed

(1) Effective strain values with corresponding values for damping and moduli are read from cards.

(2) Parameters are computed for interpolation of modulus and damping values using a linear semilogarithmic relation between the given values.

(3) The relationship between the dynamic properties and the strain is plotted--optional.

Data Cards

1st Card (3I5,F10.0,10A6)

Cols.	1-5	NSOILT	Number of different soil or rock types to be read. Maximum 4.[(a)]
	10	NPL[(b)]	Set equal to 1 for plot of curves.
	11-15	NN[(b)]	Number of strain-values in each logarithmic unit to be plotted.
	16-25	SC	Maximum value of the ordinate in the plotting.
	26-80		Title or identification data.

Next follows two sets of cards for each soil or rock type. The first set gives the relationship between the shear modulus parameters (C) and the effective strains; the second set give the relation between the critical damping ratios and the effective strains. Typical data is shown on page 40.

First Set:

1st Card (I5,F5.0,11A6)

Cols.	1-5	NV(L)	Number of strain values to be read. Maximum 20.
	6-10	FPL(L)[b]	Multiplication factor for shear-modulus parameter. Used for plotting only.[b]
	12-76	ID(L,I)	Identification for first data set. Used for plotting only.

2nd and consecutive cards (8F10.0)

Cols.	1-80	X(L,I)	Effective strain values in percent beginning with the lowest value. 8 values per card with maximum of 20 values.

Consecutive cards (8F10.0)

Cols.	1-80	Y(L,I)	Values of the shear modulus parameter [c] corresponding to the strain values given above. Eight values per card with maximum of 20 values.

Second Set:

The input format for the second set is identical to that for the first set with values of critical damping ratios in percent instead of the values for the shear modulus parameter.

<u>Explanatory notes for Option 8.</u>

(a) Three different soil or rock types can be used in the program as described in Option 2. The relationships between effective strains and the dynamic properties must be read in the same sequence as the soil type using the notation:

1 - Clay

2 - Sand

3 - Rock

(b) The values for the shear modulus parameter and the damping can be plotted against the effective strains. If plotting is specified (NPL = 1), values for the shear modulus parameter and damping are computed for a specified number of effective strains (NN) in each logarithmic unit. The computed values should be scaled (FPL(L)) to obtain good representation of all curves on the same plot. The scaled values and the corresponding effective strains are also printed.

(c) The values are used to compute the shear modulus for the different soil types. The relationship for sand and clay used in the program is based on the expressions given by Seed and Idriss (1970):

$$\text{Clay} \quad K_c(\gamma) = \frac{G_c(\gamma)}{S_u}$$

$$\text{Sand} \quad K_s(\gamma) = \frac{G_s(\gamma)}{1000 \cdot (\sigma_m')^{1/2}}$$

The relationship used for rock is the scaled ratio between the shear modulus at low effective strain (10^{-4} percent) and the shear modulus at a specified effective strain:

$$\text{Rock} \quad K_R(\gamma) = \frac{G(\gamma) \cdot 2000}{G(\gamma 10^{-4})}$$

Option 9. Compute Response Spectra

Operations performed

(1) The motion is computed at the top of a specified sublayer.

(2) Times for maxima in the acceleration, velocity and displacement spectra are computed and printed.

(3) Acceleration and velocity spectra may be plotted and/or punched on cards--optional.

Data Cards

1st Card (2I5)

Cols.	1-5	LL1	Sublayer number. Use 0 if the response spectra are to be computed for the object motion.
	10	LT1	Type of sublayer. 0 - outcropping sublayer 1 - sublayer within profile. The response spectra are computed for the motion at the top of the sublayer. May be left blank if LL1 is 0.

2nd Card (5I5)

Col. 5	ND	Total number of damping values to be used. Maximum 6 values.
10	KP	Set equal to 1 for punched output.
15	KAV	Select plot and punch option: 0 - plot and/or punch velocity spectrum 1 - plot and/or punch acceleration spectrum 2 - plot and/or punch acceleration and velocity spectrum.
20	KPL	Set equal to 1 for plot of spectra according to KAV. All spectra computed since last plotting will be plotted together.
25	KPER	Select periods to be used in the computations:

KPER = 0

9 steps from 0.1 sec to 1. sec
5 steps from 1. sec to 2. sec
4 steps from 2. sec to 4. sec

KPER = 1

18 steps from 0.1 sec to 1. sec
10 steps from 1. sec to 2. sec
8 steps from 2. sec to 4. sec

KPER = 2

38 steps from 0.05 sec to 1. sec
20 steps from 1. sec to 2. sec
30 steps from 2. sec to 5. sec

KPER = 3

Logarithmic increments with 10 steps in each log. unit from 0.1 to 5.

KPER = 4

Logarithmic increment with 25 steps in each log. unit from 0.05 to 10.

3rd Card (6F10.0)

Cols. 1-60 ZLD(I) Values of critical damping ratios in decimal to be used in the spectral analysis. ND number of values must be given.

Option 10. Increase the Time Interval

Operations performed

The time interval is increased.

Data Cards

1st Card (I5)

Cols. 1-5 IFR[a] Factor for increasing time interval. Must be a power of 2.

Explanatory notes for Option 10

(a) The Fourier Transformation of a given acceleration time history consists of a series of harmonic motions

$$\ddot{u}(t) = \sum_{s=0}^{n/2} (a_s e^{i\omega_s t} + b_s e^{-i\omega_s t})$$

With the harmonic motions given, acceleration values can be computed for any value of the time, t, and a new acceleration time history can be generated with a time interval different from the original.

Suppose, for example an acceleration record is given with 2048 values and a timestep $\Delta t = 0.01$ sec. Through Option 10 with IFR = 2 a new record with 1024 values and timestep 0.02 sec is generated. The acceleration values in the two records are identical at all times $n \cdot .02$ sec., $n = 1,2...1024$. The new record has a maximum frequency of 25 c/sec. compared to 50 c/sec. in the original records, and frequencies from 25 c/sec. to 50 c/sec. are lost in the operation.

Increasing the time interval reduces the computer time as shown under sect. 4.3. For computation of maximum accelerations a time interval of 0.02 sec. will generally give adequate accuracy while a time interval of 0.04 sec. may be sufficient for the computation of the stresses and strains in a deposit.

The difference in maximum accelerations and strains resulting from the use of different time intervals are shown in Tables 4 and 5 for the example run. The effect may be somewhat higher for earthquakes with lower predominant periods and for stiffer soil systems.

Option 11. Decrease the Time Interval

Operations performed

The time interval is decreased.

Data Cards

1st Card (I5)

Col. 1-5	IFR[a]	Factor for decreasing the time interval; must be a power of 2.

Explanatory notes for Option 11.

(a) See explanation to Option 10. Through Option 11 a new time history is generated with the time interval reduced by a power of 2. Compared with the usual linear interpolation, this method has the advantage of not introducing additional frequencies to the motion.

Option 12. Plot Fourier Spectrum of Object Motion

Operations performed

(1) The Fourier Spectrum of the object motion is plotted.

(2) The spectrum may be smoothed--optional.

Data Cards

1st Card (3I5)

Cols. 5	K1	Select for plotting: 0 - Store spectrum for later plotting. Max. of 2 spectra can be plotted together. 1 - Plot all spectra stored since last plotting.
6-10	NSW[a]	Number of times the spectrum is to be smoothed.
11-15	N	Number of values to be plotted--maximum of 2049.

Table 4. Effect of Time Interval on Maximum Strain.

Depth	Computed Maximum Strain %		
	Δt = .01	Δt = .02	Δt = .04
3.5	.00727	.00725	.00725
13.5	.129	.129	.127
25.	.0392	.0391	.0390
36	.0287	.0287	.0285
52	.00982	.00982	.00981
71	.0505	.0505	.0505
90	.0350	.0349	.0348
110	.0320	.0320	.0316

Table 5. Effect of Time Interval on Maximum Acceleration.

Depth	Maximum Acceleration		
	$\Delta t = .01$	$\Delta t = .02$	$\Delta t = .04$
0	.0971	.0971	.0967
7	.0960	.0958	.0954
20	.0598	.0600	.0590
30	.0554	.0553	.0548
42	.0508	.0508	.0498
62	.0471	.0470	.0462
80	.0317	.0319	.0318
100	.0238	.0239	.0242
120	.0181	.0178	.0178

Explanatory notes to Option 12.

(a) The expression used to smooth the spectrum is:

$$A_i = \frac{A_{i-1} + 2A_i + A_{i+1}}{4}$$

where A_i is the acceleration amplitude for the i^{th} frequency.

Option 13. Plot Fourier Spectrum[c] of Computed Motions

Operations performed

(1) The motions at the tops of the specified sublayers are computed.

(2) The Fourier Spectra for the computed motions are plotted and printed.

(3) The spectrum may be smoothed--optional.

Data Cards

1st Card (5I5)

Cols.	Variable	Description
1-5	LL(1)	Sublayer number.
10	LT(1)	Type of sublayer: 0 - Outcropping[b] sublayer 1 - Sublayer within profile.
15	LP(1)	Select for plotting: 0 - Store spectrum for later plotting; max. of 2 spectra can be plotted together 1 - Plot all spectra stored since last plotting.
16-20	LNSW(1)[a]	Number of times the spectrum is to be smoothed.
21-25	LLL(1)	Number of values to be plotted. Max. of 2049.

2nd Card (5I5)

As for Card 1 for a second motion. A blank card must be used if only one spectrum is to be computed.

Explanatory notes for Option 13

(a) See Option 12.

(b) See section 2.2.

(c) See section 2.3.

Option 14. Plot Time History of Object Motion[a].

Operations performed

The time history of the object motion is plotted.

Data Cards

1st Card (2I5)

Cols.	1-5	NSKIP	Number of values skipped in the plotting. 0 - every value is plotted 1 - every second value is plotted etc.
	6-10	NN	Number of values to be plotted. Max. of 2049 values.

Explanatory notes to Option 14.

(a) The time history of a computed motion can be plotted by setting this motion as the object motion through Option 7.

Option 15. Compute Amplification Spectrum.

Operations performed

(1) The amplification spectrum between any two sublayers in a given soil system is computed.

(2) The maximum amplification and the corresponding period are printed.

(3) The amplification spectrum may be plotted and printed--optional.

Data Cards

1st Card (5I5, F5.0,8H6)

Cols.	1-5	LIN[a]	Number of first sublayer.
	6	LINT	Type of first sublayer 0 - outcropping[b] sublayer 1 - sublayer within profile
	11-15	LOUT[a]	Number of second sublayer.
	20	LOTP	Type of second sublayer 0 - outcropping sublayer 1 - sublayer within profile.
	25	KP	Select for plotting: 0 - Store spectrum for later plotting. Maximum of 8 spectra can be stored. 1 - Plot all spectra stored since last plotting.

26-30	DFA	Frequency steps. The amplification factor is computed for the first 200 frequencies with interval DFA c/sec. beginning at 0.
32-78	IDAMP(I)	Identif[illegible]ion.

Explanatory notes to Option 15.

(a) The amplification factors are computed from the first sublayer to the second.

(b) See section 2.2.

Option 16. Compute Stress or Strain History in the Middle of Specified Sublayers.

Operations performed

(1) The stress and/or strain time history in the middle of any two specified sublayers are computed.

(2) The computed time histories may be plotted or punched on cards.

Data Cards

1st Card (5I5,F10.0,5A6)

Cols. 1-5	LLL(1)	Sublayer number. The stress or strain history is computed on the middle of the sublayer.
10	LLGS(1)	Select type of response: 0 - strain 1 - stress
15	LLPCH(1)	Set equal to 1 for punched output.
20	LLPL(1)	Set equal to 1 for plotting.
21-25	LNV(1)	Number of values to be plotted; maximum of 2049.
26-35	SK(1)	Scale for plotting--i.e. maximum value of ordinate. If blank, the largest value in the response is set as the maximum value of the ordinate.
37-65	ID(1,)	Identification.

2nd Card. As for Card 1 for second sublayer. Use blank card if only one response is to be computed.

6. EXAMPLE RUN

6.1 Selection of soil system and input motion.

An example problem is shown in Fig. 6. Maximum accelerations, stresses and strains in the soil deposit and response spectra for the surface accelerations are wanted for a magnitude 7.4 earthquake occuring 100 miles from the site.

Based on the relations given by Seed and Idriss (1970), the soil system shown on Fig. 7 was selected for analysis. The factors used for clay are equal to the undrained shear strength in kips/sq. ft. The factors for sand are estimated from relative densities and content of gravel.

The motion in rock for a magnitude 7.4 earthquake 100 miles from the causative fault is estimated to have maximum acceleration of .02g and a predominant period of 0.65 sec (Schnabel and Seed, 1972; Seed et al., 1969). Among the available strong motion records, the Pasadena record from the 1952 Kern County earthquake seems to have characteristics most similar to those desired. The magnitude of the earthquake was 7.7, the record was obtained some 75 miles from the fault, the maximum acceleration was 0.057g and the predominant period was 0.65 sec. Modification of this record to give a maximum acceleration 0.02g gives the desired characteristics for the motion in an outcropping rock formation near the example site.

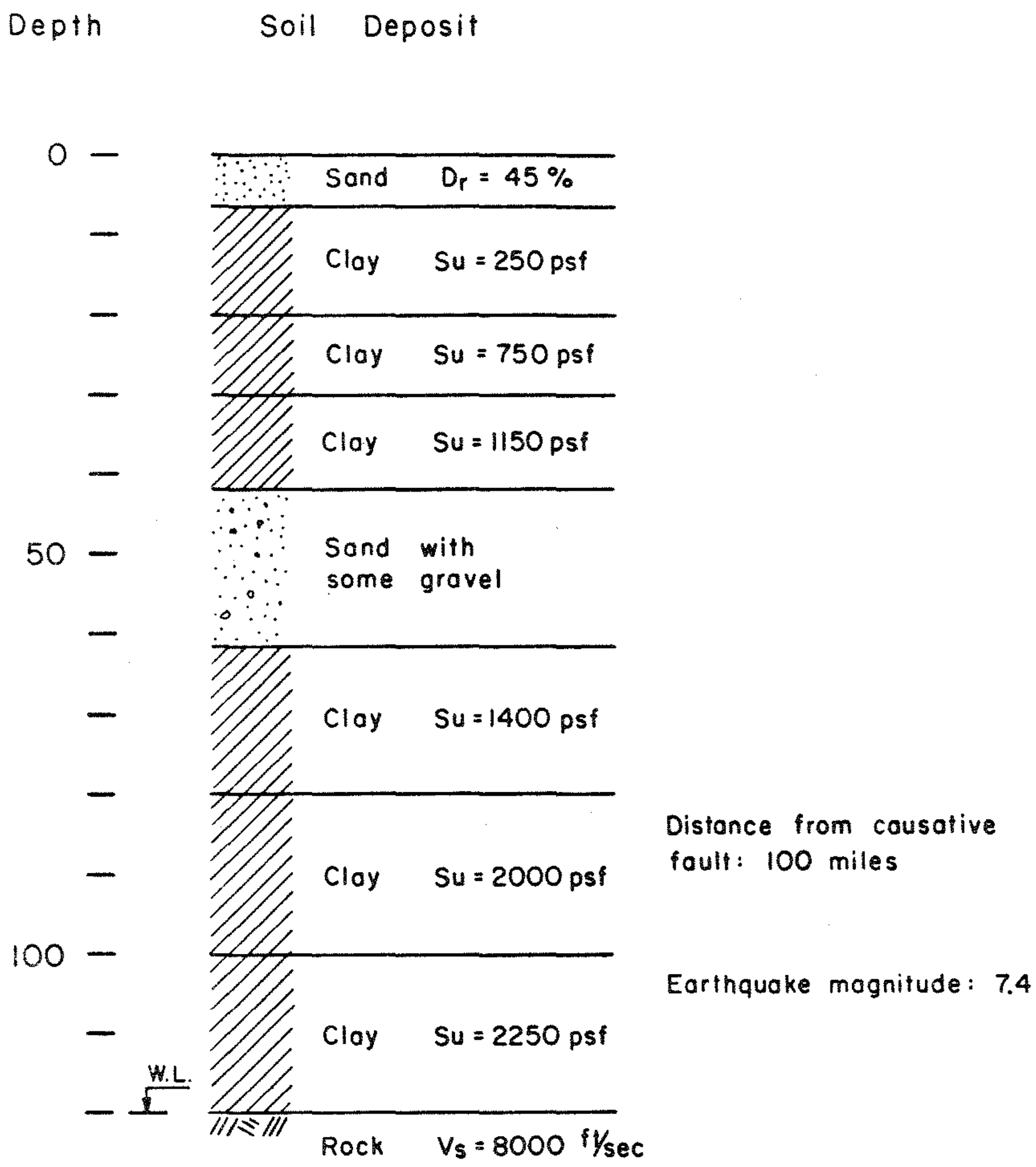


Fig. 6 EXAMPLE PROBLEM

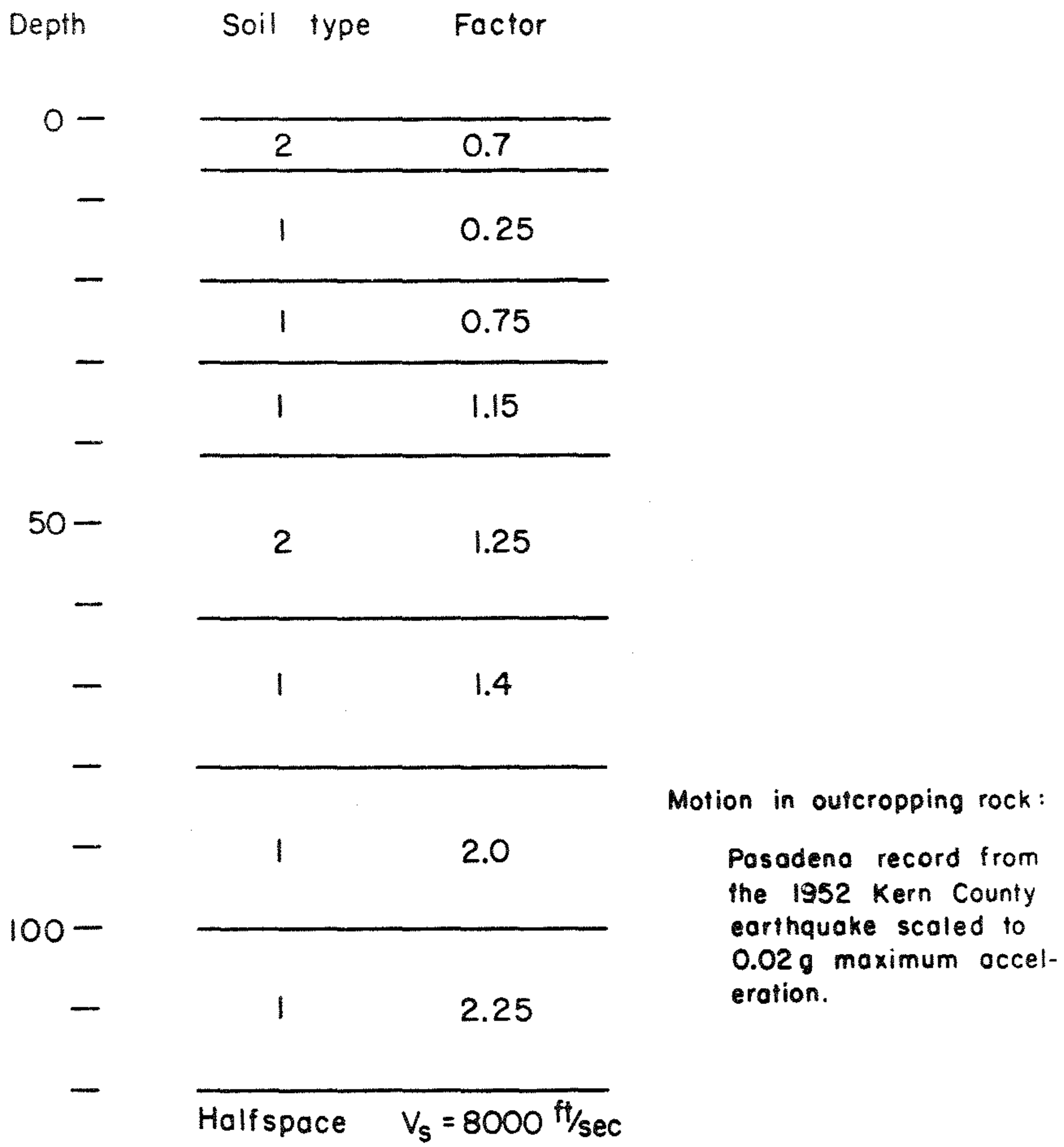


Fig. 7 SYSTEM USED IN THE ANALYSIS OF THE EXAMPLE PROBLEM

6.2 Input data for the analysis.

```
     INITIALIZATION        1 CARD

1........10........20........30........40........50........60........70........80
1024
```

```
     OPTION 8              28 CARDS

1........10........20........30........40........50........60........70........80
   8
   1    1   10    50.
 11 .01  SHEAR MODULUS CLAY   MAY 24 - 1972
.0001     .000316    .001      .00316     .01      .0316      .1       .316
1.          3.16     10.
2300.     2170.      1750.     1300.      920.      600.      390.      175.
84.        30.       10.
 10  1.  DAMPING CLAY  MAY 24 - 1972
 .0001     .001      .00316    .01                 .0316      .1       .316      1.
3.16      10.
 2.0      2.5        3.5       4.75       6.5       9.25      13.75     20.
26.       29.
 11 .5   SHEAR MODULUS SAND SQ.ROOT REL. MAY 24-1972
.0001     .000316    .001      .00316     .01      .3316      .1       .316
1.         3.16      10.
61.        60.       57.       50.4       40.       27.       15.       7.
3.         1.        3.
  9  1.  DAMPING SAND  FEBRUARY 1971
 .0001     .001      .003      .01        .03       .1        .3       1.
10.
1.        1.6        3.12      5.8        9.5       15.6      20.9      25.
 25.5
  8 .01  ATTENUATION OF ROCK     AVERAGE    APRIL 1971
.0001     .0003      .001      .003       .01       .03       .1        1.
2000.     2000.      1975.     1905.      1800.     1620.     1450.     1100.
  5  1.  DAMPING IN ROCK   AVERAGE  9/4   APRIL 1971
.0001     .001       .01       .1         1.
 .4       .8         1.5       3.         4.6
```

```
          OPTION 1              103 CARDS

1........10........20........30........40........50........60........70........80

    1
800 1024   .02      PASADENA 1952
           .02
-.002493 -.003313 -.002623 -.002526 -.001317 -.000128  .001274  .002382    1
 .002625  .002518  .002590  .002513  .002569  .002502  .002551  .002491    2
 .002533  .002478  .002516  .002465  .002500  .002451  .002486  .002408    3
 .001994  .001425  .000925  .000445  .000425  .000420  .000066 -.000829    4
-.001525 -.002386 -.002381 -.001979 -.001647 -.001658 -.001639 -.001645    5
-.001099 -.000510  .000131 -.000088 -.000763 -.001374 -.002079 -.002893    6
-.003579 -.003281 -.002718 -.002255 -.001509  .000499  .002231  .002679    7
 .003059  .003649  .004454  .005218  .005970  .006832  .006573  .004815    8
 .003340  .000761 -.001550 -.001732 -.001298 -.000592  .000267  .000936    9
 .001844  .001562  .000454 -.000521 -.001442 -.002425 -.003165 -.003689   10
-.004324 -.005168 -.005828 -.005715 -.005336 -.005068 -.003841 -.002305   11
-.001126 -.000120  .001399  .002990  .004590  .004992  .004919  .004081   12
 .002851  .001865  .001481  .001031  .001121  .001382  .001816  .001063   13
-.001154 -.003149 -.005312 -.006564 -.007083 -.007836 -.007772 -.006705   14
-.005669 -.004535 -.003444 -.002326 -.001229 -.000185  .000867  .002097   15
 .003343  .004508  .004360  .003868  .004611  .005548  .006484  .007403   16
 .008347  .009253  .010469  .012118  .012267  .011130  .010349  .008871   17
 .006792  .005192  .004711  .003808  .005427  .011079  .011994  .012237   18
 .012588  .013780  .015396  .016909  .018496  .020026  .021497  .021543   19
 .021695  .019953  .015352  .013395  .013656  .013217  .009669  .005633   20
 .004387  .003030  .002845  .003635  .004411  .004443  .0045[illegible]  .003431   21
 .000276 -.001939 -.001932 -.006423 -.009774 -.011147 -.01229[illegible] -.012660   22
-.013513 -.014858 -.017037 -.018811 -.020927 -.022735 -.024635 -.025974   23
-.027901 -.026475 -.019656 -.014708 -.007272  .002294  .001546  .006332   24
 .004549  .003636  .002636  .002806  .001202 -.000432 -.002572 -.001484   25
-.000616  .000291 -.000436 -.006645 -.014722 -.017778 -.03357[illegible] -.042871   26
-.043009 -.045807 -.043294 -.041669 -.037765 -.025278 -.019201  .001040   27
 .013648  .012866  .015826  .016378  .018696  .019668  .021342  .020955   28
 .021339  .022949  .026435  .029246  .031983  .033228  .034739  .031762   29
 .027738  .024080  .020339  .017203  .011562  .007591 -.015690 -.028448   30
-.029791 -.039846 -.042214 -.043695 -.040997 -.038664 -.033649 -.037992   31
-.020213 -.001769  .002023  .007762  .006125  .004710  .007523  .007469   32
 .010966  .011913  .012652  .020094  .028702  .032657  .038837  .040749   33
 .041798  .038336  .032963  .031175  .029425  .026144  .025072  .022677   34
 .021590  .016643  .017778  .015500  .012219 -.005005 -.018653 -.035037   35
-.047254 -.042567 -.045124 -.039513 -.034339 -.020552 -.004749 -.002274   36
-.000997 -.001284 -.000624 -.000064  .000558  .000123 -.001028 -.003321   37
-.000648  .000458  .003457  .006631  .007229  .005943  .005730  .005723   38
 .005276  .003131  .003588  .004355  .001724 -.000949  .002235  .003089   39
 .004174  .003623  .003442  .003680  .004803  .005154  .005346  .007711   40
 .010554  .009195  .008490  .005691  .005305  .003425 -.003943 -.006070   41
-.007420 -.009936 -.010439 -.012590 -.011308 -.019622 -.039587 -.041576   42
-.046392 -.048356 -.052906 -.052793 -.049356 -.045835 -.043181 -.027839   43
-.014535 -.013859  .025816  .043109  .043491  .047904  .047682  .051035   44
 .051602  .056637  .054828  .057238  .055020  .049601  .043953  .040517   45
 .037062  .034520  .031703  .024568  .014474  .011676  .004249 -.007235   46
-.026973 -.041443 -.042865 -.045273 -.045146 -.044333 -.043249 -.033307   47
-.017015 -.004583 -.004544 -.003638 -.004924 -.004706 -.005666 -.005841   48
-.007728 -.008074 -.010774 -.012404 -.014436 -.009161 -.007826  .003369   49
 .024767  .025711  .029978  .032436  .034883  .034808  .035693  .035950   50
 .031252  .022314  .016231  .008574 -.003059 -.007785 -.009396 -.009446   51
-.009794 -.008981 -.009330 -.009324 -.009375 -.009651 -.009853 -.011662   52
-.013760 -.015836 -.017792 -.019124 -.019907 -.016268 -.013307 -.003454   53
```

.002631	.004139	.004371	.001234	-.001186	-.005053	-.008826	-.012269	54
-.013740	-.015331	-.017610	-.022831	-.024390	-.026574	-.024601	-.022072	55
-.018882	-.019641	-.011956	-.012234	-.014489	-.016073	-.017898	-.021668	56
-.027007	-.027043	-.017194	-.007552	.001476	.017401	.023309	.023177	57
.027040	.028719	.032583	.031626	.030859	.028315	.027878	.023949	58
.023372	.013997	-.008389	-.017724	-.021337	-.033693	-.037941	-.036294	59
-.036374	-.035359	-.034194	-.030404	-.027147	-.023444	-.020092	-.016374	60
-.012404	-.008319	-.004306	-.000756	.002788	.006267	.010007	.013599	61
.017748	.020997	.018017	.012843	.010150	.006306	.004310	-.002774	62
-.011569	-.013108	-.012718	-.009093	-.004293	.000696	.001663	.003167	63
.003833	.005218	.005565	.005307	.004555	.004324	.002268	-.002006	64
-.005485	-.008136	-.010942	-.013972	-.017321	-.020956	-.023507	-.019832	65
-.016115	-.014444	-.012891	-.011308	-.009298	-.007287	-.006066	-.004843	66
-.004426	-.005197	-.005685	-.006885	-.009521	-.010996	-.009946	-.009179	67
-.007934	-.005983	-.004401	-.005072	-.005589	-.006038	-.002838	.000617	68
.003857	.006366	.007463	.005531	.004975	.002051	-.001933	-.008681	69
-.011511	-.011291	-.011264	-.011423	-.011180	-.012156	-.013166	-.014751	70
-.015533	-.016972	-.018909	-.024014	-.024367	-.021703	-.017011	-.016185	71
.007941	.017308	.015199	.017725	.017247	.018997	.018977	.019598	72
.018284	.018230	.017224	.017375	.016698	.015711	.010446	.008182	73
.009113	.010604	.011417	.011690	.011490	.011663	.011506	.011620	74
.011817	.012871	.013767	.013843	.009655	.005485	.001648	-.001211	75
-.005169	-.009233	-.013879	-.018128	-.015787	-.010113	-.006307	-.002833	76
-.000194	.002856	.005626	.008930	.011888	.014931	.016787	.018965	77
.020805	.022943	.025658	.026834	.023618	.021884	.019231	.015899	78
.006415	-.003205	-.005577	-.014988	-.018955	-.021957	-.024742	-.027639	79
-.030061	-.028838	-.026851	-.025145	-.026489	-.029640	-.032318	-.035157	80
-.035179	-.036898	-.033905	-.032181	-.031237	-.028657	-.025223	-.019982	81
-.014925	-.009185	-.003261	.001808	.005464	.009307	.012679	.014940	82
.017126	.017247	.020912	.022423	.024320	.025809	.029569	.031827	83
.030313	.028309	.026858	.022232	.013520	.010163	.006899	.003967	84
.000597	-.000495	.000129	.000476	.000989	.001265	.000967	.000524	85
.000241	-.000063	-.000264	-.000584	.000541	.002474	.004355	.005954	86
.007249	.008512	.009877	.010134	.009723	.009107	.007355	.005186	87
.004931	.006719	.009156	.009798	.012428	.016216	.018755	.016836	88
.014459	.011738	.008580	.005413	.002914	.001680	.000421	-.000937	89
-.002750	-.004659	-.005680	-.012302	-.015390	-.015736	-.016604	-.017175	90
-.017957	-.019356	-.014196	-.013422	-.009050	-.006920	-.005341	-.002633	91
-.000012	.003354	.004365	.004209	.004327	.003693	.001851	.000085	92
-.001814	-.003043	-.003466	-.004068	-.004504	-.003832	-.001625	-.000235	93
.002278	.005874	.014722	.025498	.026123	.028565	.029956	.031019	94
.029316	.028463	.026981	.026664	.025729	.025371	.024097	.023324	95
.021865	.021047	.019546	.014896	.012006	.010343	.008051	.005314	96
.001797	-.002501	-.007363	-.010712	-.015489	-.021659	-.021587	-.019652	97
-.018365	-.016573	-.015225	-.013493	-.011212	-.007042	-.006514	-.007858	98
-.009239	-.010467	-.012825	-.015684	-.016584	-.010786	-.005233	.000579	99
.005328	.009647	.012139	.015901	.018338	.021552	.019846	.021718	100

OPTION 2 10 CARDS

```
1........10........20........30........40........50........60........70........80

2
1    9    9      EXAMPLE SITE
1    2    1       7.00 1000.        .05         .120                     .700 1.00
2    1    1      13.00  200.        .1          .100                     .250 1.00
3    1    1      10.00 1000.        .05         .100                     .750 1.00
4    1    1      12.00 1000.        .05         .100                     1.15 1.00
5    2    1      20.00 2000.        .05         .125                    1.250 1.00
6    1    1      18.00 1000.        .05         .125                    1.4   1.
7    1    1   20.       2000.       .05         .125                    2.000 1.00
8    1    1   20.       2500.       .05         .125                    2.250 1.00
9                                   0.          .150    8000.
```

OPTION 3 2 CARDS

```
1........10........20........30........40........50........60........70........80

3
3    0.
```

OPTION 4 2 CARDS

```
1........10........20........30........40........50........60........70........80

4
3    4    4.        .65
```

OPTION 5 4 CARDS

```
1........10........20........30........40........50........60........70........80

5
1    2    3    4    5    6    7    8    9    9
1    1    1    1    1    1    1    1    1
0    0    0    0    0    0    0    0    0
```

```
      OPTION 9           4 CARDS
1.......10........20........30........40........50........60........70........80
     0
     1    0
     1    0    2    1    1
    .05

      OPTION 0           1 CARD
1.......10........20........30........40........50........60........70........80
     0
```

6.3 Computer output from the analysis.

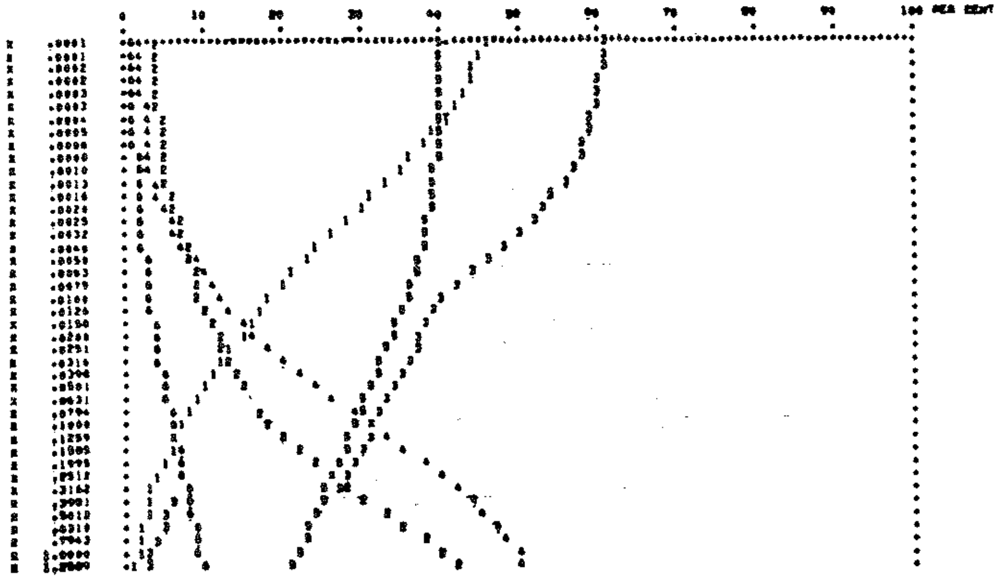
```
MAX. NUMBER OF TERMS IN FOURIER TRANSFORM =        1024
NECESSARY LENGTH OF BLANK COMMON E         =        6419
EARTH PRESSURE AT FIRST ONE SAND           =        .490
```

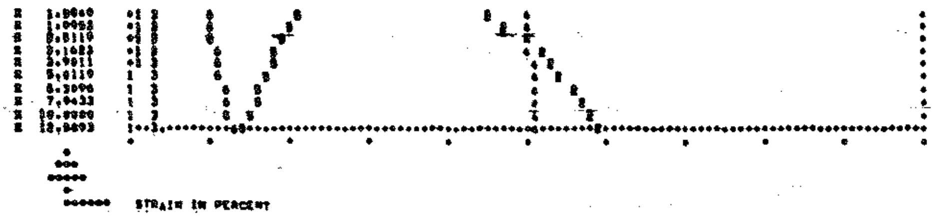
```
******   OPTION  8  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN

   CURVES FOR RELATION STRAIN VERSUS SHEAR MODULUS AND DAMPING

 MODULUS AND DAMPING VALUES ARE SCALED FOR PLOTTING

SHEAR MODULUS CLAY  MAY 24 - 1972                       MULTIPLICATION FACTOR =    .918
DAMPING CLAY  MAY 24 - 1972                             MULTIPLICATION FACTOR =   1.000
SHEAR MODULUS SAND 50,ROOT REL. MAY 24-1972             MULTIPLICATION FACTOR =    .500
DAMPING SAND  FEBRUARY 1971                             MULTIPLICATION FACTOR =   1.000
ATTENUATION OF ROCK   AVERAGE   APRIL 1971              MULTIPLICATION FACTOR =    .918
DAMPING IN ROCK   AVERAGE  0/6  APRIL 1971              MULTIPLICATION FACTOR =   1.000
                                                                 100 PER CENT CORRESPONDS TO  50.0000
```





CURVE 1 - SHEAR MODULUS CLAY MAY 24 - 1972
CURVE 2 - DAMPING CLAY MAY 24 - 1972
CURVE 3 - SHEAR MODULUS SAND 20.ROOT WELL MAY 24-1972
CURVE 4 - DAMPING SAND FEBRUARY 1971
CURVE 5 - ATTENUATION OF ROCK AVERAGE APRIL 1971
CURVE 6 - DAMPING IN ROCK AVERAGE 0/A APRIL 1971

ABSCISSA	CURVE 1	CURVE 2	CURVE 3	CURVE 4	CURVE 5	CURVE 6
.0001	23.0000	2.0000	30.5000	1.0000	20.0000	.4000
.0001	22.5997	2.0500	30.3999	1.0000	20.0000	.4400
.0002	22.1995	2.1000	30.2999	1.1200	20.0000	.4800
.0002	21.7992	2.1500	30.1998	1.1000	20.0000	.5200
.0003	21.3990	2.2000	30.1997	1.2000	20.0000	.5600
.0003	20.0978	2.2500	29.9991	1.3000	19.9091	.5000
.0004	20.2902	2.3000	29.6992	1.3600	19.9412	.6000
.0005	19.5907	2.3500	29.3996	1.4200	19.8936	.6400
.0006	18.8991	2.4000	29.0996	1.4800	19.8456	.7200
.0008	18.1996	2.4500	28.7990	1.5400	19.7978	.7600
.0010	17.5000	2.5000	28.5000	1.6000	19.7500	.8000
.0013	16.5994	2.7001	27.8396	1.9106	19.6033	.8700
.0016	15.6989	2.9003	27.1792	2.2372	19.4566	.9400
.0020	14.7983	3.1004	26.5188	2.5557	19.3099	1.0100
.0025	13.8977	3.3005	25.8583	2.8743	19.1631	1.0800
.0032	12.9976	3.5000	25.1967	3.2373	19.0041	1.1500
.0040	12.2381	3.7506	24.1574	3.7490	18.8032	1.2200
.0050	11.4786	4.0005	23.1180	4.2024	18.6024	1.2900
.0063	10.7190	4.2503	22.0787	4.7749	18.4016	1.3600
.0079	9.9595	4.5002	21.0393	5.2875	18.2008	1.4300
.0100	9.2000	4.7500	20.0000	5.8000	18.0000	1.5000
.0126	8.5596	5.1002	19.5725	6.5795	17.6227	1.6500
.0158	7.9192	5.4504	19.1451	7.3516	17.2455	1.8000
.0200	7.2788	5.8007	18.7176	8.1295	16.8682	1.9500
.0251	6.6384	6.1509	18.2902	8.9019	16.4909	2.1000
.0316	5.9984	6.5017	17.8627	9.7582	16.1256	2.2500
.0398	5.4987	7.0514	17.4352	10.8065	15.8005	2.4000
.0501	4.9991	7.6010	17.0078	12.0149	15.4794	2.5500
.0631	4.4994	8.1507	16.5803	13.1433	15.1582	2.7000
.0794	3.9997	8.7003	16.1529	14.2716	14.8291	2.8500
.1000	3.5000	9.2500	15.7254	15.4000	14.5000	3.0000
.1259	3.1490	10.1506	15.2980	16.5527	14.1500	3.1000
.1585	2.7996	11.0511	14.8705	17.7055	13.8000	3.3200
.1995	2.4493	11.9517	14.4430	18.8582	13.4500	3.4000
.2512	2.0991	12.8523	14.0156	20.0110	13.1000	3.6400
.3162	1.7494	13.7530	13.5881	21.0794	12.7500	3.8000
.3981	1.5075	15.0031	3.8990	21.8635	12.6000	3.9600
.5012	1.3057	16.2523	2.6992	22.6476	12.0500	4.1200
.6310	1.2038	17.5016	2.2995	23.4318	11.7000	4.2800
.7943	1.0219	18.7500	1.8997	24.2159	11.3500	4.4400
1.0000	.8400	20.0000	1.5000	25.0000	11.0000	4.6000
1.2589	.7319	21.2000	1.5000	25.0500	10.6500	4.7600
1.5849	.6239	22.4013	1.5000	25.1000	10.3000	4.9200
1.9953	.5158	23.6023	1.5000	25.1500	9.9500	5.0800
2.5119	.4077	24.8030	1.5000	25.2000	9.6000	5.2400
3.1623	.2999	26.0019	1.5000	25.2500	9.2500	5.4000
3.9811	.2599	26.6015	1.5000	25.3000	8.9000	5.5600
5.0119	.2199	27.2011	1.5000	25.3500	8.5500	5.7200
6.3096	.1799	27.8000	1.5000	25.4000	8.2000	5.8800
7.9433	.1400	28.4004	1.5000	25.4500	7.8500	6.0400
10.0000	.1000	29.0000	1.5000	25.5000	7.5000	6.2000
12.5893	.0600	29.5996	1.5000	25.5500	7.1500	6.3600

****** OPTION 1 *** READ INPUT MOTION

EARTHQUAKE - PASADENA 1952

800 ACCELERATION VALUES AT TIME INTERVAL .0200

THE VALUES ARE LISTED ROW BY ROW AS READ FROM CARDS
TRAILING ZEROS ARE ADDED TO GIVE A TOTAL OF 1024 VALUES

1	-.002493	-.003313	-.002623	-.002925	-.001317	-.000128	.001274	.002382
2	.002425	.002510	.002540	.002513	.002549	.002502	.002351	.002491
3	.002533	.002470	.002514	.002465	.002569	.002451	.002486	.002488
4	.001994	.001425	.000925	.000448	.000425	.000420	.000066	-.000029
5	-.001525	-.002388	-.002361	-.001979	-.001647	-.001650	-.001630	-.001445
6	-.001890	-.000510	.000131	-.000086	-.000763	-.001374	-.002079	-.002093
7	-.003579	-.003201	-.002718	-.002255	-.001509	.000490	.002231	.002475
8	.003059	.003049	.004456	.003218	.003976	.004032	.004573	.004815
9	.003340	.000761	-.001356	-.001932	-.001290	-.000592	.000267	.000934
10	.001064	.001562	.000454	-.000521	-.001442	-.002425	-.003145	-.003409
11	-.004324	-.003760	-.005028	-.005715	-.005336	-.003060	-.003841	-.002305
12	-.001126	-.000120	.001390	.002900	.004506	.004992	.004910	.004081
13	.002051	.001065	.001461	.001031	.001121	.001302	.001016	.001043
14	-.001134	-.003149	-.005318	-.006064	-.007082	-.007036	-.007772	-.006705
15	-.005669	-.004035	-.003446	-.002324	-.001229	-.000105	.000047	.002097
16	.003343	.004500	.004360	.003060	.004611	.005540	.009409	.007403
17	.008347	.009903	.010469	.012110	.012267	.011130	.010349	.008871
18	.006792	.009192	.004731	.003000	.005427	.011070	.011994	.012237
19	.012500	.013706	.013394	.010909	.010496	.020026	.021497	.021543
20	.021695	.019953	.019352	.013395	.013056	.013217	.009649	.005033
21	.004307	.003030	.002045	.003035	.004611	.004443	.004406	.003431
22	.000276	-.001939	-.001932	-.000483	-.009774	-.011147	-.012292	-.012460
23	-.013513	-.014050	-.017037	-.010011	-.020027	-.022735	-.024035	-.025974
24	-.027901	-.020475	-.019696	-.014788	-.007272	.002294	.003546	.006332
25	.004549	.003036	.002630	.002086	.001202	-.000432	-.002572	-.001404
26	-.000616	.000201	-.000406	-.006645	-.014722	-.012776	-.013975	-.042031
27	-.063069	-.045087	-.043294	-.041609	-.037745	-.025276	-.019201	.001440
28	.013648	.012066	.015024	.016378	.010696	.019060	.021342	.020935
29	.021309	.022949	.029435	.029249	.031983	.033228	.034739	.031742
30	.027730	.024080	.020339	.017263	.011562	.007591	-.015690	-.028446
31	-.029791	-.038044	-.042214	-.043695	-.048997	-.038664	-.033449	-.030902
32	-.020213	-.001766	.002023	.007762	.006125	.004716	.007523	.009468
33	.010966	.011913	.012652	.020086	.020742	.032657	.030837	.040949
34	.041790	.030336	.032940	.031175	.029425	.026144	.025072	.022677
35	.021990	.016443	.017770	.019560	.010219	-.005005	-.010453	-.035037
36	-.047254	-.042507	-.045124	-.039513	-.034399	-.020552	-.004769	-.002274
37	-.000997	-.001284	-.000624	.000064	.000550	.000125	-.001020	-.000921
38	-.000648	.000400	.003457	.000631	.007229	.005943	.005720	.005723
39	.005276	.003131	.003500	.004305	.001724	-.000940	.000235	.003089
40	.004174	.002023	.003442	.003606	.004003	.005154	.005346	.007711
41	.010554	.009195	.000490	.005091	.005505	.000425	-.003963	-.004670
42	-.007420	-.009936	-.010630	-.012590	-.011340	-.019022	-.039507	-.041574
43	-.040392	-.048356	-.052910	-.052703	-.049356	-.045035	-.043101	-.027039
44	-.014535	-.013069	.025010	.043100	.043601	.047994	.047602	.051035
45	.051602	.054037	.054060	.057236	.055020	.049601	.043950	.040517
46	.037062	.034029	.031703	.024900	.014474	.011070	.004249	-.007235
47	-.026073	-.041443	-.042069	-.049273	-.048160	-.044333	-.040259	-.033307
48	-.017015	-.006003	-.004044	-.002038	-.004024	-.004796	-.005664	-.005041
49	-.007720	-.008074	-.010776	-.012404	-.016424	-.029181	-.007826	.003369
50	.024747	.025711	.029900	.032436	.034083	.034098	.035693	.035058
51	.031292	.022316	.016231	.008576	-.003039	-.007705	-.009396	-.009464
52	-.008794	-.008901	-.007000	-.009324	-.009379	-.009681	-.009893	-.011068
53	-.013780	-.013036	-.017792	-.018124	-.018987	-.014268	-.010387	-.003454
54	.002631	.004109	.004371	.001234	-.001186	-.005093	-.008826	-.012269
55	-.013740	-.015331	-.017010	-.022031	-.024396	-.026574	-.024601	-.022072
56	-.010002	-.015641	-.011096	-.012234	-.014409	-.016093	-.017090	-.021648
57	-.027007	-.027643	-.027196	-.007557	.001476	.017401	.023309	.023177
58	.027040	.028719	.032503	.031020	.030059	.028315	.027070	.023949
59	.023372	.013997	-.000309	-.017724	-.021337	-.033093	-.037941	-.036294
60	-.036374	-.035350	-.036196	-.030464	-.027147	-.023444	-.020092	-.016374
61	-.012406	-.009319	-.004300	-.008759	.002788	.006267	.010007	.013599
62	.017748	.020097	.018017	.012843	.010150	.006305	.004310	-.002774
63	-.011569	-.013108	-.012710	-.009093	-.004293	.000090	.001663	.003167
64	.003833	.008218	.008068	.005367	.004555	.004324	.002260	-.002004
65	-.005405	-.008136	-.014912	-.013972	-.017321	-.020956	-.023507	-.019032
66	-.010119	-.014466	-.012091	-.011300	-.009290	-.007287	-.006066	-.004042
67	-.004420	-.005197	-.006685	-.006060	-.009521	-.010996	-.009946	-.009179
68	-.007934	-.005903	-.006461	-.005072	-.005589	-.006030	-.002030	.000617
69	.003057	.006366	.007463	.005531	.004975	.002081	-.001933	-.000681
70	-.011911	-.011291	-.011264	-.011423	-.011106	-.012136	-.013166	-.014751
71	-.015533	-.010972	-.010909	-.024914	-.026367	-.021703	-.017011	-.016165
72	.007941	.017300	.015199	.017725	.017247	.018997	.018977	.019598
73	.018204	.010238	.017224	.017375	.016090	.015711	.010446	.008182
74	.009113	.010404	.011417	.011490	.011498	.011403	.011506	.011020
75	.011017	.012071	.013767	.013843	.009655	.005405	.001648	-.001211
76	-.005169	-.009233	-.013079	-.018128	-.015707	-.010113	-.006007	-.002833
77	-.008194	.002056	.005626	.008930	.011080	.014931	.016787	.018965
78	.020604	.022963	.025658	.026034	.023615	.021004	.018231	.015499
79	.006415	-.003265	-.005577	-.014900	-.018955	-.021957	-.024742	-.027639
80	-.030063	-.028038	-.026951	-.025149	-.026409	-.029660	-.032310	-.035157
81	-.035179	-.036098	-.033965	-.032101	-.030237	-.028657	-.025223	-.019002
82	-.014025	-.007105	-.003261	.001560	.005444	.009307	.012470	.014940
83	.017126	.019247	.020912	.022423	.024020	.025604	.029509	.031029
84	.030313	.020309	.020090	.022232	.013920	.010105	.004099	.003947
85	.000597	-.000495	.000120	.000479	.000909	.001265	.000967	.000524
86	.000241	-.000063	-.000204	-.000589	.000541	.002474	.004354	.005954
87	.007249	.009512	.009077	.010134	.009723	.009107	.007355	.005156
88	.004931	.006719	.000196	.009796	.012420	.010216	.010755	.010034
89	.014450	.011730	.006088	.005413	.002010	.001060	.000421	-.000937
90	-.002758	-.004450	-.006400	-.012302	-.015390	-.015706	-.016684	-.017173
91	-.017957	-.010398	-.010190	-.010422	-.009058	-.006920	-.005391	-.002631
92	-.000002	.003094	.006300	.004209	.004327	.003693	.001001	.000005
93	-.001016	-.003063	-.003466	-.004004	-.004504	-.003832	-.001025	-.000235
94	.002270	.003074	.014732	.029690	.026123	.020906	.029956	.031018
95	.029316	.029463	.026901	.026464	.025729	.025371	.024097	.023324
96	.021605	.021047	.010946	.014004	.012096	.010343	.009093	.005314
97	.001757	-.002801	-.007363	-.015712	-.015407	-.021650	-.021507	-.019052
98	-.010365	-.010070	-.015026	-.013002	-.011212	-.007007	-.006514	-.007050
99	-.009230	-.010067	-.012050	-.013064	-.016084	-.010706	-.008233	.000579
100	.000320	.009647	.010139	.019901	.010330	.021000	.019090	.021710

MAXIMUM ACCELERATION = .05724
AT TIME = 7.10 SEC

THE VALUES WILL BE MULTIPLIED BY A FACTOR = 1.049
TO GIVE NEW MAXIMUM ACCELERATION = .06000

MEAN SQUARE FREQUENCY = 1.00 C/SEC.

****** OPTION 2 *** READ SOIL PROFILE

NEW SOIL PROFILE NO. 1 IDENTIFICATION EXAMPLE SITE

NUMBER OF LAYERS 9 DEPTH TO BEDROCK 120.00
NUMBER OF FIRST SUBMERGED LAYER 9 DEPTH TO WATER LEVEL 120.00

LAYER	TYPE	FACTOR MOD.	FACTOR DAMP.	THICKNESS	DEPTH	EFF. PRESS.	MODULUS	DAMPING	UNIT WEIGTH	SHEAR VEL
1	2	.70	1.00	7.00	3.50	.42	1000	.054	.1200	516
2	1	.25	1.00	13.00	13.50	1.49	200	.106	.1000	254
3	1	.75	1.00	10.00	25.00	2.64	1000	.050	.1000	507
4	1	1.15	1.00	12.00	36.00	3.74	1000	.050	.1000	507
5	2	1.25	1.00	24.00	52.00	5.80	2000	.056	.1250	718
6	1	1.40	1.00	18.00	71.00	7.96	1000	.050	.1250	508
7	1	2.00	1.00	20.00	90.00	10.36	2000	.050	.1250	718
8	1	2.25	1.00	20.00	110.00	12.84	2500	.050	.1250	802
9	BASE						200137	0.	.1500	8000

PERIOD = .79 FROM AVERAGE SHEARVEL. = 611

MAXIMUM AMPLIFICATION = 14.16
FOR FREQUENCY = 1.41 C/SEC.
PERIOD = .71 SEC.

****** OPTION 3 *** READ WHERE OBJECT MOTION IS GIVEN

OBJECT MOTION IN LAYER NUMBER 9 OUTCROPPING

****** OPTION 4 *** OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES

MAXIMUM NUMBER OF ITERATIONS = 4
MAXIMUM ERROR IN PERCENT = 5.00
FACTOR FOR EFFECTIVE STRAIN IN TIME DOMAIN = .65

EARTHQUAKE - PASADENA 1952
SOIL PROFILE - EXAMPLE SITE

ITERATION NUMBER 1
THE CALCULATION HAS BEEN CARRIED OUT IN THE TIME DOMAIN WITH EFF. STRAIN = .65* MAX. STRAIN

LAYER	TYPE	DEPTH	EFF. STRAIN	NEW DAMP.	DAMP USED	ERROR	NEW G	G USED	ERROR
1	2	3.5	.00223	.027	.050	-84.3	598.089	1000.000	-67.2
2	1	13.5	.03007	.069	.100	-44.8	139.898	200.000	-43.0
3	1	25.0	.01267	.050	.050	.7	650.725	1000.000	-53.7
4	1	36.0	.01577	.054	.050	8.1	912.336	1000.000	-9.6
5	2	52.0	.01072	.060	.050	17.1	2955.784	2000.000	32.3
6	1	71.0	.02705	.063	.050	20.2	900.490	1000.000	-11.0
7	1	90.0	.01542	.054	.050	7.6	1599.892	2000.000	-25.1
8	1	110.0	.01351	.052	.050	4.0	1881.928	2500.000	-32.8

VALUES IN TIME DOMAIN

LAYER	TYPE	THICKNESS FT	DEPTH FT	MAX STRAIN PRCNT	MAX STRESS PSF	TIME SEC
1	2	7.0	3.5	.00344	20.56	5.04
2	1	13.0	13.5	.04627	64.73	5.04
3	1	10.0	25.0	.01949	129.85	5.02
4	1	12.0	36.0	.02426	221.33	5.02
5	2	20.0	52.0	.01649	487.57	5.06
6	1	18.0	71.0	.04162	374.78	5.89
7	1	20.0	90.0	.02372	379.34	5.44
8	1	20.0	110.0	.02078	391.03	5.44

EARTHQUAKE - PASADENA 1952
SOIL PROFILE - EXAMPLE SITE

ITERATION NUMBER 2
THE CALCULATION HAS BEEN CARRIED OUT IN THE TIME DOMAIN WITH EFF. STRAIN = .65* MAX. STRAIN

LAYER	TYPE	DEPTH	EFF. STRAIN	NEW DAMP.	DAMP USED	ERROR	NEW G	G USED	ERROR
1	2	3.5	.00428	.039	.027	30.7	544.094	598.089	-9.9
2	1	13.5	.06086	.081	.069	13.9	114.441	139.898	-22.2
3	1	25.0	.01893	.057	.050	12.0	560.935	650.725	-16.0
4	1	36.0	.01825	.059	.054	.8	902.712	912.336	-1.1
5	2	52.0	.00637	.048	.060	-25.0	3277.533	2955.784	9.8
6	1	71.0	.02723	.063	.063	.2	897.965	900.490	-.3
7	1	90.0	.01797	.056	.054	4.1	1513.903	1599.892	-5.7
8	1	110.0	.01466	.055	.052	5.7	1751.483	1881.928	-7.4

VALUES IN TIME DOMAIN

LAYER	TYPE	THICKNESS FT	DEPTH FT	MAX STRAIN PRCNT	MAX STRESS PSF	TIME SEC
1	2	7.0	3.5	.00659	35.84	5.88
2	1	13.0	13.5	.09363	107.15	5.88
3	1	10.0	25.0	.02912	163.10	5.88
4	1	12.0	36.0	.02808	225.60	5.88
5	2	20.0	52.0	.00980	321.39	7.64
6	1	18.0	71.0	.04189	376.18	8.08
7	1	20.0	90.0	.02765	415.59	5.90
8	1	20.0	110.0	.02255	440.28	5.06

EARTHQUAKE - PASADENA 1952
SOIL PROFILE - EXAMPLE SITE

ITERATION NUMBER 3
THE CALCULATION HAS BEEN CARRIED OUT IN THE TIME DOMAIN WITH EFF. STRAIN = .65* MAX. STRAIN

LAYER	TYPE	DEPTH	EFF. STRAIN	NEW DAMP.	DAMP USED	ERROR	NEW G	G USED	ERROR
1	2	3.5	.00442	.048	.039	1.0	540.818	544.084	-.6
2	1	13.5	.06908	.084	.081	3.6	107.569	114.461	-6.4
3	1	25.0	.02134	.050	.057	3.1	531.856	556.935	-4.7
4	1	36.0	.01606	.055	.055	1.0	890.965	902.712	-1.3
5	2	52.0	.00615	.047	.048	-1.7	3301.410	3277.533	.7
6	1	71.0	.02901	.064	.043	1.5	873.308	897.045	-2.8
7	1	90.0	.02002	.058	.056	2.0	1453.069	1513.963	-4.1
8	1	110.0	.01865	.057	.055	3.1	1679.053	1751.483	-4.3

VALUES IN TIME DOMAIN

LAYER	TYPE	THICKNESS FT	DEPTH FT	MAX STRAIN PRCNT	MAX STRESS PSF	TIME SEC
1	2	7.0	3.5	.00680	36.77	5.90
2	1	13.0	13.5	.10658	114.32	5.90
3	1	10.0	25.0	.03284	174.64	7.66
4	1	12.0	36.0	.02504	231.08	7.60
5	2	20.0	52.0	.00946	312.38	7.64
6	1	18.0	71.0	.04463	389.76	8.10
7	1	20.0	90.0	.03080	447.80	8.08
8	1	20.0	110.0	.02898	482.09	8.08

EARTHQUAKE - PASADENA 1952
SOIL PROFILE - EXAMPLE SITE

ITERATION NUMBER 4
THE CALCULATION HAS BEEN CARRIED OUT IN THE TIME DOMAIN WITH EFF. STRAIN = .65* MAX. STRAIN

LAYER	TYPE	DEPTH	EFF. STRAIN	NEW DAMP.	DAMP USED	ERROR	NEW G	G USED	ERROR
1	2	3.5	.00448	.044	.048	.7	539.481	540.818	-.2
2	1	13.5	.07596	.086	.084	2.6	102.420	107.569	-5.0
3	1	25.0	.02364	.061	.059	2.6	510.558	531.856	-4.2
4	1	36.0	.01780	.056	.055	1.5	873.612	890.965	-2.0
5	2	52.0	.00626	.048	.047	.9	3289.198	3301.410	-.4
6	1	71.0	.03108	.065	.064	1.6	846.497	873.308	-3.2
7	1	90.0	.02163	.059	.058	2.0	1410.880	1453.069	-3.0
8	1	110.0	.01999	.058	.057	1.0	1636.639	1679.053	-2.6

VALUES IN TIME DOMAIN

LAYER	TYPE	THICKNESS FT	DEPTH FT	MAX STRAIN PRCNT	MAX STRESS PSF	TIME SEC
1	2	7.0	3.5	.00689	37.16	7.60
2	1	13.0	13.5	.11686	119.68	7.70
3	1	10.0	25.0	.03647	185.67	7.68
4	1	12.0	36.0	.02738	239.21	7.66
5	2	20.0	52.0	.00964	316.95	7.64
6	1	18.0	71.0	.04781	404.72	8.10
7	1	20.0	90.0	.03328	469.40	8.10
8	1	20.0	110.0	.03075	503.27	8.08

PERIOD = .86 FROM AVERAGE SHEARVEL. = 581

MAXIMUM AMPLIFICATION = 13.15
FOR FREQUENCY = 1.23 C/SEC.
PERIOD = .82 SEC.

****** OPTION 5 *** COMPUTE MOTION IN NEW SUBLAYERS

EARTHQUAKE = PASADENA 1952
SOIL DEPOSIT = EXAMPLE SITE

LAYER	DEPTH FT	MAX. ACC. G	TIME SEC	MEAN SQ. FR. C/SEC	ACC. RATIO QUIET ZONE	PUNCHED CARDS ACC. RECORD
WITHIN	0.	.07377	7.68	1.30	.264	0
WITHIN	7.5	.09259	7.68	1.38	.262	0
WITHIN	20.0	.05934	8.12	1.28	.204	0
WITHIN	30.0	.05487	8.14	1.23	.191	0
WITHIN	42.0	.05062	8.12	1.22	.181	0
WITHIN	62.0	.04066	8.08	1.21	.170	0
WITHIN	88.0	.03195	7.24	1.29	.171	0
WITHIN	100.0	.02423	7.14	1.49	.128	0
WITHIN	120.0	.01793	8.70	1.00	.043	0
OUTCR.	120.0	.02000	7.34	1.80	.000	6

****** OPTION 9 *** COMPUTE RESPONSE SPECTRUM

COMPUTE RESPONSE SPECTRUM IN LAYER 1

RESPONSE SPECTRUM ANALYSIS FOR LAYER NUMBER
CALCULATED FOR DAMPING .050

TIMES AT WHICH MAX. SPECTRAL VALUES OCCUR
TD = TIME FOR MAX. RELATIVE DISP.
TV = TIME FOR MAX. RELATIVE VEL.
TA = TIME FOR MAX. ABSOLUTE ACC.
DAMPING RATIO = .05

PER = [illegible]	TIMES FOR MAXIMA --	TD = 7.6600	TV = 8.3200	TA = 7.6600
PER = .10	TIMES FOR MAXIMA --	TD = 7.6600	TV = 7.7800	TA = 7.6600
PER = .15	TIMES FOR MAXIMA --	TD = 7.6400	TV = 7.4200	TA = 7.6400
PER = .20	TIMES FOR MAXIMA --	TD = 7.7000	TV = 9.6200	TA = 7.7000
PER = .25	TIMES FOR MAXIMA --	TD = 7.2800	TV = 6.0000	TA = 7.2800
PER = .30	TIMES FOR MAXIMA --	TD = 7.3000	TV = 8.3400	TA = 7.3000
PER = .35	TIMES FOR MAXIMA --	TD = 8.5000	TV = 6.0000	TA = 8.5000
PER = .40	TIMES FOR MAXIMA --	TD = 7.6400	TV = 7.5000	TA = 7.6200
PER = .45	TIMES FOR MAXIMA --	TD = 12.9600	TV = 12.8400	TA = 12.9400
PER = .50	TIMES FOR MAXIMA --	TD = 7.6800	TV = 7.5200	TA = 7.6600
PER = .55	TIMES FOR MAXIMA --	TD = 7.7200	TV = 7.8800	TA = 7.7200
PER = .60	TIMES FOR MAXIMA --	TD = 8.1000	TV = 7.9200	TA = 8.0800
PER = .65	TIMES FOR MAXIMA --	TD = 8.5600	TV = 8.7400	TA = 8.5400
PER = .70	TIMES FOR MAXIMA --	TD = 6.4000	TV = 6.2200	TA = 6.3800
PER = .75	TIMES FOR MAXIMA --	TD = 6.4600	TV = 6.2800	TA = 6.4400
PER = .80	TIMES FOR MAXIMA --	TD = 8.6400	TV = 8.8400	TA = 8.6200
PER = .85	TIMES FOR MAXIMA --	TD = 8.7200	TV = 8.9200	TA = 8.7000
PER = .90	TIMES FOR MAXIMA --	TD = 8.8000	TV = 8.5800	TA = 8.7800
PER = .95	TIMES FOR MAXIMA --	TD = 8.4200	TV = 8.6400	TA = 8.4000
PER = 1.00	TIMES FOR MAXIMA --	TD = 8.4600	TV = 8.2400	TA = 8.4400
PER = 1.10	TIMES FOR MAXIMA --	TD = 8.8600	TV = 8.2800	TA = 8.8400
PER = 1.20	TIMES FOR MAXIMA --	TD = 8.8800	TV = 8.3000	TA = 8.8600
PER = 1.30	TIMES FOR MAXIMA --	TD = 8.0800	TV = 8.3000	TA = 8.0600
PER = 1.40	TIMES FOR MAXIMA --	TD = 7.6400	TV = 7.8600	TA = 7.6000
PER = 1.50	TIMES FOR MAXIMA --	TD = 7.6600	TV = 7.4400	TA = 7.6400
PER = 1.60	TIMES FOR MAXIMA --	TD = 15.5600	TV = 7.4400	TA = 15.5000
PER = 1.70	TIMES FOR MAXIMA --	TD = 15.5800	TV = 13.5800	TA = 15.5400
PER = 1.80	TIMES FOR MAXIMA --	TD = 15.8600	TV = 13.9800	TA = 15.8200
PER = 1.90	TIMES FOR MAXIMA --	TD = 7.6400	TV = 7.8600	TA = 7.6000
PER = 2.00	TIMES FOR MAXIMA --	TD = 7.6600	TV = 7.8600	TA = 7.6200
PER = 2.25	TIMES FOR MAXIMA --	TD = 13.4600	TV = 7.4600	TA = 13.3800
PER = 2.50	TIMES FOR MAXIMA --	TD = 7.2200	TV = 7.4600	TA = 7.1800
PER = 2.75	TIMES FOR MAXIMA --	TD = 7.2600	TV = 7.6000	TA = 7.2200
PER = 3.00	TIMES FOR MAXIMA --	TD = 7.2800	TV = 8.3800	TA = 7.2200
PER = 3.25	TIMES FOR MAXIMA --	TD = 5.9600	TV = 8.3800	TA = 5.8800
PER = 3.50	TIMES FOR MAXIMA --	TD = 6.7200	TV = 5.7200	TA = 6.6000
PER = 3.75	TIMES FOR MAXIMA --	TD = 6.7600	TV = 7.8600	TA = 6.7000
PER = 4.00	TIMES FOR MAXIMA --	TD = 15.6400	TV = 7.8600	TA = 7.6800

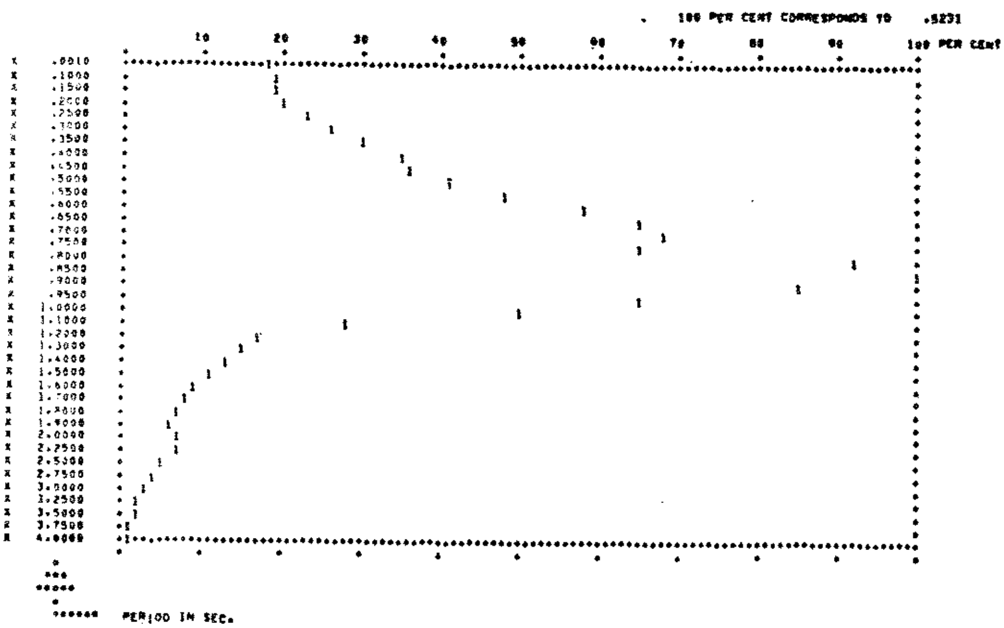
SPECTRAL VALUES--
PASADENA 1952 — EXAMPLE SITE — DAMPING RATIO = .05

NO.	PERIOD SEC.	REL. DISP. FT.	REL. VEL. FT./SEC.	PSU.REL.VEL. FT./SEC.	ABS. ACC. G.	PSU.ABS.ACC.	FREQ. C/SEC.
1	.00	.00000	.00000	.00045	.09377	.0[illegible]	1000.00
2	.10	.00081	.06814	.05072	.09873	.0[illegible]	10.00
3	.15	.00185	.02296	.07735	.10091	.10[illegible]	6.67
4	.20	.00345	.03828	.10836	.10564	.10572	5.00
5	.25	.00604	.07353	.15182	.11854	.11850	4.00
6	.30	.00989	.11405	.20716	.13496	.13474	3.33
7	.35	.01581	.17580	.28386	.15811	.15826	2.86
8	.40	.02408	.28806	.37693	.18536	.18388	2.50
9	.45	.03136	.36363	.43788	.18944	.18984	2.22
10	.50	.04387	.40265	.55135	.21487	.21517	2.00
11	.55	.06112	.59161	.69825	.24875	.24773	1.82
12	.60	.08913	.84720	.93333	.30520	.30353	1.67
13	.65	.11627	.99684	1.12395	.33929	.33741	1.54
14	.70	.14222	1.21203	1.27660	.35790	.35586	1.43
15	.75	.15604	1.25725	1.30724	.34080	.36011	1.33
16	.80	.25047	1.92676	1.96717	.48143	.47982	1.25
17	.85	.30716	2.25209	2.27049	.52310	.52122	1.18
18	.90	.29064	2.11149	2.02906	.46272	.41992	1.11
19	.95	.24876	1.79494	1.64526	.33994	.33794	1.05
20	1.00	.21183	1.47429	1.33090	.26148	.25972	1.00
21	1.10	.14183	1.01383	.81012	.14463	.14371	.91
22	1.20	.10527	.77513	.55120	.09044	.08963	.83
23	1.30	.11061	.75453	.53460	.08095	.08024	.77
24	1.40	.11116	.72513	.49890	.07027	.06954	.71
25	1.50	.10594	.65305	.44375	.05841	.05773	.67
26	1.60	.09658	.50143	.37928	.04663	.04626	.63
27	1.70	.10319	.51595	.38137	.04410	.04377	.59
28	1.80	.09503	.53842	.33170	.03627	.03590	.56
29	1.90	.09457	.57469	.31307	.03270	.03215	.53
30	2.00	.11765	.50094	.36961	.03403	.03606	.50
31	2.25	.14161	.64789	.39545	.03475	.03430	.44
32	2.50	.11709	.62395	.29429	.02358	.03313	.40
33	2.75	.12181	.51216	.27832	.02024	.01975	.36
34	3.00	.10076	.40353	.21102	.01421	.01373	.33
35	3.25	.08342	.43928	.16224	.01019	.00974	.31
36	3.50	.08848	.40092	.16407	.00826	.00805	.29
37	3.75	.08033	.40336	.13450	.00722	.00700	.27
38	4.00	.07855	.39099	.12330	.00619	.00602	.25

VALUES IN PERIOD RANGE .1 TO 2.5 SEC.

AREA OF ACC. RESPONSE SPECTRUM = .330
AREA OF VEL. RESPONSE SPECTRUM = 1.789
MAX. ACCELERATION RESPONSE VALUE = .523
MAX. VELOCITY RESPONSE VALUE = 2.252

PLOT OF ACCELERATION SPECTRA



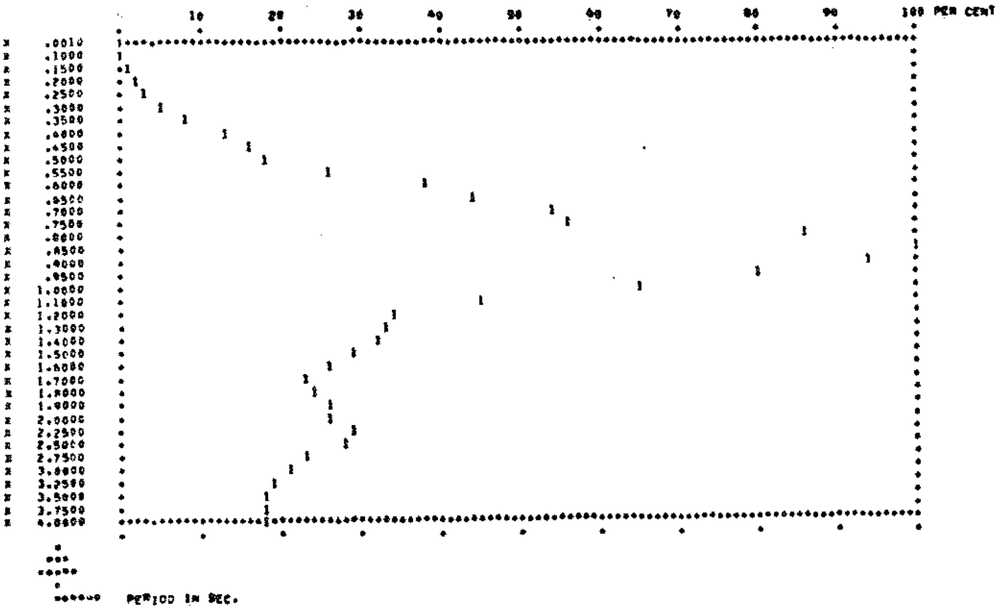
CURVE 1 - PASADENA 1952 — EXAMPLE SITE

ABSCISSA	CURVE 1
.0010	.0938
.1000	.0987
.1500	.1009
.2000	.1056
.2500	.1185
.3000	.1350

.3500	.1581
.4000	.1854
.4500	.1894
.5000	.2149
.5500	.2487
.6000	.3052
.6500	.3393
.7000	.3571
.7500	.3408
.8000	.4814
.8500	.5231
.9000	.4427
.9500	.3399
1.0000	.2615
1.1000	.1440
1.2000	.0904
1.3000	.0810
1.4000	.0703
1.5000	.0584
1.6000	.0466
1.7000	.0441
1.8000	.0363
1.9000	.0326
2.0000	.0366
2.2500	.0348
2.5000	.0236
2.7500	.0202
3.0000	.0142
3.2500	.0102
3.5000	.0083
3.7500	.0072
4.0000	.0062

PLOT OF VELOCITY SPECTRA

100 PER CENT CORRESPONDS TO 2.2536



CURVE 1 - PASADENA 1952 EXAMPLE SITE

ABSISSA	CURVE 1
.0010	.0000
.1000	.0081
.1500	.0236
.2000	.0383
.2500	.0735

.3000	.1141
.3500	.1758
.4000	.2881
.4500	.3636
.5000	.4026
.5500	.5916
.6000	.8473
.6500	.9960
.7000	1.2120
.7500	1.2572
.9000	1.4268
.8500	2.2530
.9000	2.1115
.9500	1.7949
1.0000	1.4743
1.1000	1.6138
1.2000	.7751
1.3000	.7545
1.4000	.7251
1.5000	.6530
1.6000	.5814
1.7000	.5160
1.8000	.5384
1.9000	.5747
2.0000	.5805
2.2500	.6477
2.5000	.6248
2.7500	.5122
3.0000	.4835
3.7500	.4393
3.5000	.4099
3.7500	.4034
4.0000	.3978

7. PROGRAM IDENTIFICATION AND ABSTRACT

7.1 Program Identification

1. Program title: Vertical propagation of shear waves through a horizontally layered soil/rock system.

2. Program name: SHAKE.

3. Writers: Per B. Schnabel, Research Assistant
   John Lysmer, Associate Professor of Civil Engineering.

4. Organization: Geotechnical Engineering
   Department of Civil Engineering
   University of California
   Berkeley, California 94720

5. Date: December, 1972.

6. Version: 2

7. Source language: FORTRAN IV

7.2 Abstract

The program computes the response in a horizontally layered soil rock system subjected to transient, vertical travelling shear waves. The method is based on Kanai's solution to the wave equation and the Fast Fourier Transform algorithm. The motion used as basis for the analysis can be applied to any layer in the system. Systems with elastic base and with variable damping in each layer can be analyzed. Equivalent linear soil properties are used with an iterative procedure to obtain soil properties compatible with the strains developed in each layer. A varied set of operations of interest in earthquake response analysis can be performed.

8. <u>SOURCE LISTING FOR PROGRAM SHAKE</u>.

```
      PROGRAM SHAKE2(INPUT, OUTPUT, PUNCH)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
C   THIS PROGRAM COMPUTES RESPONSE IN A HORISONTALLY LAYERED SEMI-
C   INFINITE SYSTEM SUBJECTED TO VERTICALLY TRAVELLING SHEAR WAVES
C   THE METHOD IS BASED ON THE CONTINOUS SOLUTION TO THE SHEAR WAVE
C   EQUATION
C
C
C   PROGRAMMED BY  PER B SCHNABEL RESEARCH ASSISTANT
C                  JOHN LYSMER    ASSOCIATE PROFESSOR
C
C                                 GEOTECHNICAL ENGINEERING
C                                 UNIVERSITY OF CALIFORNIA
C                                 BERKELEY
C
C
C   PROGRAM VERSION      SHAKE1   JANUARY 1972
C                        SHAKE2   APRIL 1972
C                                 JUNE 1972
C                                 CHANGE - OPTION 7 CORRECTED
C                                        - SUBROUTINES STEPG AND FFT
C                                          ADAPTED TO UNIVAC COMPUTERS
C                                 DECEMBER 1972
C                                 CHANGE - SUBROUTINES DRCTSP AND STRAIN
C
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
C
C   DEFINITIONS
C        INPUT MOTION      = MOTION READ IN FROM CARDS
C        OBJECT MOTION     = MOTION USED AS BASIS FOR COMPUTING NEW
C                            MOTIONS IN A SOIL PROFILE
C        COMPUTED MOTION   = MOTION COMPUTED ANYWHERE IN A GIVEN SOIL
C                            SOIL PROFILE FROM A GIVEN OBJECT MOTION
C        OPTION            = OPERATION TO BE PERFORMED ON GIVEN DATA,
C                            INITIALIZATION OR CHANGE OF DATA
C        QUIET ZONE        = ZONE CONTAINING THE TRAILING ZEROES IN
C                            THE INPUT MOTION
C        OUTCROP           = PLACE WHERE A SOIL SUBLAYER OR THE BASE
C                            ROCK REACHES A FREE SURFACE
C        OUTCROP MOTION    = MOTION AT AN OUTCROP OF ROCK OR SOIL SUBLAYER
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
C   FIRST CARD  FORMAT(I5,F10.0)
C           COL.    1- 5   MAX. NUMBER OF TERMS TO BE USED IN THE
C                          FOURIER TRANSFORMATION IN ANY OF THE PROBLEMS
C                          TO BE RUN
C           COL.    6-15   EARTH PRESSURE AT REST FOR SAND. USED ONLY
C                          FOR COMPUTING SHEAR MODULUS FOR SAND. IF
C                          BLANK THE VALUE IS SET TO .45
C
C   AFTER THIS FIRST CARD FOLLOWS SWITCH FOR OPTION TO BE PERFORMED. THE
C   AVAILABLE OPTIONS ARE LISTED BELOW. THE OPTIONS CAN BE EXECUTED AND
C   REPEATED IN ANY LOGICAL ORDER.
C
C
C   SECOND CARD AND CARD PRECEEDING EVERY OPTION, FORMAT(I5)
C           COL.    1- 5   SWITCH
C
C           SWITCH =   0    STOP, NO MORE DATA
C                      1    READ INPUT MOTION, TRANSFER TO FREQUENCY
C                           DOMAIN AND SET AS NEW OBJECT MOTION
C                      2    READ NEW SOIL PROFILE
C                      3    READ WHERE IN THE SOIL PROFILE THE OBJECT
C                           MOTION IS GIVEN
C                      4    OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES
C                      5    COMPUTE NEW MOTIONS  PRINT OR PUNCH RESULTS
C                      6    PRINT AND/OR PUNCH TIME HISTORY OF OBJECT
C                           MOTION
C                      7    CHANGE PARAMETERS OF OBJECT MOTION OR
C                           SET A COMPUTED MOTION AS OBJECT MOTION
C                      8    READ SOIL PROPERTY/STRAIN-RELATIONS
C                      9    COMPUTE RESPONSE SPECTRA
C                     10    INCREASE TIMESTEP
C                     11    DECREASE TIMESTEP
C                     12    PLOT FOURIER SPECTRUM OF OBJECT MOTION
C                     13    PLOT FOURIER SPECTRUM OF COMPUTED MOTION
C                     14    PLOT TIME HISTORY OF OBJECT MOTION
C                           USE OPTION 7 FIRST FOR PLOT OF COMPUTED
C                           MOTION
C                     15    COMPUTE AMPLIFICATION FACTORS
C                     16    COMPUTE STRESS OR STRAIN HISTORY
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   DATA CARDS FOR THE DIFFERENT OPTIONS
C
C
C   1 READ INPUT MOTION
C        1 CARD (2I5, F10.0, 5A6)
C             COL.  1- 5   NUMBER OF VALUES TO BE READ
C             COL.  6-10   NUMBER OF VALUES TO BE USED IN FOURIER
C                          TRANSFORM  MUST BE A POWER OF 2
C             COL. 11-20   TIMESTEP BETWEEN EACH VALUE (SEC.)
C             COL. 21-50   IDENTIFICATION FOR EARTHQUAKE
C
C        2 CARD  (8F10.0)
C             COL.  1-10   MULTIPLICATION FACTOR FOR ACC. VALUES
C                          USED ONLY IF COL. 11-20 IS 0.
C             COL. 11-20   SPECIFIED MAX. ACCELERATION
C             COL. 21-30   MAX. FREQUENCY TO BE USED IN FOURIER
C                          TRANSFORM (C/SEC.)
C
C        3 AND CONSEC. CARDS  (8F9.0, I7)
C            COL.  1-72    8 ACCELERATION VALUES
C            COL. 73-79    CARD NUMBER. CARDS MUST BE IN SEQUENCE
C
C
C   2 READ DATA FOR NEW SOIL PROFILE
C        1 CARD (3I5, 6A6)
C             COL.  1- 5   SOIL PROFILE NUMBER, OPTIONAL
C            COL.   6-10   TOTAL NUMBER OF SOIL LAYER INFORMATION CARDS
C                          TO BE READ INCLUDING CARD FOR HALFSPACE
```

```
C          COL. 11-15   NUMBER OF FIRST SUBMERGED SUBLAYER
C          COL. 16-52   SOIL PROFILE IDENTIFICATION
C
C      2 AND CONSEC. CARDS - SOIL LAYER INFORMATION CARDS
C        ONE CARD FOR EACH LAYER INCLUDING HALFSPACE (3I5, 6F10.0, F5.0)
C          COL.  1- 5   LAYER NUMBER
C                       LAYERS MUST BE IN SEQUENCE WITH SURFACE LAYER
C                       AS NUMBER 1
C          COL.     10  SOIL TYPE
C                         1 - CLAY   G = K*(UNDR. SHEAR STRENGTH)
C                         2 - SAND   G = K*(MEAN EFF. STRESS)**1/2
C                         3 - ROCK   G = K*(SHEAR MOD. AT LOW STRAIN)
C                         4 - SAND   G = K*(MAX. EFF. STRESS)**1/3
C                       WHERE K IS GIVEN THROUGH OPTION 8
C          COL. 11-15   NUMBER OF SUBLAYERS. THE LAYER WILL BE
C                       DIVIDED INTO SUBLAYERS OF EQUAL THICKNESS
C                       MAXIMUM TOTAL NUMBER OF SUBLAYERS FOR WHOLE
C                       PROFILE IS 19
C          COL. 16-25   THICKNESS OF LAYER (FT.)
C          COL. 26-35   SHEAR MODULUS (KIPS/SQ.FT.)
C                       NOT NECCESSARY IF SHEAR VEL. IS GIVEN
C          COL. 36-45   CRITICAL DAMPING RATIO
C          COL. 46-55   UNIT WEIGTH (KIPS/CUB.FT.)
C          COL. 56-65   SHEAR VELOCITY (FT./SEC.)
C                       NOT NECCESSARY IF SHEAR MOD. IS GIVEN
C          COL. 66-75   FACTOR FOR SHEAR MODULUS
C                       CLAY - UNDR. SHEAR STRENGTH (KIPS/SQ.FT.)
C                       SAND - FACTOR ON AVERAGE CURVE
C                       ROCK - WAVE VELOCITY IN 1000FT/SEC.
C          COL. 76-80   FACTOR FOR DAMPING
C
C                       FOR HALFSPACE ONLY COL. 1- 5, 26-35 OR 56-65,
C                       AND 46-55 ARE NECESSARY
C
C
C    3 SUBLAYER WHERE OBJECT MOTION IS GIVEN
C        1 CARD (2I5)
C          COL.  1- 5   SUBLAYER NUMBER
C          COL.     10  TYPE OF MOTION 0 - OUTCROPPING ROCK OR
C                                          OUTCROPPING SOIL SUBLAYER
C                                      1 - BASE ROCK OR SOIL SUBLAYER
C                                          WITHIN PROFILE
C
C
C
C    4 OBTAIN SOIL PROPERTIES COMPATIBLE WITH EFFECTIVE STRAINS
C        1 CARD (2I5, 7F10.0)
C          COL.      5  SET EQ TO 1 FOR PUNCHED OUTPUT OF NEW SET
C                       OF SOIL DATA CARDS
C          COL.  6-10   MAXIMUM NUMBER OF ITERATIONS
C          COL. 11-20   MAX ERROR IN PRCNT.  ITERATION  STOPS WHEN
C                       ERROR IS LESS OR WHEN MAX. NUMBER OF
C                       ITERATIONS ARE REACHED
C          COL. 21-30   RATIO EFFECTIVE STRAIN/MAX. STRAIN
C
C
C    5 COMPUTE NEW MOTIONS
C        1 CARD (15I5)
C          COL.   1-75  ARRAY WITH NUMBER OF SUBLAYERS WHERE MOTION
C                       IS TO BE COMPUTED. MOTION IS COMPUTED AT THE
C                       TOP OF THE SUBLAYER
C
C        2 CARD (15I5)
C          COL.   1-75  ARRAY WITH TYPE OF ABOVE SUBLAYERS
C                                  0 - OUTCROPPING SUBLAYER
C                                  1 - SUBLAYER WITHIN PROFILE
C
C        3 CARD(15I5)
C          COL.   1-75  ARRAY WITH MODE OF OUTPUT
C                       0 - TABLE OF MAX. ACCELERATIONS ONLY
C                       1 - PUNCHED TIME HISTORY IN ADDITION TO TABLE
C
C
C    6 PRINT AND/OR PUNCH TIME HISTORY OF OBJECT MOTION
C        1 CARD (2I5)
C          COL.  5      0 - MAX. ACCELERATION ONLY
C                       1 - PUNCHED OUTPUT OF TIME HISTORY
C                       2 - PUNCED AND PRINTED OUTPUT OF TIME HISTORY
C
C
C
C    7 CHANGE OBJECT MOTION
C        1 CARD  (2I5, F10.0)
C          COL.  1- 5   SUBLAYER NUMBER
C                       THE ACCELERATIONS AT THE TOP OF THE SUBLAYER
C                       WILL BE SET AS NEW OBJECT MOTION
C                       SET = 0 IF ORIGINAL OBJECT MOTION IS KEPT
C          COL.  6-10   TYPE OF MOTION  0 - OUTCROPPING SUBLAYER
C                                       1 - WITHIN PROFILE
C          COL. 11-20   MULTIPLICATION FACTOR FOR MOTION
C          COL. 21-30   NEW TIMESTEP (SEC.)
C
C    8 READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN
C        1 CARD (3I5, F10.0)
C          COL.  1- 5   NUMBER OF DIFFERENT SOIL OR ROCK TYPES TO BE
C                       READ  MAX. 4
C          COL.     10  SET EQ. TO 1 FOR PLOT OF PROPERTY STRAIN
C                       RELATION
C          COL.  11-15  NUMBER OF VALUES IN EACH LOG10 FOR
C                       PLOTTING OF PROPERTY/STRAIN RELATION IN
C                       SEMILOG PLOT
C          COL. 16-25   SCALE FOR PLOTTING (MAX. ORDINATE VALUE)
C
C        NEXT FOLLOWS TWO SETS OF CARDS FOR EACH SOIL/ROCK TYPE
C        FIRST SET  -  RELATION STRAIN-SHEAR MODULUS
C        1 CARD (I5,F5.0, 11A6)
C          COL.  1- 5   NUMBER OF STRAIN VALUES FOR WHICH SHEAR
C                       MODULUS PARAMETERS ARE GIVEN. MAX.20
C          COL.  6-10   MULTIPLICATION FACTOR FOR SHEAR MODULUS
C                       USED FOR PLOTTING ONLY
C          COL. 11-76   TITLE FOR SOIL TYPE
C
C        2 CARD AND CONSECUTIVE CARDS (8F10.0)
C             STRAIN VALUES. 8 VALUES PER CARD (PERCENT)
C
C        CONSECUTIVE CARDS (8F10.0)
C             VALUES OF MODULUS PARAMETER CORRESPONDING TO THE STRAIN
C             VALUES GIVEN. 8 VALUES PER CARD.
C
C        SECOND SET - RELATION STRAIN-DAMPING
C             CARDS AS FOR FIRST SET BUT WITH VALUES OF CRITICAL
C             DAMPING RATIO INSTEAD OF MODULUS PARAMETER VALUES
C
C
C    9 RESPONSE SPECTRUM
```

```
C       1 CARD (I5)
C             CCL.  1- 5   SUBLAYER NUMBER
C                          SET = 0 IF OBJECT MOTION
C             CCL.     10  TYPE OF SUBLAYER  0 - CUTCROPPING
C                                            1 - WITHIN
C
C       2 CARD (4I5)
C             CCL.      5  TOTAL NUMBER OF DAMPING VALUES MAX. 6
C             CCL.     10  SET EQ. TO 1 FOR PUNCHED OUTPUT
C             CCL.     15  SWITCH  0 - PLOT AND/OR PUNCH VEL. SPECTRUM
C                                  1 - PLOT AND/OR PUNCH ACC. SPECTRUM
C                                  2 - PLCT AND/OR PUNCH ACC. AND VEL. SPECTRA
C             COL.     20  SWITCH FOR PLOTTIND
C                                  0 - STORE SPECTRA FOR LATER PLOTTING
C                                      MAX. 5
C                                  1 - PLOT ALL SPECTRA COMPUTED AND
C                                      STORED SINCE LAST PLOTTING
C             COL.     25  SWITCH FOR PERIODS TO BE USED. FIRST PERIOD
C                          IS .001 SEC.
C                          0 - 9 STEPS FROM  .1 TO 1.
C                              5 STEPS FROM 1.  TO 2.
C                              4 STEPS FROM 2.  TO 4.
C                          1 -18 STEPS FROM  .1 TO 1.
C                             10 STEPS FROM 1.  TO 2.
C                              8 STEPS FROM 2.  TO 4.
C                          2 -38 STEPS FROM  .05 TO 1.
C                             20 STEPS FROM 1.  TO 2.
C                             30 STEPS FROM 2.  TO 5.
C                          3 -LCGARITMIC INCREMENTS
C                             10 STEPS IN EACH LOG. UNIT FROM .1 TO 5.
C                          4 -LOGARITMIC INCREMENTS
C                             25 STEPS IN EACH LOG. UNIT FROM .05 TO 10.
C
C       3 CARD (6F10.0)
C            VALUES CF CRITICAL CAMPING RATIO   MAX. 6 VALUES
C
C
C  10 INCREASE TIMESTEP
C       1 CARD (I5)
C             COL.  1- 5   FACTOR FOR INCREASING TIMESTEP
C                          MUST BE A POWER OF 2
C
C  11 CECREASE TIMESTEP
C       1 CARD (I5)
C             COL.  1- 5   FACTCR FOR DECREASING TIMESTEP
C                          MUST BE A POWER OF 2
C
C
C  12 PLCT FOURIER SPECTRUM OF OBJECT MOTION
C       1 CARD (3I5)
C             COL.      5  SWITCH FOR PLOTTING
C                                  0 - STORE SPECTRUM FOR LATER PLOTTING
C                                      MAX. 2 SPECTRA PLOTTED TOGETHER
C                                  1 - PLOT ALL SPECTRA STORED SINCE
C                                      LAST PLOTTING
C             COL.  6-10   NUMBER OF TIMES SPECTRUM IS TO BE SMOOTHENED
C             COL.  11-15  NUMBER CF FREQUENCIES TO BE PLOTTED MAX. 2049
C
C
C  13 PLCT FCURIER SPECTRA CF COMPUTED MOTION
C       1 CARD (5I5)
C             COL.  1- 5   SUBLAYER NUMBER FOR FIRST COMPUTED MOTION
C             COL.     10  TYPE OF ABOVE SUBLAYER    0 - OUTCROP
C                                                    1 - WITHIN
C             COL.     15  SWITCH FOR PLOTTING
C                                  0 - STORE SPECTRUM FOR LATER PLOTTING
C                                      MAX. 2 SPECTRA PLCTTED TOGETHER
C                                  1 - PLOT ALL SPECTRA STORED SINCE
C                                      LAST PLOTTING
C             COL.  16-20  NUMBER OF TIMES SPECTRA ARE TO BE SMOOTHENED
C             COL.  21-25  NUMBER CF FREQUENCIES TO BE PLOTTED MAX. 2049
C
C       2 CARD (5I5)
C            AS FIRST CARD FOR SECCND MOTION. BLANK IF CNLY ONE MOTION
C
C
C  14 PLOT TIME- HISTCRY OF OBJECT MOTION
C       1 CARD (I5)
C             COL.  1- 5   STEPS IN PLOTTING
C                          1 - PLOT EACH VALUE
C                          2 - PLCT EVERY SECOND VALUE
C                          AND SO CN
C             COL.  6-10   NUMBER OF VALUES TO BE PLOTTED, MAX. 2049
C                          IF BLANK WHOLE RECORD IS PLOTTED
C
C
C
C  15 CCMPUTE AMPLIFICATION FUNCTICN
C       1 CARD (5I5,F5.0, 8A6)
C             CCL.  1- 5   SUBLAYER NUMBER FROM WHICH AMPLIFICATION
C                          FACTORS IS COMPUTED
C             CCL.     10  TYPE OF ABOVE SUBLAYER    0 - CUTCROP
C                                                    1 - WITHIN
C             COL. 11-15   SUBLAYER NUMBER TO WHICH AMPLIFICATION
C                          FACTORS IS COMPUTED
C             CCL.     20  TYPE OF ABCVE SUBLAYER    0 - CUTCROP
C                                                    1 - WITHIN
C             COL.     25  IF   0 - PRINT MAX AMP. FACTCR AND FREQUENCY
C                                   STORE FUNCTION FOR LATER PLOTTING
C                                   MAXIMUM 8 CURVES CAN BE STORED
C                               1 - PLOT AMPLIFICATION FUNCTION TOGETHER
C                                   WITH ALL FUNCTIONS STORED
C             CCL. 26-30   FREQUENCY STEPS IN COMPUTING AMPLIFICATION
C                          FUNCTICN. THE FIRST 200 FREQ. ARE COMPUTED
C             CCL. 31-78   IDENTIFIER
C
C  16 CCMPUTE STRAIN CR STRESS  TIME HISTCRY
C       1 CARD (4I5,F10.0,5A6)
C             COL.  1- 5   NUMBER CF SUBLAYER WHERE RESPONSE IS TO BE
C                          COMPUTED AT MIDDLE OF LAYER
C             COL.     10  RESPCNSE TYPE
C                            0 - STRAIN HISTORY
C                            1 - STRESS HISTORY
C             CCL.     15  SET EQUAL TO 1 IF PUNCHED CUTPUT IS WANTED
C             COL.     20  SET EQUAL TO 1 FOR PLOTTING
C             CCL. 21-25   NUMBER CF VALUES TO BE PLOTTED, MAX. 2049
C             COL. 26-35   SCALE FCR PLOTTING - I.E. MAX VAL. OF CRDINATE
C                          IF 0. LARGEST VALUE IS SET AS MAX. ORD. VALUE
C             CCL. 37-65   IDENTIFICATION
C
C       2 CARD             AS CARD 1 FOR NEW RESPONSE.
C                          BLANK IF ONLY CNE RESPONSE IS WANTED. (MAX 2 RESP)
C
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
      COMMON X(35000)
      COMMON /SGK/  WW, GT, SKO
C
      WW = .0624
      GT = 32.2
      READ 1000, MAMAX, SKO
      NAX = MAMAX + 5
      NAA = NAX + 3*(MAMAX + 4)
      NS = NAA + 2*MAMAX
      NINV = NS + NAX/8 + 1
      NTOT = NINV + NAX/8 + 1
      IF (SKO .LT. .000001)   SKO = .45
      PRINT 2000, MAMAX, NTOT, SKO
      CALL SHAKIT(X(1), X(NAX), X(NAA), X(NS), X(NINV))
      STOP
 1000 FORMAT(I5, F10.0)
 2000 FORMAT(// 45H  MAX. NUMBER OF TERMS IN FOURIER TRANSFORM =   I10/
     1          45H  NECESSARY LENGTH OF BLANK COMMON X        =   I10/
     2          45H  EARTH PRESSURE AT REST FOR SAND           =   F10.3)
      END
```

```
      SUBROUTINE SHAKIT(X,AX,AA,S,INV)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE CALLS THE DIFFERENT SEQUENCES OF OPERATION.15 DIFFERENT
C   OPERATIONS CAN BE PERFORMED AS LISTED BELOW.
C
C      OPERATION                                            SUBROUTINES
C
C      1  READ INPUT MOTION                                 EARTHQ
C                                                           XMX
C                                                           FFT
C                                                           RFFT
C                                                           RFSN
C      2  READ SOIL PROFILE                                 SOILIN
C                                                           CXSOIL
C
C      3  READ LAYER WHERE OBJECT MOTION IS GIVEN
C
C      4  ITERATE ON SOIL PROPERTIES                        STRT
C                                                           XMX
C                                                           AMP
C                                                           MOTION
C                                                           FFT
C                                                           RFSN
C                                                           RFFT
C
C      5  COMPUTE MOTION IN NEW LAYER AND GIVE OUTPUT       MOTION
C                                                           UTPR
C                                                           XMX
C                                                           FFT
C                                                           RFSN
C                                                           RFFT
C
C      6  PRINT OR PUNCH OBJECT MOTION                      UTPR
C                                                           XMX
C                                                           FFT
C                                                           RFSN
C                                                           RFFT
C
C      7  CHANGE OBJECT MOTION                              [illegible]
C
C      8  READ RELATION BETWEEN STRAIN AND SOIL PROPERT.    CG
C                                                           STEPG
C                                                           CURVEG
C                                                           PLOT
C
C                                                           STEPG
C      9  COMPUTE RESPONSE SPECTRA                          RESP
C                                                           MOTION
C                                                           JKCSP
C                                                           CMPMAX
C                                                           FFT
C                                                           RFSN
C                                                           RFFT
C                                                           PLOT
C
C     10  REDUCE NO. OF VALUES AND INCREASE TIMESTEP        REDUCE
C
```

```
C        11 INCREASE NO. OF VALUES AND DECREASE TIMESTEP   INCR
C
C        12 PLOT FOURIER SPECTRUM OF OBJECT MOTION          PLOT
C
C        13 PLOT FOURIER SPECTRA OF COMPUTED MOTION        PLOT
C
C        14 PLOT TIME HISTORY OF OBJECT MOTION
C                                                          RFFT
C                                                          RFSN
C                                                          PLOT
C
C        15 COMPUTE AND PLOT AMPLIFICATIONFUNCTION         AMP
C                                                          PLOT
C
C        16 COMPUTE STRAIN/STRESS-HISTORY                  STRAIN
C                                                          PLOT
C                                                          FFT
C                                                          RFFT
C                                                          RFSN
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   CODED BY PER B. SCHNABEL  1970/1971/1972
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TITLE,TP
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      DIMENSION ABSIS(10), ABSPR(10),ABSCL(10)
      DIMENSION LL(3), LT(3),LNSW(3)
      DIMENSION LLL(2), LLGS(2),LLPCH(2),LLPL(2),SK(2),LNV(2)
      DIMENSION X(300),AX(3,270),AA(2,550),S(70),INV(70)
      DIMENSION LLS(15), LTS(15), LPS(15),LP(3)
      DIMENSION IDAMP(9,11)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /SOILC/ MSOIL,MWL
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON /CCG/ ID(9,11), T(2049)
C
      DATA IBLANK /6H      /
      DATA (ABSIS(I),I=1,10)/6H TIME  ,6HIN SEC ,6HONDS  ,7*6H      /
      DATA (ABSCL(I),I=1,10)/6H  CYCL ,6HES/SEC   , 8*6H      /
      DATA (ABSPR(I), I=1,10)/6H PERIO, 6HD IN S, 6HEC.   , 7*6H      /
C
C
C * * * * * * * * * *
C
      DO 102 I = 1,3
      LL(I) = 3
  102 LT(I) = 0
      DO 103 L = 1,9
      DO 103 I = 1,11
      ID(L,I) = IBLANK
  103 IDAMP(L,I) = IBLANK
      NF = 0
      NR = 0
      NP = 3
      NA = 1
C
C * * * * * * * * * *
  101 READ 1000, KK
      IF (KK .EQ. 0) STOP
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16), KK
C
C * * * * * * * * * *
    1 PRINT 1002,KK
      CALL EARTHQ(X,AX,AA, S, INV)
      NSN = 0
      GO TO 101
C
C * * * * * * * * * *
    2 PRINT 2002,KK
      CALL SOILIN(N1)
      NSN = 1
C
C   FIND FUNDAMENTAL PERIOD OF DEPOSIT FROM AVERAGE SHEAR WAVE VELOCITY
C   AND FROM THE PERIOD WHICH GIVE MAXIMUM AMPLIFICATION
      SH = 0.
      N = N1 + 1
      SHV = 0.
      DO 21 I = 1,N1
      SH = SH + H(I)
   21 SHV = SHV + H(I)*SQRT(GL(I)/R(I))
      VSAV = SHV/SH
      TT = 4.*SH/VSAV
      PRINT 4006, TT, VSAV
      DFA = .01/TT
      CALL AMP(N1,N ,1,.,0,0,IDAMP, 9, DFA)
      GO TO 101
C
C * * * * * * * * * *
    3 PRINT 3332, KK
      READ 1000, IN, INT
      IF (INT .EQ. 0) PRINT 3331,IN
      IF (INT .NE. 0) PRINT 3000, IN
      GO TO 101
C
C
C * * * * * * * * * *
    4 PRINT 4007,KK
      READ 4000,KS,ITMAX,ERR,PRMUL
      PRINT 4331, ITMAX,ERR,PRMUL
      LL(1) = 1
      LT(1) = 0
      DO 41 L = 1,ITMAX
      IF (IN.EQ.1) GO TO 412
      CALL MOTION(N1,IN, INT, LL, LT, X,AX)
  412 CALL STRT( L, N1, DGMAX,PRMUL,X,AX,AA,S,INV)
      IF (DGMAX.LT.ERR) GO TO 411
   41 CONTINUE
C
C   FIND FUNDAMENTAL PERIOD OF DEPOSIT FROM AVERAGE SHEAR WAVE VELOCITY
C   AND FROM THE PERIOD WHICH GIVE MAXIMUM AMPLIFICATION
  411 SH = 0.
      N = N1 + 1
      SHV = 0.
      DO 43 I = 1,N1
      SH = SH + H(I)
   43 SHV = SHV + H(I)*SQRT(GL(I)/R(I))
      VSAV = SHV/SH
      TT = 4.*SH/VSAV
```

```
      PRINT 6030, TT, WSAV
      DFA = .03/TT
      CALL ARP(N1,M ,1,1,0,0,IDAMY, 9, DFA)
      IF (KS .EQ. 3)  GO TO 101
C
C   PUNCH NEW SET OF SOILDEPOSIT DATA CARD WITH NEW PROPERTIES
      PUNCH 4003, MSOIL, N, MWL, IDNT, (TITLE(I),I=1,4)
      DO 42 I = 1,N1
   42 PUNCH 4334,I,TP(I), H(I), GL(I), BL(I), WL(I), FAC(I) ,BF(I)
      PUNCH 4005,N,GL(N),BL(N),WL(N)
      GO TO 101
C
C * * * * * * * * * *
    5 PRINT 5031,KK
      READ 1000, (LL5(L),L=1,15)
      READ 1000, (LT5(L),L=1,15)
      READ 1000, (LP5(L),L=1,15)
      PRINT  5002, TITLE, IDNT
      I = 3
      DO 51 LOOP = 1,5
      DO 511 L = 1,3
      I = I + 1
      LL(L) = LL5(I)
      LT(L) = LT5(I)
      LP(L) = LP5(I)
      IF (LL(1).EQ.0) GO TO 101
  511 CONTINUE
      CALL MOTION(N1,IN, INT, LL, LT, X,AX)
      DO 51  L = 1,3
      N = LL(L)
      K = L
      IF (N.EQ.0) GO TO 101
      IF (N.LE.N1)  DPTH = DEPTH(N) - H(N)/2.
      IF (N.GT.N1)  DPTH = DEPTH(N-1) + H(N-1)/2.
      CALL OTPR(KK,DPTH,K,LP(L),LL(L),LT(L),X,AX,AA,S,INV)
   51 CONTINUE
      GO TO 101
C
C * * * * * * * * * *
    6 PRINT 6002,KK
      READ 1000, K2
      LS = 0
      LN = IN
      IF (K2.EQ.0)  PRINT 5333, LN
      IF (K2.EQ.1)  PRINT 6001, LN
   62 CALL OTPR(KK,DPTH,LS,K2,LN,INT    ,X,AX,AA,S,INV)
      GO TO 101
C
C * * * * * * * * * *
    7 PRINT 7002,KK
      READ 7001, LL1,LT1,XF,DTNEW
      IF (DTNEW.LT..001) DTNEW=DT
      IF (LL1  .EQ.0) GO TO 71
C
C   CHECK IF MOTION IN SUBLAYER LL1 IS IN AX()
      DO 72 I = 1,3
      IF (LL1.NE.LL(I) .OR. LT1.NE.LT(I)) GO TO 72
      L = I
      GO TO 720
   72 CONTINUE
      LL(1) = LL1
      LT(1) = LT1
      L = 1
      CALL MOTION(N1,IN, INT, LL, LT, X,AX)
  720 DO 73 I = 1,MFOLD
   73 X(I) = AX(L,I)*XF
      NEW = LL(L)
      INT = LT(L)
      GO TO 73
   71 DO 74 I = 1,MFOLD
   74 X(I) = X(I)*XF
      NEW = IN
   73 IN = NEW
      PRINT 7003, NEW , XF,DT, DTNEW
      DT = DTNEW
      DF = 1./(MA*DT)
      GO TO 101
C
C * * * * * * * * * *
    8 PRINT 8001,KK
      CALL CG
      GO TO 101
C
C * * * * * * * * * *
    9 PRINT 9002,KK
      READ 1000, LL1, LT1
      IF (LL1.NE.0) GO TO 171
      PRINT 9001
      LS = 0
      LN = IN
      GO TO 173
  171 DO 170 I = 1,3
      IF (LL1.NE.LL(I) .OR. LT1.NE.LT(I)) GO TO 170
      LS = I
      GO TO 172
  170 CONTINUE
      LS = 1
      LL(1) = LL1
      LT(1) = LT1
      CALL MOTION(N1,IN, INT, LL, LT, X,AX)
  172 LN = LL(LS)
      PRINT 9303,LN
  173 CALL RESP(LL,LN,LS,NR,X,AX,AA,S,INV)
      GO TO 101
C
C * * * * * * * * * *
   10 PRINT 1013,KK
      READ 1000, IFR
      CALL REDUCE(IFR,X,AX,LL)
      GO TO 101
C
C * * * * * * * * * *
   11 PRINT 1101,KK
      READ 1000, IFR
      CALL INCR(IFR,X,AX,LL)
      GO TO 101
C
C * * * * * * * * * *
   12 PRINT 1203,KK
      READ 1303, KI, NSW, N
      IF (INT    .EQ. 0) PRINT 1201, IN
      IF (INT    .EQ. 1) PRINT 1202, IN
      MF = MF + 1
      IF (N.LE.0)  N= MFOLD - 1
```

```
      IF (N.GT.2049)   N=2049
      DO 120 I = 1,N
  120 AA(NF,I) = CABS(X(I))
      DO 121 I = 1,5
  121 ID(NF,I) = TITLE(I)
      DO 126 I = 6,11
  126 ID(NF,I) = IBLANK
      IF (NSW.EQ.0) GO TO 123
      M = N-1
      DO 124 LOOP = 1,NS4
      AA(NF,1) = (3.*AA(NF,1) + AA(NF,2))/4.
      AA(NF,N) = (3.*AA(NF,N) + AA(NF,N-1))/4.
      DO 124 I = 2,M
  124 AA(NF,I) = (AA(NF,I-1) + 2.*AA(NF,I) + AA(NF,I+1))/4.
  123 IF (K1.NE.1) GO TO 101
      DO 122 I = 1,N
      T(I ) = FLOAT(I-1)*DF
  122 CONTINUE
      PRINT 1200
      CALL PLOT(NF,  N,T,AA,ABSCL,ID,0.,2,N)
      NF = 3
      GO TO 101
C
C * * * * * * * * * *
   13 PRINT 1301,KK
      DO 183 I = 1,2
  180 READ 1000, LL(I), LT(I), LP(I), LNSW(I), LLL(I)
      CALL MOTION(N1, IN, INT, LL, LT, X, AX)
      DO 194 L = 1,2
      IF (LL(L).EQ.0) GO TO 101
      IF (LT(L).EQ.3) PRINT 1201,LL(L)
      IF (LT(L).EQ.1) PRINT 1202,LL(L)
      N = LLL(L)
      IF (N.LE.0)   N = NFOLD - 1
      IF (N.GT.2049)   N = 2049
      NF = NF + 1
      IF (NF.LE.2)  GO TO 182
      PRINT 1800
 1800 FORMAT(//  24H TOO MANY ARRAYS STORED   /)
      GO TO 101
  182 DO 188 I = 1,5
  188 ID(NF,I) = TITLE(I)
      DO 187 I = 6,11
  187 ID(NF,I) = IDNT(I-5)
      DO 185 I = 1,N
  185 AA(NF,I) = CABS(AX(L,I))
      NSW = LNSW(L)
      IF (NSW.EQ.0) GO TO 181
      M = N-1
      DO 186 LOOP = 1,NS4
      AA(NF,1) = (3.*AA(NF,1) + AA(NF,2))/4.
      AA(NF,N) = (3.*AA(NF,N) + AA(NF,N-1))/4.
      DO 186 I = 2,M
  186 AA(NF,I) = (AA(NF,I-1) + 2.*AA(NF,I) + AA(NF,I+1))/4.
      IF (LP(L).EQ.0) GO TO 184
  181 DO 183 I = 1,N
  183 T(I) = DF*FLOAT(I-1)
      PRINT 1200
      CALL PLOT(NF,  N,T,AA,ABSCL,ID,0.,2,N)
      NF = 0
  184 CONTINUE
      GO TO 101
C
C * * * * * * * * * *
   14 PRINT 1404,KK
      READ 1000, NSKIP, NN, NSW
      NP = NP + 1
      CALL RFSN(X,MX,INV,S,IFERR)
      IF (NN.LE.0)  NN = NNA/NSKIP
      IF (NN.GT.2049)  NN = 2049
      NN =  NN*NSKIP
      M = 0
      DO 136 I=1, NN, NSKIP
      M = M + 1
      T(M) = FLOAT(I-1)*DT
  136 CONTINUE
      N = 0
      M = NN/2
      DO 130 I = 1,M
      N = N + 1
      AA(NP,N) = REAL(X(I))
      N = N + 1
      AA(NP,N) = AIMAG(X(I))
  130 CONTINUE
      IF  (NSKIP.EQ.1) GO TO 135
      N = 0
      DO 134 I = 1,NN ,NSKIP
      N = N + 1
      AA(NP,N) = AA(NP,I)
  134 CONTINUE
  135 CALL RFFT(X,MX,INV,S,IFERR)
      DO 131 I = 1,5
  131 ID(NP,I) = TITLE(I)
      DO 132 I = 6,11
      ID(NP,I) = IDNT(I-5)
      IF (NSW.EQ.0)  ID(NP,I)  = IBLANK
  132 CONTINUE
      IF (NSW.EQ.1) GO TO 101
      CALL PLOT(NP, N, T, AA, ABSIS, ID, 3., 2, N)
      NP = 0
      GO TO 101
C
C * * * * * * * * * *
   15 PRINT 1502,KK
      READ 1400, LIN, LINT ,LOUT,LOTP,KP,DFA,(IDAMP(NA,I),I=1,4)
      PRINT 1401, LIN,LOUT
      IF  (LOTP.EQ.0) PRINT 1403
      IF  (LINT.EQ.0) PRINT 1402
      CALL AMP(N1, LIN, LINT, LOUT, LOTP, KP, IDAMP,NA, DFA)
      GO TO 101
C
C * * * * * * * * * *
   16 PRINT 1601,KK
      DO 151 L = 1,2
      READ 1500, LLL(L),LLGS(L),LLPCH(L),LLPL(L),LNV(L),SK(L),
     1(ID(L,I),I=7,11)
      IF (LLL(L).GT.0) PRINT 1501,LLL(L),SK(L),(ID(L,I),I=7,11)
  151 CONTINUE
      DO 152 L = 1,3
  152 LT(L) = 0
      LL(3) = 0
      LL(2) = 0
      LL(1) = 1
      CALL MOTION(N1, I4, INT, LL, LT, X, AX)
```

```
      CALL STRAIN(LLL,LLGS,LLPCH,LLPL,LHV,SK,X,AX,AA,NI,S,INV)
      DO 193 I = 1,3
  193 LL(I) = 3
      GO TO 101
C
C * * * * * * * * * *
C
 1000 FORMAT(15I5)
 1002 FORMAT(16H1******    OPTION  I3,
     1 53H  ***  READ INPUT MOTION                                    ///)
 2002 FORMAT(16H1******    OPTION  I3,
     1 58H  ***  READ SOIL PROFILE                                    ///)
 3000 FORMAT(//32H  OBJECT MOTION IN LAYER NUMBER   I3//)
 3001 FORMAT(//23H   OBJECT MOTION IN LAYER NUMBER I3,12H OUTCROPPING /)
 3002 FORMAT(16H1******    OPTION  I3,
     1 53H  ***  READ WHERE OBJECT MOTION IS GIVEN                      )
 4000 FORMAT( 2I5, 7F10.3)
 4001 FORMAT(
     149H  MAXIMUM NUMBER OF ITERATIONS                  =    I5/
     149H  MAXIMUM ERROR IN PERCENT                      = F6.2/
     149H  FACTOR FOR EFFECTIVE STRAIN IN TIME DOMAIN    = F6.2////)
 4003 FORMAT(3I5,6A5, 6A5)
 4004 FORMAT(2I5,4X,1H ,F10.2,F10.0,2F10.3,10X,F10.3, F5.2)
 4005 FORMAT(I5,9X,1H ,3X,F10.0,2F10.3)
 4006 FORMAT( //13H  PERIOD = F5.2,25H FROM AVERAGE SHEARVEL. = F8.3/)
 4007 FORMAT(15H)******    OPTION   I3,
     1 58H  ***  OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES             ///)
 5001 FORMAT(16H1******    OPTION  I3,
     1 58H  ***  COMPUTE MOTION IN NEW SUBLAYERS                      ///)
 5002 FORMAT(15H   EARTHQUAKE - 5A6/  17H  SOIL DEPOSIT -  6A6//
     19X, 5HLAYER
     1 10X,5HDEPTH 8X,11HMAX. ACC. 10X, 4HTIME 6X, 12HMEAN SQ. FR.
     1  9X, 10HACC. RATIO , 6X, 14HPUNCHED CARDS
     2/ 22X, 2HFT 12X, 1HG 15X, 4HSEC  9X, 5HC/SEC 13X,10HQUIET ZONE
     37X, 11HACC. RECORD   //)
 6000 FORMAT(/27H  PRINT          ACCELERATION IN LAYER  I3/)
 6001 FORMAT(/46H  PRINT AND PUNCH          ACCELERATION IN LAYER I3/)
 6002 FORMAT(15H1******    OPTION  I3,
     1 54H  ***  PRINT OR PUNCH OBJECT MOTION                         ///)
 7000 FORMAT(//21H  SET MOTION IN LAYER  I3,17H AS OBJECT MOTION /
     141H MULTIPLICATION FACTOR FOR NEW MOTION =  F6.3/
     227H  TIMESTEP OF CHANGED FROM F6.3, 3H TO F6.3, 5H SEC./)
 7001 FORMAT(2I5, 9F10.3)
 7002 FORMAT(16H1******    OPTION   I3,
     1 53H  ***  CHANGE OBJECT MOTION                                   )
 8001 FORMAT(15H1******    OPTION   I3,
     1 58H  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN     ///)
 9000 FORMAT( /35H  COMPUTE RESPONSE SPECTRUM IN LAYER  I3/)
 9001 FORMAT(//43H COMPUTE RESPONSE SPECTRUM OF OBJECT MOTION /)
 9002 FORMAT(15H1******    OPTION  I3,
     1 58H  ***  COMPUTE RESPONSE SPECTRUM                              )
 1010 FORMAT(16H1******    OPTION    I3,
     1 58H  ***  INCREASE TIMESTEP                                    ///)
 1101 FORMAT(16H1******    OPTION    I3,
     1 58H  ***  DECREASE TIMESTEP                                    ///)
 1200 FORMAT(26H1 PLOT OF FOURIER SPECTRA //)
 1201 FORMAT(15H  LAYER NUMBER I4, 12H OUTCROPPING //)
 1202 FORMAT(14H  LAYER NUMBER I4//)
 1230 FORMAT(15H1******    OPTION    I3,
     1 55H  ***  PLOT OF FOURIER SPECTRUM OF OBJECT MOTION            ///)
 1231 FORMAT(16H1******    OPTION    I3,
     1 58H  ***  PLOT FOURIER SPECTRUM OF COMPUTED MOTION             ///)
 1400 FORMAT(5I5, F5.0, 8A5)
 1401 FORMAT(41H    AMPLIFICATION SPECTRUM BETWEEN LAYER I4, 4H AND I4)
 1402 FORMAT(26H  INPUT LAYER OUTCROPPING )
 1403 FORMAT(25H  OUTPUT LAYER OUTCROPPING )
 1404 FORMAT(16H1******    OPTION  I3,
     1 58H  ***  PLOT TIME HISTORY OF OBJECT MOTION                   ///)
 1500 FORMAT(5I5,F10.0, 5A6)
 1501 FORMAT(//  49H  COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF
     1 6H LAYER  I5 /21H  SCALE FOR PLOTTING  F13.4/  15H IDENTIFICATION
     2 3H -    5A6,6X)
 1502 FORMAT(16H1******    OPTION  I3,
     1 58H  ***  COMPUTE AMPLIFICATION FUNCTION                       ///)
 1601 FORMAT(16H1******    OPTION  I3,
     1 58H  ***  COMPUTE STRESS/STRAIN HISTORY                        ///)
      END
```

```
      SUBROUTINE EARTHQ(X,AX,AA,S,INV)
C
C*****************************************************************************
C
C     THIS ROUTINE  READS THE MOTION IN THE TIME DOMAIN, ADDS TRAILING
C     ZEROS, SCALES THE VALUES, FIND MAXIMUM VALUE AND VARIOUS PARAMETERS
C     AND TRANSFER THE MOTION INTO THE FREQUENCY DOMAIN.
C
C     CODED BY PBS SEPT. 1970
C
C
C
C          X        = INPUT MOTION
C          AX       = TEMPORARY STORAGE OF X
C          TITLE    = IDENTIFICATION FOR MOTION
C          DT       = TIME STEP BETWEEN VALUES IN TIME DOMAIN
C          NV       = NUMBER OF ACC. VALUES TO BE READ
C          MA       = LENGTH OF MOTION INCLUDING TRAILING ZEROS
C          MMA      = LENGTH OF SIGNIFICANT PART OF MOTION
C          XF       = MULTIPLCATION FACTOR FOR ACCELERATION VALUES
C          DF       = FREQUENCY STEPS IN FREQ. DOMAIN
C
C*****************************************************************************
C
      INTEGER TITLE
      COMPLEX X, AX
      DIMENSION XR(8)
      DIMENSION X(300),AX(3,270),AA(2,550),S(70),INV(70)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF, MX
C
      PI2 = 6.28
      READ 1001, NV, MA, DT, TITLE
      READ 1003, XF,XMAX,FMAX
      IF (FMAX.LT. .001) FMAX = 100000.
      MA2=2
    2 IF(MA2.GE.MA) GO TO 3
      MA2=MA2*2
      GO TO 2
    3 MA=MA2
      PRINT 2312, TITLE, NV, DT, MA
      MMA = NV + NV/10
      IF (MMA.GT.MA) MMA=MA
      MA2 = MA + 2
      MFOLD = MA2/2
      MFOLD = MFOLD + 1
      DF = 1./(MA*DT)
      FMA = FLOAT(MA)
      MX = (ALOG10(FMA)/ALOG10(2.))- 1
    1 MMX = 2**(MX+1)
      IF (MA  .LE. MMX) GO TO 11
      MX = MX + 1
      GO TO 1
   11 NCARDS = (NV-1)/8 + 1
      JL=8*NCARDS-NV
      NV = NV + 1
      N = 0
      LC = 0
      DO 31 I = 1,NCARDS
      LC = LC + 1
      READ 5002, (XR(J), J=1,8)
 5002 FORMAT(8F9.6)
C     READ 1002, (XR(J), J=1,8), K
      IF(I.NE.NCARDS) GO TO 6
      IF(JL.EQ.0) GO TO 6
      JL=9-JL
      DO 5  J=JL,8
    5 XR(J)=0.
    6 PRINT 2008, K, (XR(J), J=1,8)
      K = LC
      IF (K .EQ.LC) GO TO 311
      LC = K
      PRINT 2003, I
C
C   FIND MAX. INPUT ACC. (XMAX)
C
  311 DO 31 J = 1,8,2
      N = N + 1
      X(N) = CMPLX(XR(J),XR(J+1))
   31 CONTINUE
      N = N + 1
      DO 32 I = N,MFOLD
   32 X(I) = 0.
      CALL XMX(X,MA,XM,NXMAX)
      IF (XMAX.LT. .000001) GO TO 300
      XF = XMAX/XM
  300 DO 30 I = 1,N
   30 X(I) = X(I)*XF
      XMAX = XM*XF
      TMAX = FLOAT(NXMAX-1)*DT
      PRINT 2014,XM,TMAX,XF,XMAX
C
      CALL RFFT(X,MX,INV,S,IFERR)
C     X(1) = 0.
C
C
C   REMOVE FREQUENCIES ABOVE FMAX AND FIND MAX. ACC. OF NEW MOTION
C
      FREQ = 0.
      SXX = 0.
      SFX = 0.
      DO 33 I = 1,MFOLD
      IF (FREQ.GT.FMAX)     X(I) = 0.
      XA = CABS(X(I))
      SXX= SXX + XA*XA
      SFX = SFX + FREQ*XA*XA
      AX(1,I) = X(I)
      FREQ = FREQ + DF
   33 CONTINUE
      SFX = SFX/SXX
      PRINT 2005,SFX
      IF (FMAX.GT.FREQ) RETURN
      CALL RFSN(X,MX,INV,S,IFERR)
      CALL XMX(X,MA,XM,NXMAX)
      DO 72 I = 1,MFOLD
   72 X(I) = AX(1,I)
      PRINT 2001,XM,FMAX
C
 1001 FORMAT(2I5,  F10.3, 5A6)
 1002 FORMAT(8F9.5,I7)
 1003 FORMAT(8F10.0)
 2001 FORMAT(//21H  MAX ACCELERATION =  F10.5, 22H FOR FREQUENCIES REMOV
     19HED ABOVE F10.2, 7H C/SEC.//)
 2003 FORMAT(17H   ACC. CARD NO. I4,16H OUT OF SEQUENCE  )
 2005 FORMAT(25H MEAN SQUARE FREQUENCY =  F10.2, 7H C/SEC. /)
```

```
2008 FORMAT(2X, I5, 5X, 8F15.6)
2012 FORMAT(16H EARTHQUAKE  -  ,5A6//
    ,I5,37H ACCELERATION VALUES AT TIME INTERVAL,F10.4//
    255H    THE VALUES ARE LISTED ROW BY ROW AS READ FROM CARDS/
    347H    TRAILING ZEROS ARE ADDED TO GIVE A TOTAL OF, I5,7H VALUES/)
2014 FORMAT(/23H MAXIMUM ACCELERATION =  F9.5/
    1         23H AT TIME                =  F6.2, 4H SEC//
    1 44H THE VALUES WILL BE MULTIPLIED BY A FACTOR = F7.3/
    3 44H TO GIVE NEW MAXIMUM ACCELERATION          = F9.5 /)
     RETURN
     END
```

```
      SUBROUTINE XMX(X,MX,XMAX,NXMAX)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C    THIS ROUTINE FIND MAX. VALUE, XMAX, AND NUMBER OF MAX. VALUE,NXMAX.
C    OF ARRAY X WITH MX NUMBER OF VALUES
C
C    CODED PER B SCHNABEL OCT. 1971
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION X(1)
      XMAX = 0.
      DO 1 I = 1,MX
      XA = ABS(X(I))
      IF (XMAX.GT.XA) GO TO 1
      NXMAX = I
      XMAX = XA
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SOIL1(N1)
C
C***********************************************************************
C
C   THIS ROUTINE READS PROPERTIES OF A SOIL PROFILE, ASSIGNS VALUES TO
C   EACH LAYER, CALCULATES EFFECTIVE PRESSURE AND DEPTH IN MIDDLE OF
C   EACH LAYER AND PRINTS THE RESULTS
C
C         IDNT     = IDENTIFIER FOR SOIL PROFILE
C         BL       = RATIO OF CRITICAL DAMPING
C         GL       = SHEAR MODULUS
C         FACT     = FACTOR FOR CALCULATING SHEAR MODULUS FROM STRAIN
C         H        = LAYER THICKNESS
C         R        = DENSITY
C         WL       = UNIT WEIGTH
C         TP       = SOIL TYPE
C         DEPTH    = DEPTH TO MIDDLE OF LAYER
C         WEIGTH   = EFFECTIVE PRESSURE
C         ML       = NUMBER OF LAYERS INCLUDING HALFSPACE
C         N1       = NUMBER OF SUBLAYERS EXCLUDING HALFSPACE
C         MWL      = NUMBER OF FIRST SUBMERGED LAYER
C         NLN      = NUMBER OF SUBLAYERS IN EACH LAYER
C         W        = UNIT WEIGTH
C         VS       = SHEAR WAVE VELOCITY
C         BFAC     = FACTOR ON DAMPING
C         FACTOR   = FACTOR ON SHEAR MODULUS
C         HL       = THICKNESS OF LAYER
C         H        = THICKNESS OF SUBLAYER
C         GMOD     = SHEAR MODULUS
C         B        = CRITICAL DAMPING RATIO
C
C    CODED BY PER B SCHNABEL OCT. 1970
C    MODIFIED APRIL 1972
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TP, TYPE
      COMMON /SOILA/ IDNT(5),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /SOILC/ MSOIL,MWL
      COMMON /WGK/  WW, GT, SKO
      DIMENSION SMEAN(20)
C
      READ 1003,     MSOIL, ML, MWL, IDNT
      PRINT 2020, MSOIL, IDNT
C
C   READ SOIL PROPERTIES FOR EACH LAYER AND ASSIGN VALUES TO EACH SUBLAYER
C
      J = 0
      DO 14 N = 1, ML
      READ 1004, K, TYPE, NLN,   HL, GMOD, B , W, VS, FACTOR , BFAC
      IF (NLN.EQ. 0) NLN = 1
      IF (K .EQ. N) GO TO 141
      PRINT 3334, N
      STOP
C
C   COMPUTE MODULUS FROM SHEARWAVEVELOCITY
  141 IF (GMOD .EQ. 0.) GMOD = VS*VS*W/GT
      DO 14 I = 1,NLN
      J = J+1
      BL(J) = B
      GL(J) = GMOD
      FAC(J)=FACTOR
      FACT(J) =  FACTOR
      BF(J) = BFAC
      WL(J) = W
      H(J) = HL/NLN
      TP(J) = TYPE
   14 R(J) = W/GT
      N1 = J -1
C   CALCULATE AVERAGE DEPTH AND EFFECTIVE PRESSURE IN EACH LAYER
C
      W1 = WL(1)
      IF (MWL .EQ. 1) W1 = WL(1) - WW
      DEPTH(1) = H(1)/2.
      WEIGHT(1) = H(1)*W1/2.
      SMEAN(1) = WEIGHT(1)*(1.+2.*SKO)/3.
      IF  (N1 .EQ. 1)  GO TO 151
      DO 15 I = 2,N1
      W2 = WL(I)
      IF (MWL .LT. I+1) W2 = WL(I) - WW
      DEPTH(I) = DEPTH(I-1) + H(I)/2. + H(I-1)/2.
      WEIGHT(I) = WEIGHT(I-1) + H(I)*W2/2. + H(I-1)*W1/2.
      SMEAN(I) = WEIGHT(I)*(1.+2.*SKO)/3.
   15 W1 = W2
  151 TD = DEPTH(N1) + H(N1)/2.
      IF (MWL .LT. N1+1)  WD = DEPTH(MWL)- H(MWL)/2.
      IF (MWL .EQ. N1+1)  WD = DEPTH(MWL-1) + H(MWL-1)/2.
C
C   CALCULATE FACTOR FOR SHEAR MODULUS
      DO 16 I = 1,N1
      IF (TP(I) .EQ. 0) GO TO 16
      IF (BF(I).LT..01) BF(I) = 2.53 - .45*ALOG10(WEIGHT(I)*1000.)
      NTP = TP(I)
      GO TO (161,162,163,164), NTP
  161 IF (FACT(I).LT. .001)  FACT(I) = GL(I)/2000.
      FAC(I) = FACT(I)
      FACT(I) = FACT(I)*1000.
      GO TO 16
  162 IF (FACT(I).LT. .001)  FACT(I) = GL(I)/(60.*SQRT(SMEAN(I)*1000.))
      FAC(I) = FACT(I)
      FACT(I) = FACT(I)*SQRT(SMEAN(I)*1000.)*1000.
      GO TO 16
  163 IF (FACT(I).LT. .0001)  FACT(I) = SQRT(GL(I)/R(I)/1000.)
      FAC(I) = FACT(I)
      FACT(I) = FACT(I)*FACT(I)*1000000.*R(I)
      FACT(I) = FACT(I)/2.
      GO TO 16
  164 FACT(I) = FACT(I)*((WEIGHT(I)*1000.)**(1./3.))*1000.
   16 CONTINUE
  131 PRINT 2021,ML,TD,MWL,WD
      PRINT 2015
      DO 17 I = 1,N1
      VS = SQRT( GL(I)/R(I))
      PRINT 2005, I, TP(I),FAC(I),BF(I), H(I),DEPTH(I)
     1,WEIGHT(I),GL(I),BL(I),WL(I),VS
   17 CONTINUE
      I = N1 + 1
      VS = SQRT(GL(I)/R(I))
      PRINT 2105, I, GL(I), BL(I), WL(I), VS
      CALL CXSOIL(N1)
 1003 FORMAT(3I5, 6A5)
 1004 FORMAT(3I5, 5F10.0,F5.0)
```

```
2004 FORMAT(17H    SOIL CARD NO. I4,17H OUT OF SEQUENCE )
2020 FORMAT(25H      NEW SOIL PROFILE NO. I3,5X,17H IDENTIFICATION  6A6
    1/)
2021 FORMAT(17H0NUMBER OF LAYERS ,I20,10X,16HDEPTH TO BEDROCK,F14.2/
    1 32H NUMBER OF FIRST SUBMERGED LAYER ,I5,
    210X,20HDEPTH TO WATER LEVEL,F10.2//)
2015 FORMAT(51H LAYER  TYPE       FACTOR       THICKNESS       DEPTH     ,
    157H    EFF. PRESS.       MODULUS           DAMPING     UNIT WEIGTH
    2 5X, 9HSHEAR VEL /15X,11HMOD.  DAMP. //)
2005 FORMAT(I4,I7,2X,2F6.2,F10.2,F12.2,F13.2,F15.0,F15.3,F15.4,F15.0)
2105 FORMAT(     I4, 4X, 4HBASE  48X, F15.0, F15.3, F15.4, F15.3)
     RETURN
     END
```

```
      SUBROUTINE CXSOIL(N1)
C
C*************************************************************************
C
C   THIS ROUTINE CALCULATES THE COMPLEX SOIL PROPERTIES AND TRANSFER
C   FUNCTIONS FOR THE LAYERS
C
C        N1       = NUMBER OF SOIL LAYERS
C        BL       = RATIO OF CRITICAL DAMPING
C        GL       = SHEAR MODULUS
C        R        = DENSITY
C        G        = COMPLEX SHEAR MODULUS
C        V        = COMPLEX SHEAR WAVE VELOCITY
C        PLUS     = COMPLEX TRANSFER FUNCTION
C        MINUS    = COMPLEX TRANSFER FUNCTION
C
C   CODED BY PER B SCHNABEL OCT 1971
C
C*************************************************************************
C
      COMPLEX G, V, PLUS, MINUS, MU
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
C
      N = N1 + 1
      DO 1 I = 1,N
      GIMAG = 2.*BL(I)*GL(I)
      G(I) = CMPLX(GL(I),GIMAG)
      V(I) = CSQRT(G(I)/R(I))
    1 CONTINUE
      DO 2 I = 1,N1
      J = I + 1
      MU = CSQRT(R(I)/R(J)*G(I)/G(J))
      PLUS(I) = (1. + MU)/2.
      MINUS(I)= (1. - MU)/2.
    2 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MOTION(N1,IN,INT,LL,LT, X,AX)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE CALCULATES THE MOTION IN ANY TWO SOIL LAYERS OR IN
C   ROCK FROM MOTION GIVEN IN ANY LAYER OR IN ROCK
C
C         N1        = NUMBER OF SOIL LAYERS EXCLUDING ROCK
C         IN        = NUMBER OF LAYER WHERE OBJECT MOTION IS GIVEN
C         INT       = MOTION TYPE
C                     IF EQ 0      OUTCROPPING LAYER
C         LL()      = NUMBER OF LAYERS WHERE OUTPUT MOTION IS WANTED
C                     MAX  3 LAYERS
C         LT()      = MOTION TYPE
C                     0 - OUTCROPPING LAYER
C                     1 - LAYER WITIN PROFILE
C         X()       = OBJECT MOTION
C         AX()      = OUTPUT MOTION
C
C
C   CODED BY PER B SCHNABEL  OCT 1970
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER LL(3), LT(3)
      INTEGER TITLE
      COMPLEX AA(3)
      COMPLEX X, AX
      COMPLEX   G, V, PLUS, MINUS
      COMPLEX E, F, EE, FF, A, EX, AIN, IPI2
      DIMENSION X(333),AX(3,270),           S(70),INV(70)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
C
C
      IPI2 = CMPLX(0., 6.28)
      DO 20 L = 1,3
      IF (LL(L) .GT. 0) AX(L,1) = X(1)
   20 CONTINUE
      FREQ = 0.
      DO 19 I = 2, MFOLD
      E = 1.
      FF = 1.
      FREQ = FREQ + DF
      A = FREQ*IPI2
      DO 191 K = 1,N1
      IF (K.NE.IN) GO TO 192
      AIN = E + FF
      IF (INT.EQ.0) AIN = 2.*E
C    FIND SUBLAYER WHERE MOTION IS WANTED
  192 DO 11 L = 1,3
      IF (K.NE.LL(L)) GO TO 11
C    AMPLIFICATION FACTOR FOR SUBLAYER WITHIN PROFILE
      AA(L) = E + FF
C    AMPLIFICATION FACTOR FOR OUTCROPPING SUBLAYER
      IF (LT(L).EQ.0)  AA(L) = 2.*E
   11 CONTINUE
      EX = CEXP(H(K)*A/V(K))
      EE = E*EX
      F = FF/EX
      E = EE*PLUS(K) + MINUS(K)*F
      FF = PLUS(K)*F + MINUS(K)*EE
  191 CONTINUE
      IF (IN.NE.N1+1) GO TO 193
      AIN = E + FF
      IF (INT.EQ.0) AIN = 2.*E
  193 DO 21 L = 1,3
      IF (LL(L).NE.N1+1) GO TO 21
      AA(L) = E + FF
      IF (LT(L).EQ.0) AA(L) = 2.*E
   21 CONTINUE
      DO 23 L = 1,3
      IF (LL(L) .GT. 0) AX(L,I) = X(I)*AA(L)/AIN
   23 CONTINUE
   19 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE STRT( IT,NL,DGMAX,PRMUL,X,AX,AA,SF,INV)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE CALCULATES STRAIN IN THE MIDDLE OF EACH LAYER AND FIND
C   NEW SOIL PROPERTIES COMPATIBLE WITH THE STRAINS
C
C        IT       = ITERATION NUMBER
C        NL       = NUMBER OF LAYERS EXCLUDING ROCK
C        DGMAX    = MAX ERROR IN SOIL PARAMETERS B OR G IN PERCENT
C        X        = OBJECT MOTION
C        AX(1, ) = ACCELERATION VALUES AT THE SURFACE
C        AX(2, ) = INCIDENT WAVE-COMPONENT
C        AX(3, ) = REFLECTED WAVE-COMPONENT
C        PRMUL    = RATIO EFF. STRAIN/MAX. STRAIN
C
C   CODED PER B SCHNABEL OCT. 1970
C   MODIFIED PBS  SEPT. 1971
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TITLE,TP
      COMPLEX IPI2, EX, E, F, EE, FF
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /SOILA/ IDNT(5),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /SOILC/ MSOIL,MNL
      COMMON /SOILDG/ S(9,20), AS(9,20), BS(9,20), NV(9)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      DIMENSION TMAX(20),          EMAX(20),STR(20)
      DIMENSION X( 68), AX(3, 64), AA(2,128),SF(10), INV(10)
C
      DO 43 I = 1,MFOLD
      AA(1,I) = REAL(X(I))
   43 AA(2,I) = AIMAG(X(I))
      DO 1  I = 1,MFOLD
      AX(2,I) = AX(1,I)/2.
    1 AX(3,I) = AX(2,I)
      PI2=6.283
      IPI2=CMPLX(0.,PI2)
      GT = 32.2
      DO 2 K = 1,NL
      FREQ = 0.
      X(1) = 0.
      FF = GT/(IPI2*V(K))
      EE = H(K)/2.*IPI2/V(K)
      DO 20 I = 2,MFOLD
      FREQ = FREQ + DF
      EX = CEXP(FREQ*EE)
      X(I) = (AX(2,I)*EX - AX(3,I)/EX)*FF/FREQ
      EX = EX*EX
      E = AX(2,I)*EX
      F = AX(3,I)/EX
      AX(2,I)= PLUS(K)*E + MINUS(K)*F
      AX(3,I)= PLUS(K)*F + MINUS(K)*E
   20 CONTINUE
      EMAX(K) = 0.
C
C   DETERMINE MAX. STRAIN BY INVERTING FOURIER TRANSFORM OF STRAIN
C   INTO THE TIME DOMAIN
C
      CALL RFSN(X,MX,INV,SF,IFERR)
      CALL XMX(X,MA,XMAX,NXMAX)
C
      EMAX(K) = XMAX
      TMAX(K) = FLOAT(NXMAX-1)*DT
    2 CONTINUE
      IF (IT.GT.1) PRINT 2002
      PRINT 2017, TITLE, IDNT
      PRINT 2027,IT
      PRINT 2037, PRMUL
      PRINT 2030
      DGMAX = 0.
      DO 23 I = 1,NL
      EM = EMAX(I)*PRMUL*100.
      EMAX(I) = EMAX(I)*100.
      IF (TP(I) .NE. 0)  GO TO 231
      STR(I) = EMAX(I)*GL(I)*10.
      PRINT 2107, I, TP(I), DEPTH(I), EM , BL(I), GL(I)
      GO TO 23
C
C   USE EFFECTIVE STRAIN AMPLITUDE (EM) TO GET NEW VALUES FOR DAMPING
C   AND SHEAR MODULUS
  231 IN = TP(I)*2 - 1
      SS= ABS(EM)
      SL = ALOG10(SS)
      LL = NV(IN)
      DO 31 L = 1,LL
      IF (SS.LE. S(IN,L)) GO TO 311
   31 CONTINUE
      L = LL
  311 GN =AS(IN,L)*SL +BS(IN,L)
      GG = GN*FACT(I)/1000.
      IN = IN + 1
      LL = NV(IN)
      DO 32 L = 1,LL
      IF (SS.LE. S(IN,L)) GO TO 321
   32 CONTINUE
      L = LL
  321 B  =AS(IN,L)*SL +BS(IN,L)
      B = B*BF(I)
C
      STR(I) = EMAX(I)*GG*10.
      B = B/100.
      DG = (GG - GL(I))*100./GG
      DB = ( B - BL(I))*100./B
      PRINT 2007, I, TP(I), DEPTH(I), EM, B, BL(I), DB, GG, GL(I), DG
      IF (ABS(DG) .GT. DGMAX)  DGMAX = ABS(DG)
      IF (ABS(DB) .GT. DGMAX)  DGMAX = ABS(DB)
      BL(I) = B
      GL(I) = GG
   23 CONTINUE
      PRINT 2011
      PRINT 2001, (I,TP(I), H(I),DEPTH(I), EMAX(I), STR(I), TMAX(I),
     1 I = 1,NL)
      CALL CXSOIL(NL)
      DO 44 I = 1,MFOLD
   44 X(I) = CMPLX(AA(1,I),AA(2,I))
      RETURN
```

```
C
 2000 FORMAT(2X,5HLAYER2X,4HTYPE,6X,5HDEPTH7X,11HEFF. STRAIN9X,
     19HNEW DAMP.4X,9HDAMP USED6X,5HERROR13X,5HNEW G6X,6HG USED9X
     2,5HERROR//)
 2002 FORMAT(1H1)
 2011 FORMAT(///23H  VALUES IN TIME DOMAIN //
     1 2X, 5HLAYER 2X, 4HTYPE 6X, 9HTHICKNESS 10X, 5HDEPTH 5X, 10HMAX STR
     2AIN 5X, 10HMAX STRESS 10X, 4HTIME /
     323X, 2HFT 14X, 2HFT 9X, 5HPRCNT 12X, 3HPSF 13X, 3HSEC /)
 2001 FORMAT(2I5, 2F15.1, F15.5,2F15.2)
 2337 FORMAT(2I5    , F12.1,        5X, F12.5, 5X, 2F12.3, F12.1, 5X,
     1 2F12.3, F12.1)
 2107 FORMAT(2I5, F12.1, 3X, F12.5,17X,F12.3,29X,F12.3)
 2027 FORMAT(/17H  ITERATION NUMBER   I2)
 2017 FORMAT(5X,15HEARTHQUAKE    - 5A6/5X,15HSOIL PROFILE -    6A6/)
 2037 FORMAT(50H  THE CALCULATION HAS BEEN CARRIED OUT IN THE TIME DOMAI
     171HN WITH EFF. STRAIN = F3.2, 1H* 12H MAX. STRAIN /)
      END
```

```
      SUBROUTINE UTPR(KK,DPTH,LS,K2,LH,LT,X,AX,AA,S,INV)
C
C
C*****************************************************************************
C
C   THIS ROUTINE TRANSFERES THE VALUES IN AX(LH, ) INTO THE TIME DOMAIN
C   IN X( ), PRINTS AND PUNCHES OUT THE RESULTS.
C
C
C        KK      = 5 TABULATE MAX. ACC.
C                  6 PRINT MAX ACC. SEPARATELY
C        DPTH    = DEPTH OF LAYER
C        X( )    = OBJECT MOTION
C        AX(LS, )= COMPUTED MOTION
C        LS      = COMPUTED MOTION NUMBER
C                  0 IF OBJECT MOTION
C        LH      = SUBLAYER NUMBER
C        LT      = SUBLAYER TYPE
C                  0 - OUTCROPPING
C                  1 - INSIDE
C        AA,S,INV  SCRATCH ARRAYS
C
C   CODED  PER B SCHNABEL  OCT. 1970
C   MODIFIED PBS AUG. 1971
C
C*****************************************************************************
C
      INTEGER TITLE
      COMPLEX SAVE
      COMPLEX X, AX
      DIMENSION XR(8)
      DIMENSION X(333),AX(3,273),AA(2,553),S(70),INV(70)
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
C
      FREQ = 0.
      SFX = 0.
      SXX = 0.
C   TRANSFORM VALUES IN X OR IN AX INTO THE TIMEDOMAIN
      DO 24  I = 1,MFOLD
      IF (LS.EQ.0) GO TO 241
      SAVE = X(I)
      X(I) = AX(LS,I)
      AX(LS,I) = SAVE
  241 XA = CABS(X(I))
      SXX= SXX + XA*XA
      SFX = SFX + XA*FREQ*XA
      FREQ = FREQ + DF
   24 CONTINUE
      SFX = SFX/SXX
C
      CALL RFSN(X,MX,INV,S,IFERR)
C
      CALL XMX(X,MA,XMAX,NMAX)
      TMAX = DT*FLOAT(NMAX-1)
      XEND = 0.
      N = MA/20
      NN = 2*N
      N = 8*N
      DO 25 I = N,NN
      XABS = REAL(X(I))
```

```
      XABS = ABS(XABS)
      IF (XABS.GT.XEND) XEND = XABS
      XABS = AIMAG(X(I))
      XABS = ABS(XABS)
      IF (XABS.GT.XEND) XEND = XABS
   25 CONTINUE
      XEND = XEND/XMAX
C
C   PRINT AND OR PUNCH OUTPUT
      N = 1
      NN = 4
      NCARDS=MA/8
      NC = NCARDS
      IF (KZ.EQ.0) NC = 0
      IF (KK.EQ.5) GO TO 252
      IF (LT.EQ.0)  PRINT 2000,LH, IDNT
      IF (LT.EQ.1)  PRINT 2002,LH, IDNT
      PRINT  2005, SFX
      PRINT 2003, XMAX, TMAX
  252 IF (KK.EQ.5.AND.LT.EQ.0)  PRINT 2001, DPTH,XMAX,TMAX,SFX,XEND,NC
      IF (KK.EQ.5.AND.LT.EQ.1)  PRINT 2010, DPTH,XMAX,TMAX,SFX, XEND,NC
      IF (KZ.EQ.0) GO TO 262
      PUNCH 2006, XMAX, TITLE
      IF (LT.EQ.1)  PUNCH 2002,LH, IDNT
      IF (LT.EQ.0)  PUNCH 2000,LH, IDNT
      DO 26 I = 1,NCARDS
      K = 0
      DO 261 J = N,NN
      K = K+ 1
      XR(K) = REAL(X(J))
      K = K + 1
      XR(K) = AIMAG(X(J))
  261 CONTINUE
      PUNCH 2008,(XR(J),J=1,8),I
      IF (KZ .EQ. 2) PRINT 2019, (XR(J), J = 1,8), I
      NN = 4 + NN
      N = N + 4
   26 CONTINUE
  262 CALL RFFT(X,MX,INV,S,IFERR)
      IF (LS.EQ.0)   RETURN
      DO 27 I = 1,MFOLD
      SAVE = AX(LS,I)
      AX(LS,I) = X(I)
   27 X(I) = SAVE
      RETURN
C
 2000 FORMAT(43H  ACCELERATION VALUES AT OUTCROPPING LAYER I3,3H - 6A6)
 2001 FORMAT(5X,6HOUTCR, F15.1,F15.5,2F15.2,F20.3,I20/)
 2010 FORMAT(5X,6HWITHIN F13.1,F15.5,2F15.2,F20.3,I20/)
 2002 FORMAT(42H  ACCELERATION VALUES AT THE TOP OF LAYER I3,3H - 6A6)
 2003 FORMAT(/15H  MAX. ACC. =  F9.6,11H AT TIME = F6.3, 5H SEC. //)
 2005 FORMAT(/26H   MEAN SQUARE FREQUENCY = F10.2/)
 2006 FORMAT(21X,6HX MAX= F7.4,5A6)
 2008 FORMAT(2X, I5, 5X, 8F15.6)
 2009 FORMAT(8F9.6,I7)
 2019 FORMAT(8F14.6,I10)
      END
```

```
      SUBROUTINE RESP(LL,LN,LS,NN,X,AX,A,S,INV)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS PROGRAM READS DATA FOR RESPONSE SPECTRUM ANALYSIS
C   NECESSARY SUBROUTINES    DRCTSP,  CMPMAX, PLOT
C
C        NN        = RESPONSE SPECTRUM NUMBER
C        NO        = NUMBER OF DAMPING VALUES
C        KAV       = SWITCH
C                    EQ 0  ACCELERATION SPECTRUM
C                    EQ 1  VELOCITY SPECTRUM
C                    EQ 2  ACC. AND VEL. SPECTRUM
C        KPL       = SWITCH
C                    EQ 1  PLOT RESPONSE SPECTRA ACCORDING TO KAV
C        KP        = SWITCH
C                    EQ 0  NO PUNCHED OUTPUT
C                    NE 0  PUNCHED OUTPUT ACCORDING TO KAV
C        X         = FOURIER TRANSFORM OF OBJECT MOTION
C        AX        = FOURIER TRANSFORM OF COMPUTED MOTIONS
C        DW        = PERIOD STEPS
C        NM        = NUMBER OF EACH STEP
C        T         = PERIODS WHERE RESPONSE IS TO BE COMPUTED
C
C   CODED PER B SCHNABEL DEC. 1970
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      INTEGER TITLE
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /RVAL/ NNO(9), ZLD(6),T(100), SA(5,100),SV(5,100)
      COMPLEX X, AX
      DIMENSION X(64), AX(3,64),A(2,64), S(10),INV(10)
      DIMENSION ID(9,11), ABSIS(10)
      DIMENSION DW(4), NM(4)
      DATA IBLANK /6H      /
      DATA (ABSIS(I), I = 1,10)/6H PERIO, 6HD IN S, 6HEC.   ,70*6H
C
      READ 1000, ND, KP, KAV, KPL, KPER
      READ 9000, (ZLD(I), I = 1,ND)
      PRINT 9001, LN, (ZLD(I), I = 1,ND)
      IF (KPER.LE.2) GO TO 5
      T1 = .099
      TN = 5
      N = 10
      K = 2
      IF (KPER.EQ.3)  GO TO 51
      T1 = .049
      N = 25
   51 CALL STEPG(K,N,DW,NM,T1,TN,T,NNM)
      GO TO 101
    5 NM(1) = 1
      NM(2) = 9
      NM(3) = 5
      NM(4) = 4
      DW(1) = .099
      DW(2) = .1
      DW(3) = .2
      DW(4) = .5
      IF (KPER.EQ.0) GO TO 4
      GO TO (1, 2), KPER
```

```
    1 DO 21 I = 2,4
      NM(I) = NM(I)*2
      DW(I) = DW(I)*.5
   21 CONTINUE
      GO TO 4
    2 NM(2) = 39
      NM(3) = 23
      NM(4) = 30
      DW(1) = .049
      DW(2) = .325
      DW(3) = .05
      DW(4) = .1
    4 N = 0
C
C     GENERATE PERIODS IN T
      T(1) = .001
      DO 10 L = 1,4
      M = NM(L)
      DO 10  I = 1,M
      N = N+1
      T(N+1) = T(N) + DW(L)
   10 CONTINUE
      NNM = N + 1
C
  131 T(1) = .001
C     SAVE VALUES IN X IN AA
      DO 11 I = 1,NFOLD
      A(1,I) = REAL(X(I))
      A(2,I) = AIMAG(X(I))
      IF (LS.EQ.0) GO TO 11
      X(I) = AX(LS,I)
   11 CONTINUE
C
C     TRANSFORM VALUES IN X OR AX INTO THE TIME DOMAIN
      CALL RFSN(X,MX,INV,S,IFERR)
      DO 13 L = 1,NU
      IF (NN.GE.7)  NN= 0
      NN = NN + 1
      DO 133 I = 1,5
  133 ID(NN,I) = TITLE(I)
      DO 132 I = 6,11
      ID(NN,I) = IONT(I-5)
      IF (LS.EQ.0) ID(NN,I) = IBLANK
  132 CONTINUE
C
C     COMPUTE RESPONSE FOR ACCELERATIONVALUES IN AA(L, )FOR THE PERIODS
C     GIVEN IN T( )
      CALL              DRCTSP(NN,NMA, DT, NN,KAV, KP, ID, ZLD(L),NNM,X)
   13 CONTINUE
C
C     GIVE X BACK ORIGINAL VALUES
      DO 12 I = 1,NFOLD
   12 X(I) = CMPLX(A(1,I),A(2,I))
      IF (KPL.EQ.0) RETURN
      IF (KAV.EQ.3) GO TO 133
      PRINT 2001
      SC = 0.
      CALL PLCT(NN,NN,T,SA,ABSIS,ID,SC,5,100)
      IF (KAV.EQ.1) GO TO 134
  133 PRINT 2002
      SC = 0.
      CALL PLCT(NN,NN,T,SV,ABSIS,ID,SC,5,100)
  134 NN = 0
      RETURN
 1000 FORMAT(1315)
 2001 FORMAT(35H1     PLOT OF ACCELERATION SPECTRA //)
 2002 FORMAT(30H1     PLOT OF VELOCITY SPECTRA //)
 9000 FORMAT( 8F10.3)
 9001 FORMAT( 50H  RESPONSE SPECTRUM ANALYSIS FOR LAYER NUMBER       I4
     1/26H CALCULATED FOR DAMPING     8F10.3)
      END
```

```
      SUBROUTINE CRCTSP(NN, KG, DT,      MM, K4, K2, ID, D, M, A)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C  THIS ROUTINE COMPUTES RESPONSE SPECTRA BY THE STEP BY STEP METHOD
C
C        NN      = RESPONSE SPECTRUM CURVE NUMBER  USEDIN PLOTTING
C        KG      = NUMBER OF ACCELERATION VALUES
C        DT      = TIMESTEP BETWEEN EACH ACCELERATION VALUE
C        M       = NUMBER OF PERIODS FOR WHICH RESPONSE IS TO BE COMPUTED
C        T       = ARRAY WITH THE PERIODS
C        A       = ACCELERATION VALUES
C        D       = CRITICAL DAMPING RATIO
C        ID      = IDENTIFICATION
C        K4      = 0 - ACCELERATION SPECTRUM
C                  1 - VELOCITY SPECTRUM
C                  2 - ACC. AND VEL. SPECTRA
C        K2      = 0 - NO PUNCHED OUTPUT
C                  1 - PUNCHED OUTPUT ACCORDING TO K4
C
C  CODED BY I. M. IDRISS 1968
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION A(1)
      COMMON /AVAL/ NAC(9), ZLD(6),T(100), SA(5,100),SV(5,100)
      DIMENSION       PRV(100), PAA(100), RD(100)
      DIMENSION ID(9,11)
C
      GT = 32.2
      DO 10 K = 1, KG
      A(K) = GT*A(K)
   10 CONTINUE
      KUG = KG-1
      PRINT 112,D
      N = 1
      YY = SQRT(1.-D*D)
      DO 200 LOOP = 1, M
      W = 6.2831853/T(N)
      WD = YY*W
      W2 = W*W
      W3 = W2*W
      CALL CMFMAX(KUG,    T(N),W,W2,W3,WD,D,DT,ZD,ZV,ZA,A)
      SV(NN,N) = ZV
      SA(NN,N) = ZA/GT
       RD(N) = ZD
      PRV(N) = W*ZD
      PAA(N) = W2*ZD/GT
  200 N = N + 1
      PRINT 312, (ID(NN,I), I = 1,10),D
      SUMSV = 0.
      SUMSA = 0.
      SUMT  = 0.
      SVMAX = 0.
      SAMAX = 0.
      TT1 = .1
      TT2 = 0.
      DO 320 N = 1, M
      FREKV = 1./T(N)
      IF (T(N) .LT. .0999 .OR. TT2.GT.2.4999)  GO TO 320
      TT2 = (T(N+1) + T(N))/2.
      IF (TT2.GT.2.5)  TT2 = 2.5
      TT = TT2 - TT1
      SUMSA = SA(NN,N)*TT + SUMSA
      SUMSV = SV(NN,N)*TT + SUMSV
      SUMT = SUMT + TT
      TT1 = TT2
      IF (SVMAX.LT.SV(NN,N))  SVMAX = SV(NN,N)
      IF (SAMAX.LT.SA(NN,N))  SAMAX = SA(NN,N)
  320 PRINT 322,N,T(N),RD(N),SV(NN,N),PRV(N),SA(NN,N),PAA(N),FREKV
      PRINT 2001,SUMSA,SUMSV,SAMAX,SVMAX
 2001 FORMAT(///10X,40HVALUES IN PERIOD RANGE .1 TO 2.5 SEC.         //
     115X35HAREA OF ACC. RESPONSE SPECTRUM    =  F10.3/
     215X35HAREA OF VEL. RESPONSE SPECTRUM    =  F10.3/
     315X35HMAX. ACCELERATION RESPONSE VALUE =   F10.3/
     415X35HMAX. VELOCITY      RESPONSE VALUE =   F10.3//)
      IF (K2.EQ.0) GO TO 30
      IF (K4 .EQ. 0) GO TO 31
      PUNCH 412, M,(ID(NN,I), I = 1,8)
      PUNCH 402, (SA(NN,I), I = 1,M)
   31 IF (K4 .EQ. 1) GO TO 30
      PUNCH 413 , M,(ID(NN,I), I = 1,8)
      PUNCH 402, (SV(NN,I), I = 1,M)
   30 MP = M
      DO 11 K = 1,KG
   11 A(K) = A(K)/GT
      RETURN
C
  112 FORMAT(///,5X,41HTIMES AT WHICH MAX. SPECTRAL VALUES OCCUR /
     1 10X,33HTD = TIME FOR MAX. RELATIVE DISP. /
     2 10X,33HTV = TIME FOR MAX. RELATIVE VEL.  /
     3 10X,33HTA = TIME FOR MAX. ABSOLUTE ACC.   /
     4 5X, 15HDAMPING RATIO =  F5.2//)
  312 FORMAT(1H1,5X,13HSPECTRAL VALUES-- /10X,10A6,5X,
     115HDAMPING RATIO =
     1 F5.2//5X,3HNO.,4X,6HPERIOD,5X,10HREL. DISP.,6X,9HREL. VEL.,3X,
     2 12HPSU.REL.VEL.,6X,9HABS. ACC.,3X,12HPSU.ABS.ACC. 5X,5HFREQ. /
     314X,4HSEC. 11X,3HFT. 8X,8HFT./SEC. 7X,8HFT./SEC. 11X,2HG.13X,2HG.
     46X,6HC/SEC.   //)
  322 FORMAT(I8,F10.2,5F15.5,F10.2)
  402 FORMAT(8F9.5)
  412 FORMAT(I5,25H ACC. RESPONSE VALUES FOR    , 8A6)
  413 FORMAT(I5,25H VEL. RESPONSE VALUES FOR    , 8A6)
C
      END
```

```
      SUBROUTINE CMPMAX (KUG,   PR,W,W2,W3,WD,D,DT,ZO,ZV,ZA, UG)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE COMPUTES REPONSE VALUES FOR ONE SINGLE DEGREE OF
C   FREEDOM SYSTEM USING STEP BY STEP METHOD
C
C   EXPLANATICS TO PARAMETERS GIVEN IN DRCTSP
C
C   CODED BY I. M. IDRISS  1968
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSICN        XD(2), XV(2), T(3)
      DIMENSICN UG(1)
C
      ZA = 0.
      ZO = 0.
      ZV = 0.
      XD(1) = 0.
      XV(1) = 0.
      F1 = 2.*D/(W3*DT)
      F2 = 1./W2
      F3 = D*W
      F4 = 1./WD
      F5 = F3*F4
      F6 = 2.*F3
       E = EXP(-F3*DT)
       S = SIN(WD*DT)
       C= COS(WD*DT)
      G1 = E*S
      G2 = E*C
      H1 = WD*G2 - F3*G1
      H2 = WD*G1 + F3*G2
      DO 100 K = 1, KUG
       Y = K-1
      DUG = UG(K+1) - UG(K)
      Z1 = F2*DUG
      Z2 = F2*UG(K)
      Z3 = F1*DUG
      Z4 = Z1/DT
       B = XD(1) + Z2 -Z3
       A = F4*XV(1) + F5*B + F4*Z4
      XD(2) = A*G1 + B*G2 + Z3 - Z2 - Z1
      XV(2) = A*H1 - B*H2 - Z4
      XD(1) = XD(2)
      XV(1) = XV(2)
      AA = -F6*XV(1) - W2*XD(1)
       F = ABS(XD(1))
       G = ABS(XV(1))
       H = ABS(AA)
      IF(F .LE. ZO) GO TO 75
      T(1) = Y
       ZO = F
   75 IF(G .LE. ZV) GO TO 85
      T(2) = Y
       ZV = G
   85 IF(H .LE. ZA) GO TO 100
      T(3) = Y
       ZA = H
  100 CONTINUE
      DO 110 L = 1, 3
  110 T(L) = DT*T(L)
      PRINT 112, PR, (T(L),L=1,3)
  112 FORMAT(5X,5HPER = F5.2,5X,19HTIMES FOR MAXIMA -- ,3X,
     14HTD = F8.4,3X,4HTV = F8.4,3X,4HTA = F8.4)
      RETURN
      END
```

```
      SUBROUTINE STRAIN( LL, LGS, LPCH, LPL,LNV,SK,X,AX,AA,NI,S,INV)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS SUBROUTINE COMPUTES STRAIN AND/OR STRESS TIME-HISTORY AT THE
C   TOP OF ANY LAYER FOR ACCELERATION HISTORY KNOWN IN ANY LAYER
C   TWO RESPONSE HISTORIES ARE COMPUTED IN ONE RUN
C
C        LL    =   SUBLAYER NUMBER WHERE RESPONSE IS TO BE COMPUTED
C        LGS   =   SWITCH FOR STRESS OR STRAIN
C        LPCH  =   SWITCH FOR PUNCHED OUTPUT
C        LPL   =   SWITCH FOR PLOT
C        SK    =   SCALE FOR PLOTTING
C        X     =   FOURIER TRANSFORM OF OBJECT MOTION
C        AX(1, )   FOURIER TRANSFORM OF SURFACE MOTION
C        AX(2, )   FOURIER TRANSFORM OF FIRST COMPUTED RESPONSE
C        AX(3, )   FOURIER TRANSFORM OF SECOND RESPONSE
C        AA(1, )   TIME HISTORY OF FIRST RESPONSE
C        AA(2, )   TIME HISTORY OF SECOND RESPONSE
C
C
C   CODED BY PER B. SCHNABEL  JULY 1971
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TITLE,TP
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      COMPLEX E,F,EE, A,AH,IPI2, AE,AF,EX,AI
      DIMENSION ABSIS(10)
      DIMENSION AE(2), AF(2)
      DIMENSION X(1), AX(3,1), AA(2,1),S(1),INV(1)
      DIMENSION  LL(2),  LGS(2), LPCH(2), LPL(2),SK(2),LNV(2)
      COMMON /SOILA/ ICNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /CCG/ IC(9,11),T(2049)
C
      IPI2 = CMPLX(0.,6.283)
      GT = 32.2
      AX(2,1) = 0.
      AX(3,1) = 0.
      FREQ = 0.
      DATA (ABSIS(I), I=1,10)/6H TIME ,6HIN SEC , 8*6H
      AI = GT/IPI2
C
C   STARTING AT THE SURFACE THE STRAIN IS COMPUTED SUCCESSIVELY DOWNWARDS
C   FOR EACH FREQUENCY
      DO 1 I = 2,MFOLD
      E = AX(1,I)/2.
      F = E
      FREQ = FREQ + DF
      AH = AI/FREQ
      A = FREQ*IPI2
      DO 11  K = 1,NI
      DO 12 L = 1,2
      IF (K.NE.LL(L)) GO TO 12
      AE(L) = E/V(K)
      AF(L) = F/V(K)
   12 CONTINUE
      EX = CEXP(H(K)*A/V(K))
      E = E*EX
      F = F/EX
      EE = E*PLUS(K) + MINUS(K)*F
      F  = F*PLUS(K) + MINUS(K)*E
      E = EE
   11 CONTINUE
      DO 13 L = 1,2
      IF (LL(L).NE.NI+1) GO TO 13
      AE(L) = E/V(NI+1)
      AF(L) = F/V(NI+1)
   13 CONTINUE
      DO 14 L = 1,2
      IF (LL(L).LE.0) GO TO 14
      K = LL(L)
      EX = CEXP(H(K)*A/(2.*V(K)))
      AX(L+1,I) = (AE(L)*EX - AF(L)/EX)*AH
   14 CONTINUE
    1 CONTINUE
      DO 2 I = 1,MFOLD
    2 AX(1,I) = X(I)
      DO 3 L = 1,2
      IF (LL(L).EQ.0) GO TO 3
      X(1) = 0.
      DO 31 I = 2,MFOLD
   31 X(I) = AX(L+1,I)
      CALL RFSN(X,MX,INV,S,IFERR)
      DO 32 I =1,MFOLD
      AA(L,2*I-1) =REAL(X(I))*100.
   32 AA(L,2*I) = AIMAG(X(I))*100.
    3 CONTINUE
C
      DO 4 I = 1,MFOLD
    4 X(I) = AX(1,I)
C
C   COMPUTE STRESS IF WANTED AND    PUNCH AND PLOT COMPUTED RESPONSES
      DO 5 L = 1,2
      IF (LL(L) .EQ. 0) GO TO 5
      NVAL = LNV(L)
      IF (NVAL.LE.0) NVAL = MMA
      IF (NVAL.GT.MA)  NVAL = MA
      IF (NVAL.GT.2049) NVAL = 2049
      DO 51 I = 1,5
   51 IC(L,I) = TITLE(I)
      N = LL(L)
      IC(L,6) = 6HSTRAIN
      IF (LGS(L) .EQ.0) GO TO 53
      IC(L,6) = 6HSTRESS
      DO 52 I = 1,NVAL
   52 AA(L,I) = GL(N)*AA(L,I)/100.
   53 IF (LPCH(L).EQ.0) GO TO 54
      PUNCH 2000, (IC(L,I), I=1,11),N
      N = 1
      NCARDS = NVAL/8
      DO 55 K = 1,NCARDS
      NN = N + 7
      PUNCH 2001,(AA(L,I), I = N,NN), K
   55 N = N + 8
   54 IF (LPL(L).EQ.0) GO TO 5
      N = 0
      NSKIP = 1
```

```
      DO 56 I = 1,NVAL,NSKIP
      N = N + 1
      IF (NSKIP.GT.1) AA(L,N) = AA(L,I)
   56 T(N) = DT*FLOAT(I-1)
      IF  (LGS(L).EQ.0)  PRINT 2002
      IF (LGS(L).EQ.1)  PRINT 2003
      IF (LPL(L).EQ.0) GO TO 5
      IF (LPL(2).EQ.2) GO TO 59
      IF (L.EQ.1)  GO TO  58
      DO 57 I = 1,N
   57 AA(1,I) = AA(2,I)
      DO 50 I = 1,11
   50 ID(1,I) = ID(2,I)
   58 CALL PLOT(1,  N,T,AA,ABSIS,ID,SK(L),2, N)
      GO TO 5
   59 CALL PLOT(2,  N,T,AA,ABSIS,ID,SK(L),2, N)
    5 CONTINUE
      RETURN
 2000 FORMAT(11A6,5HLAYER I5)
 2001 FORMAT(8F5.4,I7)
 2002 FORMAT(41H1  TIME HISTORY OF STRAIN IN PERCENT        //)
 2003 FORMAT(41H1  TIME HISTORY OF STRESS IN KIPS           //)
      END
```

```
      SUBROUTINE CG
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THE SUBROUTINE READ POINTS ON A CURVE AND GENERATES NEW POINTS
C   BETWEEN THE GIVEN POINTS IN ARITHMETIC OR HALFLOGARITHMIC SCALE
C   NECESSARY SUBROUTINES    CURVEG(), PLOT()
C
C        NST      = NUMBER OF SOILTYPES
C        ABSIS    = TITLE ON ORDINATE FOR PLOTTING
C        NN       = NUMBER OF VALUES IN EACH 10 FOR SEMILOGPLOT
C        SC       = SCALE FOR PLOTTING
C        NC       = NUMBER OF CURVES
C        NV       = NUMBER OF VALUES WHERE STRAIN/PROPERTY-RELATION
C                   IS GIVEN
C        FPL      = MULTIPLICATION FACTOR FOR PLOTTING
C        ID       = IDENTIFICATION
C        X        = STRAIN VALUES
C        Y        = PROPERTY VALUES
C
C
C   CODED BY PER B SCHNABEL SEPT 1970
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION Y(9,20), TSTEP(9)
      DIMENSION NT(9),                              ABSIS(10), FPL(9)
      COMMON /SOILOG/ X(9,23), A (9,23), B (9,23), NV(9)
      COMMON /CCG/ ID(9,11),T(200), V(9,200)
      DATA (ABSIS(I),I=1,10)/6H STRAI ,6HN IN P ,6HERCENT ,7*6H
C
      READ 1000, NSOILT,NPL,NN,SC
      NC = 2*NSOILT
      DO 1 L = 1,NC
      READ 2001, NV(L), FPL(L), (ID(L,I), I=1,11)
      M = NV(L)
      READ 1002,( X(L,I), I = 1,M)
      READ 1002,( Y(L,I), I = 1,M)
    1 CONTINUE
      CALL CURVEG( NC, NV,  2, A, B, 10, TSTEP, NT, T, V, X, Y, NSTEP)
      IF (NPL.NE.1) RETURN
      DO 2 N = 1,NC
      DO 2 L = 1,NSTEP
      V(N,L) = V(N,L)*FPL(N)
    2 CONTINUE
      PRINT 3001
      PRINT 3000
      DO 3 L = 1,NC
    3 PRINT 3002, (ID(L,I), I = 1,10), FPL(L)
      CALL      PLOT(NC, NSTEP, T, V, ABSIS, ID, SC, 9, 200)
      RETURN
C
 1000 FORMAT(3I5,F10.3)
 1001 FORMAT(/I5,F10.2, 11A6)
 1002 FORMAT(8F10.3)
 2001 FORMAT(I9, F5.0, 11A6)
 2007 FORMAT( 12F10.4)
 3000 FORMAT(53H  MODULUS AND DAMPING VALUES ARE SCALED FOR PLOTTING //)
 3001 FORMAT(55H    CURVES FOR RELATION STRAIN VERSUS SHEAR MODULUS AND
     1 8H DAMPING ///)
 3002 FORMAT(10A6, 25H  MULTIPLICATION FACTOR = F7.2)
```

```
      SUBROUTINE  CURVEG(NC, NV, K1, A, B, NN, TSTEP, NT, T,V,X,Y,NSTEP)
C
C*****************************************************************************
C
C   THE PROGRAM GENERATES NEW POINTS ON A CURVE BY LINEAR INTERP. IN
C   AN ARITMETIC OR HALFLOGARITHMIC SCALE
C
C        NV(I)    = NUMBER OF VALUES ON CURVE I
C        NC       = NUMBER OF CURVES
C        K1          =     SWITCH     K1 = 1  ARITMETIC SCALE
C                                     K1 = 2  HALFLOGARITHMIC SCALE
C        A,B         =     PARAMETERS FOR CALCULATING NEW VALUES
C                          Y = A*X + B
C        X,Y         =     KNOWN POINTS ON CURVE
C        T           =     VALUES ON ABSISSA WHERE NEW POINTS ARE GENERATED
C        V           =     NEW ORDINATE VALUES
C
C        ARITMETIC SCALE  K1 = 1
C        NN          =     NUMBER OF INTERVALS
C        TSTEP       =     LARGEST VALUE IN EACH INTERVAL
C        NT          =     NUMBER OF STEPS IN EACH INTERVAL
C
C        HALFLOGARITHMIC SCALE
C        NN          =     NUMBER OF VALUES IN EACH LOG10
C
C
C   CODED BY PER B SCHNABEL SEPT 1973
C
C*****************************************************************************
C
      DIMENSION X(9,20), Y(9,20), A(9,20), B(9,20), NV(9), TSTEP(9)
      DIMENSION NT(9), T(233), V(9,233)
      XMIN = 100000000.
      XMAX = 0.
      DO 1 L= 1,NC
      M = NV(L)
      IF (XMAX .LT. X(L,M))    XMAX = X(L,M)
      IF (XMIN .GT. X(L,1)) XMIN = X(L,1)
      M = M - 1
      DO 1 I = 1,M
      X1 = X(L,I)
      X2 = X(L,I+1)
      IF (K1 .EQ. 2)  X1 = ALOG10(X1)
      IF (K1 .EQ. 2)  X2 = ALOG10(X2)
      X(L,I) = X(L,I+1)
      A(L,I) = (Y(L,I+1) - Y(L,I))/(X2 - X1)
    1 B(L,I) = -A(L,I)*X1 + Y(L,I)
C
      CALL STEPG(K1, NN, TSTEP, NT, XMIN, XMAX, T, NSTEP)
C
      DO 2 L = 1,NC
      M = NV(L) - 1
      DO 2 I = 1,NSTEP
      DO 3 J = 1,M
      IF (T(I) .LT. X(L,J))   GO TO  31
    3 CONTINUE
      J = M
   31 TT = T(I)
      IF (K1 .EQ. 2) TT = ALOG10(TT)
    2 V(L,I) = A(L,J)*TT   + B(L,J)
      RETURN
                                                                  END
```

```
      SUBROUTINE STEPG(KK, NN, TSTEP, NT, T1, TN, T, NSTEP)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THE ROUTINE GENERATES STEPS IN LINEAR OR LOGARITHIC INCREMENTS
C
C
C       KK      = SWITCH    KK = 1    STEP INCREASE OF VALUES
C                           KK = 2    LOGARITHIC INCREASE OF VALUES
C       NN      = NUMBER OF STEPS   OR NUMBER OF VALUES IN EACH 10
C       TSTEP   = LARGEST VALUE IN EACH STEP
C       NT      = NUMBER OF VALUES IN EACH STEP
C       T1      = FIRST VALUE IN LOG-STEP
C       TN      = LAST  VALUE IN LOG-STEP
C       T       = VALUES GENERATED
C       NSTEP   = NUMBER OF VALUES
C
C   8
C   CODED PER B SCHNABEL SEPT. 1970
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION T(233), TSTEP(9), NT(9)
C
      GO TO (1, 2), KK
    1 K = 1
      T(K) = 0.
      SAVE = 0.
      DO 11 N = 1,NN
      M = NT(N)
      STEP = (TSTEP(N) - SAVE)/FLOAT(M)
      SAVE = TSTEP(N)
      DO 11 I = 1,M
      K = K + 1
   11 T(K) = T(K-1) + STEP
      NSTEP = K
      RETURN
    2 NST = ALOG10(T1)
      IF (T1.LT. 1.) NST = NST - 1
      STEP = 1./NN
      K = 1
      TA = 10.**FLOAT(NST)
      T(1) = TA
      DO 22 J = 2,NN
      K = K + 1
      T(K) = TA*10.**(STEP*FLOAT(J))
      IF (T(K) .GT. T1) GO TO 221
   22 CONTINUE
  221 TA = T(K-1)
      K = 0
  211 DO 21 J = 1,NN
      K = K + 1
      T(K) = TA*10.**(STEP*FLOAT(J))
      IF (T(K).GT.TN)  GO TO 212
   21 CONTINUE
      TA = TA*10.
      GO TO 211
  212 NSTEP = K
      RETURN
      END
```

```
      SUBROUTINE REDUCE(IFR,X,AX,LL)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS ROUTINE INCREASES TIME INTERVAL AND REDUCES NUMBER OF VALUES
C
C
C       IFR    =   DIVIDING FACTOR ON LENGTH OF FRECORD
C                  MULTIPLICATION FACTOR ON TIMESTEP
C                  MUST BE A POWER OF 2.
C       DT     =   TIMESTEP IN SEC.
C       DF     =   FREQUENCY STEP IN C/SEC.
C       MA     =   NUMBER OF POINTS USED IN FOURIER TRANSFORM
C       X      =   FOURIER TRANSFORM OF OBJECT MOTION
C       AX     =   FOURIER TRANSFORM OF COMPUTED MOTIONS
C
C
C   CODED BY PER B. SCHNABEL DEC. 1970.
C   MODIFIED SEPT. 1971
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TITLE
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMPLEX X, AX
      DIMENSION X( 69), AX(3, 54), LL(3)
      F1 = .5/DT
      FR = FLOAT(IFR)
      DT = DT*FR
      MA = MA/IFR
      MMA = MMA/IFR
      MA2 = MA + 2
      MFOLD = MA2/2
      N = MFOLD + 1
      DO 12 I = MFOLD,N
      X(I) = 0.
C
      DO 12 L = 1,3
      IF (LL(L).LE.0) GO TO 12
      AX(L,I) = 0.
   12 CONTINUE
      MFOLD = MFOLD + 1
      F2 = .5/DT
      PRINT 1000,F1,F2,DT, MA
      FMA = FLOAT(MA)
      MX = (ALOG10(FMA)/ALOG10(2.))-1.
      IF (MA.LT.2**(MX+1)) MX = MX+1
      RETURN
 1000 FORMAT( 20H  FREQUENCIES FROM  F6.2, 3H TO F6.2,14H C/SEC ARE REM
     1 5HOVED /
     2 16H NEW TIMESTEP = F5.4/19H NUMBER OF VALUES = I5//)
      END
```

```
      SUBROUTINE INCR(IFR,X,AX,LL)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS ROUTINE INCREASES NUMBER OF POINTS IN THE RECORD
C   BY DECREASING TIMESTEP
C
C
C        IFR   =   MULTIPLYING FACTOR ON LENGTH OF FRECORD
C                  MUST BE A POWER OF 2.
C        DT    =   TIMESTEP IN SEC.
C        DF    =   FREQUENCY STEP IN C/SEC.
C        MA    =   NUMBER OF POINTS USED IN FOURIER TRANSFORM
C        X     =   FOURIER TRANSFORM OF OBJECT MOTION
C        AX    =   FOURIER TRANSFORM OF COMPUTED MOTIONS
C
C
C   CODED BY PER B. SCHNABEL DEC. 1970.
C   MODIFIED OCT.  1971
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMPLEX X, AX
      DIMENSION X( 68), AX(3, 64), LL(3)
C
      F1 = .5/DT
      FR = FLOAT(IFR)
      DT = DT/FR
      N = MFCLD- 1
      MA = MA*IFR
      MMA = MMA*IFR
      MA2 = MA + 2
      MFOLD = MA2/2
      MFOLD = MFOLD + 1
      DO 10 I = N, MFOLD
      X(I) = 0.
      DO 10 L = 1,3
   10 AX(L,I) = 0.
      F2 = .5/DT
      PRINT 1000,F1,F2,DT, MA
      FMA = FLOAT(MA)
      MX = (ALOG10(FMA)/ALOG10(2.))-1.
      IF (MA.LT.2**(MX+1)) MX = MX+1
 1000 FORMAT(27H   FREQUENCIES ADDED FROM  F6.2,3H TO F6.2/
     216H NEW TIMESTEP = F5.4/19H NUMBER OF VALUES = I5//)
      RETURN
      END
```

```
      SUBROUTINE PLOT (N,M,V,A,ABSIS,ID,XSCALE,NA,MA)
C
C  PRINTER PLOTTING OF UP TO 9 FUNCTIONS ON THE SAME GRAPH
C  FOLLOWED BY TABULATION OF THE SAME FUNCTIONS
C
C  CODED BY JOHN LYSMER  -  AUGUST 1970
C
C  ARGUMENTS
C     N          = NUMBER OF CURVES ON THE GRAPH  -  MUST BE .LE. NA
C     M          = NUMBER OF POINTS PER CURVE  -  MUST BE .LE. MA
C     V(M)       = VECTOR CONTAINING THE ABSISSAS  -  MAX(ABS(V(I)))=999.
C     A(N,M)     = ROW I CONTAINS ORDINATES OF CURVE I
C     ABSIS(10)= IDENTIFICATION FOR ABSISSA (10A6)
C     ID(N,10) = ROW I CONTAINS IDENTIFICATION FOR CURVE I  (10A6)
C     SCALE      = ORDINATE CORRESPONDING TO 100 PER CENT ON GRAPH
C                  SCALE IS AUTOMATICALLY INCREASED TO THE VALUE
C                  MAX(ABS(A(I,J))) IF SCALE IS SMALLER THAN THIS VALUE
C     NA         = DIMENSION OF 1ST SUBSCRIPT OF A  -  MUST BE .LE. 9
C     MA         = DIMENSION OF 2ND SUBSCRIPT OF A  -  NO LIMIT
C
C  NOTE  -  SKIP TO TOP OF NEW PAGE BEFORE CALLING THIS ROUTINE
C
C**********
C
      DIMENSION V(1),A(NA,MA),ABSIS(10),ID( 9,11)
      DIMENSION LINE(101),NUMBER(9)
      INTEGER X,BLANK,DOT
      DATA X,BLANK,DOT/1HX,1H ,1H*/
      DATA (NUMBER(I),I=1,9)/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
C
C**********
C
      SCALE = XSCALE
      AMAX=0.
      AMIN=0.
C
      DO 1 I=1,N
      DO 1 J=1,M
      AIJ=A(I,J)
      IF(AIJ.GT.AMAX) AMAX=AIJ
      IF(AIJ.LT.AMIN) AMIN=AIJ
    1 CONTINUE
      IF(SCALE.LT.AMAX) SCALE =AMAX
      IF(SCALE.LT.ABS(AMIN)) SCALE=ABS(AMIN)
C
      PRINT 1002,SCALE
      IF(AMIN) 2,3,3
    2 PRINT 1003
      GO TO 4
    3 PRINT 1004
    4 PRINT 1005
C
      DO 5 I=1,M
C
      DO 6 J=1,101
      LINE(J)=BLANK
      IF(I.EQ.1.OR.I.EQ.M) LINE(J)=DOT
    6 CONTINUE
      IF(AMIN) 7,8,8
    7 LINE(51)=DOT
    8 LINE(1)=DOT
```

```
      LINE(101)=DOT
C
    9 DO 13 J=1,N
      R=A(J,I)/SCALE*100.
      IF(AMIN) 11,12,12
   11 R=(R+100.)/2.
   12 R=R+1.499999399
      INDEX=R
      IF(LINE(INDEX).EQ.BLANK) GO TO 13
      IF(LINE(INDEX).EQ.DOT   ) GO TO 13
      LINE(INDEX)=X
      GO TO 10
   13 LINE(INDEX)=NUMBER(J)
   10 CONTINUE
      PRINT 1006,V(I),(LINE(J),J=1,101)
    5 CONTINUE
C
      PRINT 1005
      PRINT 1007,ABSIS
C
      DO 14 I=1,N
      PRINT 1008,I,(ID(I,J),J=1,11)
   14 CONTINUE
      PRINT 1000
      PRINT 1009,(BLANK,NUMBER(I),I=1,N)
C
      DO 15 I=1,M
      PRINT 1010,V(I),(A(J,I),J=1,N)
   15 CONTINUE
      RETURN
 1000 FORMAT(1HY)
 1002 FORMAT(84X,27H100 PER CENT CORRESPONDS TO ,F9.4/)
 1003 FORMAT(12X,4H-100,7X,3H-80,7X,3H-60,7X,3H-40,7X,3H-20
     2,8X,1H0,9X,2H20,8X,2H40,8X,2H60,8X,2H80,8X,12H100 PER CENT)
 1004 FORMAT(14X,1H0,8X,2H10,8X,2H20,8X,2H30,8X,2H40,8X,2H50
     2,  8X,2H60,8X,2H70,8X,2H80,8X,2H90,8X,12H100 PER CENT)
 1005 FORMAT(10H          ,11(4X,1H+,5X) )
 1006 FORMAT(1HX,F9.4,6X,101A1)
 1007 FORMAT(4X,1H*/5X,3H***/4X,5H*****/6X1H*/6X,8H******   ,10A6//)
 1008 FORMAT( 6H CURVE,I2,5H  -   ,11A6)
 1009 FORMAT (10H0  ABSISSA,4X,9(A1,6HCURVE ,A1,2X))
 1010 FORMAT(F10.4,2X,9(F10.4))
C
      END
```

```
      SUBROUTINE AMP( NI,IN,INT,LL,LT,KPL,ID,NA,DF)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * .   * * * * * *
C
C   THIS ROUTINE COMPUTES THE AMPLIFICATION SPECTRUM BETWEEN ANY TWO
C   LAYERS
C
C        NI       = NUMBER OF SOIL LAYERS EXCLUDING ROCK
C        IN       = NUMBER OF SUBLAYER FROM WHICH AMPLIFICATION IS COMP.
C        INT      = SUBLAYER TYPE
C                         0 - OUTCROPPING LAYER
C                         1 - LAYER WITHIN PROFILE
C        LL       = NUMBER OF SUBLAYER TO WHICH AMPLIFICATION IS COMP.
C        LT       = SUBLAYER TYPE
C                         0 - OUTCROPPING LAYER
C                         1 - LAYER WITHIN PROFILE
C        KPL      = 0 NO PLOTTING
C                   1 PLOT ALL AMP. FUNCTIONS SINCE LAST PLOTTING
C        DF       = FREQUENCY STEPS IN AMP. FUNCTION
C        NA       = CURVE NUMBER IN PLOTTING
C        ID       = IDENTIFICATION
C
C
C   CODED PER B SCHNABEL  FEB. 1971
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      COMPLEX   G, V, PLUS, MINUS
      COMPLEX E, F, EE, FF, A, EX, AIN, IPI2,AA
      DIMENSION ID (9,11)
      DIMENSION ABSIS(10)
      COMMON /SOILA/ IDNT(9), BL(20), GL(20), FACT(20), H(20),R(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON /CCG/ IA(9,11),T(200),ST(9,200)
      DATA (ABSIS(I), I=1,10)/6H CYCLE, 6HS/SEC., 8*6H
C
C
      IPI2 = CMPLX(0., 6.283)
      FREQ = 0.
      ST(NA,1) = 1.
      DO 19 I = 2,200
      E = 1.
      FF = 1.
      FREQ = FREQ + DF
      A = FREQ*IPI2
      DO 191 K = 1,NI
      IF (K.NE.IN) GO TO 192
      AIN = E + FF
      IF (INT.EQ.0) AIN = 2.*E
  192 IF (K.NE.LL) GO TO 11
      AA     = E + FF
      IF (LT.EQ.0) AA = 2.*E
   11 EX = CEXP(H(K)*A/V(K))
      EE = E*EX
      F = FF/EX
      E = EE*PLUS(K) + MINUS(K)*F
      FF = PLUS(K)*F + MINUS(K)*EE
  191 CONTINUE
      IF (IN.NE.NI+1) GO TO 193
      AIN = E + FF
```

```
      IF (INT.EQ.0) AIN = 2.*E
  193 IF (LL    .NE.N1+1) GO TO 21
      AA     = E + FF
      IF (LT.EQ.0)  AA = 2.*E
   21 ST(NA,I) = CABS(AA/AIN)
   19 CONTINUE
      DO 23 I = 1,200
   23 T(I) = DF*FLOAT(I-1)
      AMAX = 0.
      DO 22 I = 1,200
      IF (ST(NA,I) .LT.  AMAX) GO TO 22
      TMAX = T(I)
      AMAX = ST(NA,I)
   22 CONTINUE
      IF (NA.LT.9) NA=NA+1
      PERIOD = 1./TMAX
      IF (TMAX.LT. .0001)  PRINT 1001,AMAX, TMAX
      IF (TMAX.GT. .0001)  PRINT 1001,AMAX, TMAX,PERIOD
      IF (KPL.EQ.0) RETURN
      PRINT 1000
      N = NA-1
      CALL PLOT(N ,200,T,ST,ABSIS,ID,0.,9,200)
      NA = 1
      RETURN
 1000 FORMAT(33H1  PLOT OF AMPLIFICATION SPECTRA  //)
 1001 FORMAT(25H MAXIMUM AMPLIFICATION =  F6.2/
     1 25H FOR FREQUENCY           = F6.2, 7H C/SEC. /
     1 25H      PERIOD             =  F6.2, 5H SEC. /)
      END
```

```
      SUBROUTINE FFT (A,M,INV,S,IFSET,IFERR)
      DIMENSION A(1),INV(1),S(1),N(3),M(3),NP(3),W(2),W2(2),W3(2)
      EQUIVALENCE (N1,N(1)), (N2,N(2)), (N3,N(3))
10    IF (IABS(IFSET)-1) 610,610,20
610   MT=MAX0(M(1),M(2),M(3))-2
      MT=MAX0(2,MT)
      IF (MT-20) 630,630,620
620   IFERR=1
      GO TO 600
630   IFERR=0
      NT=2**MT
      NTV2=NT/2
      THETA=.7853981634
      JSTEP=NT
      JDIF=NTV2
      S(JDIF)=SIN(THETA)
      DO 660 L=2,MT
      THETA=THETA/2.
      JSTEP2=JSTEP
      JSTEP=JDIF
      JDIF=JSTEP/2
      S(JDIF)=SIN(THETA)
      JC1=NT-JDIF
      S(JC1)=COS(THETA)
      JLAST=NT-JSTEP2
      IF (JLAST-JSTEP) 660,640,640
640   DO 650 J=JSTEP,JLAST,JSTEP
      JC=NT-J
      JD=J+JDIF
650   S(JD)=S(J)*S(JC1)+S(JDIF)*S(JC)
660   CONTINUE
C
C     SET UP INV(J) TABLE
      MTLEXP=NTV2
      LM1EXP=1
      INV(1)=0
      DO 690 L=1,MT
      INV(LM1EXP+1)=MTLEXP
      DO 670 J=2,LM1EXP
      JJ=J+LM1EXP
670   INV(JJ)=INV(J)+MTLEXP
      MTLEXP=MTLEXP/2
690   LM1EXP=LM1EXP*2
      IF (IFSET) 20,600,20
20    MTT=MAX0(M(1),M(2),M(3))-2
      ROOT2=SQRT(2.)
      IF (MTT-MT) 40,40,30
30    IFERR=1
      PRINT 1000
      STOP
 1000 FORMAT(31H --- ERROR IN FOURIER TRANSFORM  )
40    IFERR=0
      M1=M(1)
      M2=M(2)
      M3=M(3)
      N1=2**M1
      N2=2**M2
      N3=2**M3
      IF (IFSET) 50,50,70
50    NX=N1*N2*N3
      FN=NX
```

```
      DO 60 I=1,NX
      A(2*I-1)=A(2*I-1)/FN
60    A(2*I)=-A(2*I)/FN
70    NP(1)=N1*2
      NP(2)=NP(1)*N2
      NP(3)=NP(2)*N3
      DO 330 ID=1,3
      IL=NP(3)-NP(ID)
      IL1=IL+1
      NI=N(ID)
      IF (NI) 330,330,80
80    IDIF=NP(ID)
      KBIT=NP(ID)
      MEV=2*(NI/2)
      IF (NI-MEV) 120,120,90
90    KBIT=KBIT/2
      KL=KBIT-2
      DO 100 I=1,IL1,IDIF
      KLAST=KL+I
      DO 100 K=I,KLAST,2
      KD=K+KBIT
      T=A(KD)
      A(KD)=A(K)-T
      A(K)=A(K)+T
      T=A(KD+1)
      A(KD+1)=A(K+1)-T
100   A(K+1)=A(K+1)+T
      IF (NI-1) 330,330,110
110   LFIRST=3
      JLAST=1
      GO TO 130
120   LFIRST=2
      JLAST=0
130   DO 320 L=LFIRST,NI,2
      JJDIF=KBIT
      KBIT=KBIT/4
      KL=KBIT-2
      DO 140 I=1,IL1,IDIF
      KLAST=I+KL
      DO 140 K=I,KLAST,2
      K1=K+KBIT
      K2=K1+KBIT
      K3=K2+KBIT
      T=A(K2)
      A(K2)=A(K)-T
      A(K)=A(K)+T
      T=A(K2+1)
      A(K2+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
      T=A(K3)
      A(K3)=A(K1)-T
      A(K1)=A(K1)+T
      T=A(K3+1)
      A(K3+1)=A(K1+1)-T
      A(K1+1)=A(K1+1)+T
      T=A(K1)
      A(K1)=A(K)-T
      A(K)=A(K)+T
      T=A(K1+1)
      A(K1+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
      R=-A(K3+1)
      T=A(K3)
      A(K3)=A(K2)-R
      A(K2)=A(K2)+R
      A(K3+1)=A(K2+1)-T
140   A(K2+1)=A(K2+1)+T
      IF (JLAST) 310,310,150
150   JJ=JJDIF+1
      ILAST=IL+JJ
      DO 160 I=JJ,ILAST,IDIF
      KLAST=KL+I
      DO 160 K=I,KLAST,2
      K1=K+KBIT
      K2=K1+KBIT
      K3=K2+KBIT
      R=-A(K2+1)
      T=A(K2)
      A(K2)=A(K)-R
      A(K)=A(K)+R
      A(K2+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
      AWR=A(K1)-A(K1+1)
      AWI=A(K1+1)+A(K1)
      R=-A(K3)-A(K3+1)
      T=A(K3)-A(K3+1)
      A(K3)=(AWR-R)/ROOT2
      A(K3+1)=(AWI-T)/ROOT2
      A(K1)=(AWR+R)/ROOT2
      A(K1+1)=(AWI+T)/ROOT2
      T=A(K1)
      A(K1)=A(K)-T
      A(K)=A(K)+T
      T=A(K1+1)
      A(K1+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
      R=-A(K3+1)
      T=A(K3)
      A(K3)=A(K2)-R
      A(K2)=A(K2)+R
      A(K3+1)=A(K2+1)-T
160   A(K2+1)=A(K2+1)+T
      IF (JLAST-1) 310,310,170
170   JJ=JJ+JJDIF
      DO 300 J=2,JLAST
      I=INV(J+1)
      IC=NT-I
      W(1)=S(IC)
      W(2)=S(I)
      I2=2*I
      I2C=NT-I2
      IF (I2C) 200,190,180
180   W2(1)=S(I2C)
      W2(2)=S(I2)
      GO TO 210
190   W2(1)=0.
      W2(2)=1.
      GO TO 210
200   I2CC=I2C+NT
      I2C=-I2C
      W2(1)=-S(I2C)
      W2(2)=S(I2CC)
210   I3=I+I2
      I3C=NT-I3
```

```
      IF (I3C) 240,230,220
220   W3(1)=S(I3C)
      W3(2)=S(I3)
      GO TO 280
230   W3(1)=0.
      W3(2)=1.
      GO TO 280
240   I3CC=I3C+NT
      IF (I3CC) 270,260,250
250   I3C=-I3C
      W3(1)=-S(I3C)
      W3(2)=S(I3CC)
      GO TO 280
260   W3(1)=-1.
      W3(2)=0.
      GO TO 280
270   I3CCC=NT+I3CC
      I3CC=-I3CC
      W3(1)=-S(I3CCC)
      W3(2)=-S(I3CC)
280   ILAST=IL+JJ
      DO 290 I=JJ,ILAST,IDIF
      KLAST=KL+I
      DO 290 K=I,KLAST,2
      K1=K+KBIT
      K2=K1+KBIT
      K3=K2+KBIT
      R=A(K2)*W2(1)-A(K2+1)*W2(2)
      T=A(K2)*W2(2)+A(K2+1)*W2(1)
      A(K2)=A(K)-R
      A(K)=A(K)+R
      A(K2+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
      R=A(K3)*W3(1)-A(K3+1)*W3(2)
      T=A(K3)*W3(2)+A(K3+1)*W3(1)
      AWR=A(K1)*W(1)-A(K1+1)*W(2)
      AWI=A(K1)*W(2)+A(K1+1)*W(1)
      A(K3)=AWR-R
      A(K3+1)=AWI-T
      A(K1)=AWR+R
      A(K1+1)=AWI+T
      T=A(K1)
      A(K1)=A(K)-T
      A(K)=A(K)+T
      T=A(K1+1)
      A(K1+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
      R=-A(K3+1)
      T=A(K3)
      A(K3)=A(K2)-R
      A(K2)=A(K2)+R
      A(K3+1)=A(K2+1)-T
290   A(K2+1)=A(K2+1)+T
300   JJ=JJDIF+JJ
310   JLAST=4*JLAST+3
320   CONTINUE
330   CONTINUE
      NTSQ=NT*NT
      M3MT=M3-MT
      IF (M3MT) 350,340,340
340   IGO3=1
      N3VNT=N3/NT
      MINN3=NT
      GO TO 360
350   IGO3=2
      N3VNT=1
      NTVN3=NT/N3
      MINN3=N3
360   JJD3=NTSQ/N3
      M2MT=M2-MT
      IF (M2MT) 380,370,370
370   IGO2=1
      N2VNT=N2/NT
      MINN2=NT
      GO TO 390
380   IGO2=2
      N2VNT=1
      NTVN2=NT/N2
      MINN2=N2
390   JJD2=NTSQ/N2
      M1MT=M1-MT
      IF (M1MT) 410,400,400
400   IGO1=1
      N1VNT=N1/NT
      MINN1=NT
      GO TO 420
410   IGO1=2
      N1VNT=1
      NTVN1=NT/N1
      MINN1=N1
420   JJD1=NTSQ/N1
      JJ3=1
      J=1
      DO 570 JPP3=1,N3VNT
      IPP3=INV(JJ3)
      DO 560 JP3=1,MINN3
      GO TO (430,440), IGO3
430   IP3=INV(JP3)*N3VNT
      GO TO 450
440   IP3=INV(JP3)/NTVN3
450   I3=(IPP3+IP3)*N2
      JJ2=1
      DO 550 JPP2=1,N2VNT
      IPP2=INV(JJ2)+I3
      DO 550 JP2=1,MINN2
      GO TO (460,470), IGO2
460   IP2=INV(JP2)*N2VNT
      GO TO 480
470   IP2=INV(JP2)/NTVN2
480   I2=(IPP2+IP2)*N1
      JJ1=1
      DO 550 JPP1=1,N1VNT
      IPP1=INV(JJ1)+I2
      DO 540 JP1=1,MINN1
      GO TO (490,500), IGO1
490   IP1=INV(JP1)*N1VNT
      GO TO 510
500   IP1=INV(JP1)/NTVN1
510   I=2*(IPP1+IP1)+1
      IF (J-I) 520,530,530
520   T=A(I)
      A(I)=A(J)
      A(J)=T
      T=A(I+1)
```

```
      A(I+1)=A(J+1)
      A(J+1)=T
530   CONTINUE
540   J=J+2
550   JJ1=JJ1+JJ01
560   JJ2=JJ2+JJ02
570   JJ3=JJ3+JJ03
      IF (IFSET) 380,500,600
580   DO 590 I=1,NX
590   A(2*I)=-A(2*I)
600   RETURN
      END
```

```
      SUBROUTINE RFFT (A,M,INV,S,IFERR)
      DIMENSION A(1), L(3), INV(1), S(1)
      IFSET=1
      L(1)=M
      L(2)=0
      L(3)=0
      NTOT=2**M
      NTOT2=2*NTOT
      FN=NTOT
      DO 10 I=2,NTOT2,2
10    A(I)=-A(I)
      DO 20 I=1,NTOT2
20    A(I)=A(I)/FN
      CALL FFT (A,L,INV,S,IFSET,IFERR)
C
C     MOVE LAST HALF OF A(J)S DOWN ONE SLOT AND ADD A(N) AT BOTTOM TO
C     GIVE ARRAY FOR A1PRIME AND A2PRIME CALCULATION
C
      DO 30 I=1,NTOT,2
      J3=NTOT2+2-I
      A(J3)=A(J3-2)
30    A(J3+1)=A(J3-1)
      A(NTOT2+3)=A(1)
      A(NTOT2+4)=A(2)
C
C     CALCULATE A1PRIMES AND STORE IN FIRST N SLOTS
C     CALCULATE A2PRIMES AND STORE IN SECOND N SLOTS IN REVERSE ORDER
      K0=NTOT+1
      DO 40 I=1,K0,2
      K1=NTOT2-I+4
      AP1RE=.5*(A(I)+A(K1))
      AP2RE=-.5*(A(I+1)+A(K1+1))
      AP1IM=.5*(-A(I+1)+A(K1+1))
      AP2IM=-.5*(A(I)-A(K1))
      A(I)=AP1RE
      A(I+1)=AP1IM
      A(K1)=AP2RE
40    A(K1+1)=AP2IM
      NTO=NTOT/2
      NT=NTO+1
      DEL=3.1415927/FLOAT(NTOT)
      SS=SIN(DEL)
      SC=COS(DEL)
      SI=0.0
      CO=1.0
C
C     COMPUTE C(J)S FOR J=0 THRU J=N
      DO 50 I=1,NT
      K6=NTOT2-2*I+5
      AP2RE=A(K6)*CO+A(K6+1)*SI
      AP2IM=-A(K6)*SI+A(K6+1)*CO
      CIRE=.5*(A(2*I-1)+AP2RE)
      CIIM=.5*(A(2*I)+AP2IM)
      CNIRE=.5*(A(2*I-1)-AP2RE)
      CNIIM=.5*(A(2*I)-AP2IM)
      A(2*I-1)=CIRE
      A(2*I)=CIIM
      A(K6)=CNIRE
      A(K6+1)=-CNIIM
      SIS=SI
      SI=SI*SC+CO*SS
```

```
      SUBROUTINE RFSN(A,M,INV,S,IFERR)
      DIMENSION A(1),L(3),INV(1),S(1)
      L(1)=M
      L(2)=3
      L(3)=0
      NTOT=2**M
      IFSET=-1
      NTOT2=NTOT+NTOT
      FN=NTOT
      NTOT3=NTOT2+4
      DO 70 I=3,NTOT2,2
      A(I)=3.5* A(I)
   70 A(I+1)= .5*A(I+1)
      DO 60 I=1,NTOT,2
      K8=NTOT2+2-I
      A(K8)= A(K8-2)
   60 A(K8+1)=A(K8-1)
      NTO=NTOT/ 2
      NT=NTO+1
      DEL=3.14159265/FN
      SS= SIN(DEL)
      SC= COS(DEL)
      SI=0.
      CO =1.0
      DO 53 I=1,NT
      K6=NTOT2-2*I+5
      CIRE= A(2*I-1) + A(K6)
      CIIM=A(2*I)-A(K6+1)
      CNIRE=(-SI*(A(2*I)+A(K6+1))+CO*(A(2*I-1)-A(K6)))
      IF(SI)62,61,62
   62 CNIIM=(A(2*I-1)-A(K6)-CO*CNIRE)/SI
      GO TO 63
   61 CNIIM=0.
   63 A(2*I-1)=CIRE
      A(2*I)=CIIM
      A(K6)=CNIRE
      A(K6+1)=CNIIM
      SIS=SI
      SI=SI*SC+CO*SS
   53 CO=CO*SC-SIS*SS
      KO=NTOT+1
      DO 40 I=1,KO,2
      K1=NTOT2-I+4
      AP1RE=A(I)-A(K1+1)
      AP2RE=-(A(I+1)+A(K1))
      AP1IM=A(I)+A(K1+1)
      AP2IM=A(I+1)-A(K1)
      A(I)=AP1RE
      A(I+1)=AP2RE
      A(K1)=AP1IM
   40 A(K1+1)=AP2IM
      NTOP=NTOT2+2
      NTOO=NTOT+1
      A(1)=A(NTOT2+3)
      A(2)=A(NTOT2+4)
   21 DO 52 I=NTOO,NTOP,2
      A(I)=A(I+2)
   52 A(I+1)=A(I+3)
      CALL  FFT(A,L,INV,S,IFSET,IFERR)
      DO 20 I=1,NTOT2
   20 A(I)=A(I)*FN
   53 CO=CO*SC-SIS*SS
C
C     SHIFT COEFS FOR J=N/2+1 TO J=N UP ONE SLOT
      DO 63 I=1,NTOT,2
      K8=NTOT+4-I
      A(K8-2)=A(K8)
   60 A(K8-1)=A(K8+1)
      DO 70 I=3,NTOT2,2
      A(I)=2.*A(I)
   70 A(I+1)= 2.*A(I+1)
      RETURN
      END
```

```
      DO 10 I=2,NTOT2,2
   10 A(I)=-A(I)
      RETURN
      END
      END
```

ACKNOWLEDGEMENTS

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SUPPLEMENT TO COMPUTER PROGRAM SHAKE*

by

T. Udaka and J. Lysmer

September 1973

Suggested corrections are shown framed on the attached segments of subroutines SHAKIT, EARTHQ, CXSOIL, MOTION, STRT, UTPR, RESP, STRAIN, REDUCE, FFT, RFFT and RFSN of program SHAKE.

The purpose of these changes are:

1. To decrease the execution time by up to 50% depending on the type of problem to be solved.
2. To redefine the complex modulus from $G^* = G(1+2i\beta)$ to $G^* = G(1-2\beta^2+i\ 2\beta\sqrt{1-\beta^2})$.

   (This change only influences subroutine CXSOIL.)

Input and output formats are unchanged by these corrections and response values will differ only slightly from those in the published* test example, see page 16.

---

*"SHAKE A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites," by P. B. Schnabel, J. Lysmer, and H. B. Seed, Report No. EERC 72-12, Earthquake Engineering Research Center, University of California, Berkeley, December 1972.

```
C      PROGRAM SHAKE2(INPUT, OUTPUT, PUNCH)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
C    THIS PROGRAM COMPUTES RESPONSE IN A HORISONTALLY LAYERED SEMI-
C    INFINITE SYSTEM SUBJECTED TO VERTICALLY TRAVELLING SHEAR WAVES
C    THE METHOD IS BASED ON THE CONTINOUS SOLUTION TO THE SHEAR WAVE
C    EQUATION
C
C
C    PROGRAMMED BY   PER B SCHNABEL RESEARCH ASSISTANT
C                    JOHN LYSMER    ASSOCIATE PROFESSOR
C
C                                   GEOTECHNICAL ENGINEERING
C                                   UNIVERSITY OF CALIFORNIA
C                                   BERKELEY
C
C
C    PROGRAM VERSION      SHAKE1    JANUARY 1972
C                         SHAKE2    APRIL 1972
C                                   JUNE 1972
C                                   CHANGE - OPTION 7 CORRECTED
C                                          - SUBROUTINES STEPG AND FFT
C                                            ADAPTED TO UNIVAC COMPUTERS
C                                   DECEMBER 1972
C                                   CHANGE - SUBROUTINES DRCTSP AND STRAIN
C                                   SEPTEMBER 1973
C                                   CHANGE - SUBROUTINES SHAKIT,EARTHQ,
C                                            CXSOIL,MOTION,STRT,STRAIN
C                                            REDUCE,UTPR,RESP,FFT,RFFT AND
C                                            RFSN.
C                                            EXECUTION TIME REDUCED BY UP
C                                            TO 50 PERCENT.
C                                            COMPLEX SHEAR MODULUS CHANGED
C                                            FROM G(1.+I*2.*BETA)
C                                            TO G(1.-2.*BETA**2+I*2.*BETA*
C                                               SQRT(1.-BETA**2))
C
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
C
C   DEFINITIONS
C        INPUT MOTION       = MOTION READ IN FROM CARDS
C        OBJECT MOTION      = MOTION USED AS BASIS FOR COMPUTING NEW
C                             MOTIONS IN A SOIL PROFILE
C        COMPUTED MOTION    = MOTION COMPUTED ANYWHERE IN A GIVEN SOIL
C                             SOIL PROFILE FROM A GIVEN OBJECT MOTION
```

```
      SUBROUTINE SHAKIT(X,AX,AA,S,INV)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE CALLS THE DIFFERENT SEQUENCES OF OPERATION.15 DIFFERENT
C   OPERATIONS CAN BE PERFORMED AS LISTED BELOW.
```

```
      INTEGER TITLE,TP
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      DIMENSION ABSIS(10), ABSPR(10),ABSCL(10)
      DIMENSION LL(3), LT(3),LNSW(3)
      DIMENSION LLL(2), LLGS(2),LLPCH(2),LLPL(2),SK(2),LNV(2)
      DIMENSION X(300),AX(3,270),AA(2,550),S(70),INV(70)
      DIMENSION LL5(15), LT5(15), LP5(15),LP(3)
      DIMENSION IDAMP(9,11)
      DIMENSION MMM(3)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),RF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /SOILC/ MSOIL,MWL
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON /CCG/ ID(9,11), T(2049)
      COMMON/FRCUT/ NCUT,NZERO
C
      DATA IBLANK /6H      /
      DATA (ABSIS(I),I=1,10)/6H TIME  ,6HIN SEC ,6HONDS  ,7*6H      /
```

```
   71 DO 74 I = 1,MFOLD
   74 X(I) = X(I)*XF
      NEW = IN
   73 IN = NEW
      PRINT 7000, NEW , XF,DT, DTNEW
      IF(IN.NE.1) GO TO 76
      DO 77 II=1,MFOLD
      AX(1,II)=X(II)
   77 CONTINUE
   76 CONTINUE
      DT = DTNEW
      DF = 1./(MA*DT)
      GO TO 101
```

```
   10 PRINT 1010,KK
      READ 1000, IFR
      CALL REDUCE(IFR,X,AX,LL)
      MMM(1)=MX
      MMM(2)=0
      MMM(3)=0
      CALL FFT(X,MMM,INV,S,0,IFERR)
      GO TO 101
C
C * * * * * * * * *
   11 PRINT 1101,KK
      READ 1000, IFR
      CALL INCR(IFR,X,AX,LL)
      MMM(1)=MX
      MMM(2)=0
      MMM(3)=0
      CALL FFT(X,MMM,INV,S,0,IFERR)
      GO TO 101
C
C * * * * * * * * *
```

[redacted]

```
   14 PRINT 1404,KK
      READ 1000, NSKIP, NN, NSW
      NP = NP + 1
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      IF (NN.LE.0)  NN = MMA/NSKIP
      IF (NN.GT.2049)  NN = 2049
      NN =  NN*NSKIP
      N = 0
      DO 136 I=1, NN, NSKIP
      N = N + 1
      T(N) = FLOAT(I-1)*DT
  136 CONTINUE
      N = 0
      M = NN/2
      DO 130 I = 1,M
      N = N + 1
      AA(NP,N) = REAL(X(I))
      N = N + 1
      AA(NP,N) = AIMAG(X(I))
  130 CONTINUE
      IF  (NSKIP.EQ.1) GO TO 135
      N = 0
      DO 134 I = 1,NN ,NSKIP
      N = N + 1
      AA(NP,N) = AA(NP,I)
  134 CONTINUE
  135 CALL RFFT(X,MX,INV,S,IFERR,2)
      DO 131 I = 1,5
  131 ID(NP,I) = TITLE(I)
      DO 132 I = 6,11
      ID(NP,I) = IDNT(I-5)
      IF (NSW.EQ.0)  ID(NP,I)  = IBLANK
  132 CONTINUE
      IF (NSW.EQ.1) GO TO 101
      CALL PLOT(NP, N, T, AA, ABSIS, ID, 0., 2, N)
      NP = 0
      GO TO 101
```

```
      SUBROUTINE EARTHQ(X,AX,AA,S,INV)
C
C*********************************************************************
C
C    THIS ROUTINE  READS THE MOTION IN THE TIME DOMAIN, ADDS TRAILING
C    ZEROS, SCALES THE VALUES, FIND MAXIMUM VALUE AND VARIOUS PARAMETERS
C    AND TRANSFER THE MOTION INTO THE FREQUENCY DOMAIN.
[redacted]
      INTEGER TITLE
      COMPLEX X, AX
      DIMENSION XR(8)
      DIMENSION X(300),AX(3,270),AA(2,550),S(70),INV(70)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF, MX
      COMMON/FRCUT/ NCUT,NZERO
C
      PI2 = 6.28
      READ 1001, NV, MA, DT, TITLE
[redacted]

   30 X(I)  =  X(I)*XF
      XMAX  =  XM*XF
      TMAX  =  FLOAT(NXMAX-1)*DT
      PRINT 2014,XM,TMAX,XF,XMAX
C
      CALL RFFT(X,MX,INV,S,IFERR,1)
C     X(1) = 0.
C
C
C    REMOVE FREQUENCIES ABOVE FMAX AND FIND MAX. ACC. OF
C
      FREQ = 0.
      SXX = 0.
      SFX = 0.
      NCUT=0
      DO 33 I = 1,MFOLD
      IF(FREQ.LE.FMAX) GO TO 34
      NCUT=NCUT+1
      X(I)=0.0
   34 CONTINUE
      XA  =  CABS(X(I))
      SXX=  SXX + XA*XA
      SFX  =  SFX + FREQ*XA*XA
      AX(1,I)  =  X(I)
      FREQ  =  FREQ + DF
   33 CONTINUE
      SFX  =  SFX/SXX
      NCUT=MFOLD-NCUT
      NZERO=NCUT+1
      PRINT 2005,SFX
      IF (FMAX.GT.FREQ) RETURN
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      CALL XMX(X,MA,XM,NXMAX)
      DO 72 I = 1,MFOLD
   72 X(I)  =  AX(1,I)
      PRINT 2001,XM,FMAX
```

```
      SUBROUTINE CXSOIL(N1)
C
C*****************************************************************************
C
C    THIS ROUTINE CALCULATES THE COMPLEX SOIL PROPERTIES AND TRANSFER
C    FUNCTIONS FOR THE LAYERS
C
C         N1        = NUMBER OF SOIL LAYERS
C         BL        = RATIO OF CRITICAL DAMPING
C         GL        = SHEAR MODULUS
C         R         = DENSITY
C         G         = COMPLEX SHEAR MODULUS
C         V         = COMPLEX SHEAR WAVE VELOCITY
C         PLUS      = COMPLEX TRANSFER FUNCTION
C         MINUS     = COMPLEX TRANSFER FUNCTION
C
C    CODED BY PER B SCHNABEL OCT 1971
C
C*****************************************************************************
C
      COMPLEX G, V, PLUS, MINUS, MU
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
C
      N = N1 + 1
      DO 1 I = 1,N
      GIMAG=2.*BL(I)*GL(I)*SQRT(1.-BL(I)*BL(I))
      GREAL=GL(I)*(1.-2.*BL(I)*BL(I))
      G(I)=CMPLX(GREAL,GIMAG)
      V(I) = CSQRT(G(I)/R(I))
    1 CONTINUE
      DO 2 I = 1,N1
      J = I + 1
      MU = CSQRT(R(I)/R(J)*G(I)/G(J))
      PLUS(I) = (1. + MU)/2.
      MINUS(I)= (1. - MU)/2.
    2 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MOTION(NI,IN,INT,LL,LT, X,AX)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE CALCULATES THE MOTION IN ANY TWO SOIL LAYERS OR IN
C   ROCK FROM MOTION GIVEN IN ANY LAYER OR IN ROCK
C
C       NI       = NUMBER OF SOIL LAYERS EXCLUDING ROCK
C       IN       = NUMBER OF LAYER WHERE OBJECT MOTION IS GIVEN
C       INT      = MOTION TYPE
C                  IF EQ 0     OUTCROPPING LAYER
C       LL()     = NUMBER OF LAYERS WHERE OUTPUT MOTION IS WANTED
C                  MAX  3 LAYERS
C       LT()     = MOTION TYPE
C                  0 - OUTCROPPING LAYER
C                  1 - LAYER WITIN PROFILE
C       X()      = OBJECT MOTION
C       AX()     = OUTPUT MOTION
C
C
C   CODED BY PER B SCHNABEL  OCT 1970
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER LL(3), LT(3)
      INTEGER TITLE
      COMPLEX AA(3)
      COMPLEX X, AX
      COMPLEX   G, V, PLUS, MINUS
      COMPLEX E, F, EE, FF, A, EX, AIN, IPI2
      DIMENSION X(300),AX(3,270),             S(70),INV(70)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA  , MMA, DF,MX
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON/FRCUT/ NCUT,NZERO
C
C
      IPI2 = CMPLX(0., 6.28)
      DO 20 L = 1,3
      IF (LL(L) .GT. 0) AX(L,1) = X(1)
      IF(NCUT.EQ.MFOLD) GO TO 20
      DO 30 I=NZERO,MFOLD
      AX(L,I)=CMPLX(0.,0.)
   30 CONTINUE
   20 CONTINUE
      FREQ = 0.
      DO 19 I=2,NCUT
      E = 1.
      FF = 1.
      FREQ = FREQ + DF
      A = FREQ*IPI2
      DO 191 K = 1,NI
      IF (K.NE.IN) GO TO 192
```

```
      SUBROUTINE STRT( IT,N1,DGMAX,PRMUL,X,AX,AA,SF,INV)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C    THIS ROUTINE CALCULATES STRAIN IN THE MIDDLE OF EACH LAYER AND FIND
C    NEW SOIL PROPERTIES COMPATIBLE WITH THE STRAINS
C

      COMMON /SOILDG/ S(9,20), AS(9,20), BS(9,20), NV(9)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON/ERCUT/ NCUT,NZERO
      DIMENSION TMAX(20),        EMAX(20),STR(20)
      DIMENSION X( 68), AX(3, 64), AA(2,128),SF(10), INV(10)
C
      DO 43 I = 1,MFOLD
      AA(1,I) = REAL(X(I))
   43 AA(2,I) = AIMAG(X(I))
      DO 1  I = 1,MFOLD
      AX(2,I) = AX(1,I)/2.
    1 AX(3,I) = AX(2,I)
      PI2=6.283
      IPI2=CMPLX(0.,PI2)
      GT = 32.2
      DO 2 K = 1,N1
      FREQ = 0.
      X(1) = 0.
      FF = GT/(IPI2*V(K))
      EE = H(K)/2.*IPI2/V(K)
      DO 20 I=2,NCUT
      FREQ = FREQ + DF

      EX = CEXP(FREQ*EE)
      X(I) = (AX(2,I)*EX - AX(3,I)/EX)*FF/FREQ
      EX = EX*EX
      E = AX(2,I)*EX
      F = AX(3,I)/EX
      AX(2,I)= PLUS(K)*E + MINUS(K)*F
      AX(3,I)= PLUS(K)*F + MINUS(K)*E
   20 CONTINUE
      EMAX(K) = 0.
      IF(NCUT.EQ.MFOLD) GO TO 22
      DO 122 II=NZERO,MFOLD
      X(II)=CMPLX(0.,0.)
  122 CONTINUE
   22 CONTINUE
C
C    DETERMINE MAX. STRAIN BY INVERTING FOURIER TRANSFORM OF STRAIN
C    INTO THE TIME DOMAIN
C
      CALL RFSN(X,MX,INV,SF,IFERR,-2)
      CALL XMX(X,MA,XMAX,NXMAX)
C
```

```
      SUBROUTINE UTPR(KK,DPTH,LS,K2,LH,LT,X,AX,AA,S,INV)
C
C
C**********************************************************************
C
C    THIS ROUTINE TRANSFERES THE VALUES IN AX(LH, ) INTO THE TIME DOMAIN
C    IN X( ), PRINTS AND PUNCHES OUT THE RESULTS.
C

C
      FREQ = 0.
      SFX = 0.
      SXX = 0.
C    TRANSFORM VALUES IN X OR IN AX INTO THE TIMEDOMAIN
      DO 24  I = 1,MFOLD
      IF (LS.EQ.0) GO TO 241
      SAVE = X(I)
      X(I) = AX(LS,I)
      AX(LS,I) = SAVE
  241 XA = CABS(X(I))
      SXX= SXX + XA*XA
      SFX = SFX + XA*FREQ*XA
      FREQ = FREQ + DF
   24 CONTINUE
      SFX = SFX/SXX
C
      CALL RFSV(X,MX,INV,S,IFERR,-2)
C

      PUNCH 2009,(XR(J),J=1,8),I
      IF (K2 .EQ. 2) PRINT 2019, (XR(J), J = 1,8), I
      NN = 4 + NN
      N = N + 4
   26 CONTINUE
  262 CALL RFFT(X,MX,INV,S,IFERR,2)
      IF (LS.EQ.0)   RETURN
      DO 27 I = 1,MFOLD
      SAVE = AX(LS,I)
      AX(LS,I) = X(I)
   27 X(I) = SAVE
      RETURN
```

```
      SUBROUTINE RESP(LL,LN,LS,NN,X,AX,A,S,INV)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS PROGRAM READS DATA FOR RESPONSE SPECTRUM ANALYSIS
C   NECESSARY SUBROUTINES    DRCTSP,  CMPMAX, PLOT
C
C          NN        = RESPONSE SPECTRUM NUMBER
C          ND        = NUMBER OF DAMPING VALUES
C          KAV       = SWITCH
C                        EQ 0  ACCELERATION SPECTRUM
C                        EQ 1  VELOCITY SPECTRUM
C                        EQ 2  ACC. AND VEL. SPECTRUM
C          KPL       = SWITCH
C                        EQ 1  PLOT RESPONSE SPECTRA ACCORDING TO KAV
C          KP        = SWITCH
C                        EQ 0  NO PUNCHED OUTPUT
C                        NE 0  PUNCHED OUTPUT ACCORDING TO KAV
C          X         = FOURIER TRANSFORM OF OBJECT MOTION
C          AX        = FOURIER TRANSFORM OF COMPUTED MOTIONS
C          DW        = PERIOD STEPS
C          NM        = NUMBER OF EACH STEP
C          T         = PERIODS WHERE RESPONSE IS TO BE COMPUTED
C
```

```
  101 T(1) = .001
C   SAVE VALUES IN X IN AA
      DO 11 I = 1,MFOLD
      A(1,I) = REAL(X(I))
      A(2,I) = AIMAG(X(I))
      IF (LS.EQ.0) GO TO 11
      X(I) = AX(LS,I)
   11 CONTINUE
C
C   TRANSFORM VALUES IN X OR AX INTO THE TIME DOMAIN
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      DO 13 L = 1,ND
      IF (NN.GE.5)  NN= 0
      NN = NN + 1
      DO 131 I = 1,5
  131 ID(NN,I) = TITLE(I)
      DO 132 I = 6,11
      ID(NN,I) = IDNT(I-5)
      IF (LS.EQ.0) ID(NN,I) = IBLANK
  132 CONTINUE
```

```
      SUBROUTINE STRAIN( LL, LGS, LPCH, LPL,LNV,SK,X,AX,AA,N1,S,INV)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C    THIS SUBROUTINE COMPUTES STRAIN AND/OR STRESS TIME-HISTORY AT THE
C    TOP OF ANY LAYER FOR ACCELERATION HISTORY KNOWN IN ANY LAYER
C    TWO RESPONSE HISTORIES ARE COMPUTED IN ONE RUN
C

      INTEGER TITLE,TP
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      COMPLEX E,F,EE, A,AH,IPI2, AE,AF,EX,AI
      DIMENSION ABSIS(10)
      DIMENSION AE(2), AF(2)
      DIMENSION X(1), AX(3,1), AA(2,1),S(1),INV(1)
      DIMENSION  LL(2),  LGS(2), LPCH(2), LPL(2),SK(2),LNV(2)
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /CCG/ ID(9,11),T(2049)
      COMMON/FRCUT/ NCUT,NZERO
C
      IPI2 = CMPLX(0.,6.283)
      GT = 32.2
      AX(2,1) = 0.
      AX(3,1) = 0.
      FREQ = 0.
      DATA (ABSIS(I), I=1,10)/6H TIME ,6HIN SEC , 8*6H      /
      AI = GT/IPI2
C
C   STARTING AT THE SURFACE THE STRAIN IS COMPUTED SUCCESSIVELY DOWNWARD
C   FOR EACH FREQUENCY
      DO 1 I=2,NCUT
      E = AX(1,I)/2.

      DO 2 I = 1,MFOLD
    2 AX(1,I) = X(I)
      DO 3 L = 1,2
      IF (LL(L).EQ.0) GO TO 3
      X(1) = 0.
      DO 31 I=2,NCUT
   31 X(I) = AX(L+1,I)
      IF(NCUT.EQ.MFOLD) GO TO 33
      DO 34 II=NZERO,MFOLD
      X(II)=CMPLX(0.,0.)
   34 CONTINUE
   33 CONTINUE
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      DO 32 I =1,MFOLD
      AA(L,2*I-1) =REAL(X(I))*100.
   32 AA(L,2*I) = AIMAG(X(I))*100.
    3 CONTINUE
```

```
      SUBROUTINE REDUCE(IFR,X,AX,LL)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C    THIS ROUTINE INCREASES TIME INTERVAL AND REDUCES NUMBER OF VALUES
C
C
C         IFR    =   DIVIDING FACTOR ON LENGTH OF FRECORD
C                    MULTIPLICATION FACTOR ON TIMESTEP
C                    MUST BE A POWER OF 2.
C         DT     =   TIMESTEP IN SEC.
C         DF     =   FREQUENCY STEP IN C/SEC.
C         MA     =   NUMBER OF POINTS USED IN FOURIER TRANSFORM
C         X      =   FOURIER TRANSFORM OF OBJECT MOTION
C         AX     =   FOURIER TRANSFORM OF COMPUTED MOTICNS
C
C
C   CODED BY PER B. SCHNABEL DEC. 1970.
C   MODIFIED SEPT. 1971
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TITLE
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON/FRCUT/ NCUT,NZERO
      COMPLEX X, AX
      DIMENSION X( 68), AX(3, 64), LL(3)
      F1 = .5/DT
      FR = FLOAT(IFR)
      DT = DT*FR
      MA = MA/IFR
      MMA = MMA/IFR
      MA2 = MA + 2
      MFOLD = MA2/2
      N = MFOLD + 1
      DO 12 I = MFOLD,N
      X(I) = 0.
C
      DO 12 L = 1,3
      IF (LL(L).LE.0) GO TO 12
      AX(L,I) = 0.
   12 CONTINUE
      MFOLD = MFOLD + 1
      F2 = .5/DT
      PRINT 1000,F1,F2,DT, MA
      FMA = FLOAT(MA)
      MX = (ALOG10(FMA)/ALOG10(2.))-1.
      IF (MA.LT.2**(MX+1)) MX = MX+1
      IF(NCUT.LE.MFOLD) GO TO 15
      NCUT=MFOLD
   15 CONTINUE
      RETURN
```

```
      SUBROUTINE FFT (A,M,INV,S,IFSET,IFERR)
      DIMENSION A(1),INV(1),S(1),N(3),M(3),NP(3),W(2),W2(2),W3(2)
      EQUIVALENCE (N1,N(1)), (N2,N(2)), (N3,N(3))
      M1=M(1)
      M2=M(2)
      M3=M(3)
      MTT=M1-2
      MT=MAX0(2,MTT)
      NT=2**MT
10    IF (IABS(IFSET)-1) 610,610,20
610   MT=MAX0(M(1),M(2),M(3))-2
      MT=MAX0(2,MT)
      IF (MT-20) 630,630,620
620   IFERR=1
      GO TO 600
630   IFERR=0

30    IFERR=1
      PRINT 1000
      STOP
 1000 FORMAT(31H --- ERROR IN FOURIER TRANSFORM  )
40    IFERR=0
C     M1=M(1)
C     M2=M(2)
C     M3=M(3)
      N1=2**M1
      N2=2**M2
      N3=2**M3
      IF (IFSET) 50,50,70
50    NX=N1*N2*N3
      FN=NX
      DO 60 I=1,NX
      A(2*I-1)=A(2*I-1)/FN
60    A(2*I)=-A(2*I)/FN
70    NP(1)=N1*2
      NP(2)=NP(1)*N2
      NP(3)=NP(2)*N3
      DO 330 ID=1,3
      IL=NP(3)-NP(ID)
      IL1=IL+1
```

```
      SUBROUTINE RFFT (A,M,INV,S,IFERR,IFSET)
      DIMENSION A(1), L(3), INV(1), S(1)
C     IFSET=1
      L(1)=M
      L(2)=0
      L(3)=0
      NTOT=2**M
      NTOT2= 2*NTOT
      FN=NTOT
      DO 10 I=2,NTOT2,2
10    A(I)=-A(I)
      DO 20 I=1,NTOT2
20    A(I)=A(I)/FN
      CALL FFT (A,L,INV,S,IFSET,IFERR)
C
C     MOVE LAST HALF OF A(J)S DOWN ONE SLOT AND ADD A(N) AT BOTTOM TO
C     GIVE ARRAY FOR A1PRIME AND A2PRIME CALCULATION
C
```

```
      SUBROUTINE RFSN (A,M,INV,S,IFERR,IFSET)
      DIMENSION A(1),L(3),INV(1),S(1)
      L(1)=M
      L(2)=0
      L(3)=0
      NTOT=2**M
      IFSET=-1
      NTOT2=NTOT+NTOT
      NN=NTOT2+2
      A(NN+2)=A(NN)
      A(NN+1)=A(NN-1)
      FN=NTOT
      NTOT3=NTOT2+4
      DO 70 I=3,NTOT2,2
      A(I)=0.5* A(I)
   70 A(I+1)= .5*A(I+1)
      DO 60 I=1,NTOT,2
      K8=NTOT2+2-I
      A(K8)= A(K8-2)
   60 A(K8+1)=A(K8-1)
      NTO=NTOT/ 2
      NT=NTO+1
      DEL=3.14159265/FN
      SS= SIN(DEL)
      SC= COS(DEL)
      SI=0.
      CO =1.0
      DO 50 I=1,NT
```

COMPARISON BETWEEN ORIGINAL AND NEW RESULTS

The redefinition of the complex modulus G^* from

$$G^* = G(1 + 2i\beta)$$

where β is the fraction of critical damping to the improved value

$$G^* = G(1 - 2\beta^2 + 2i\beta\sqrt{1 - \beta^2})$$

slightly changes the response values computed by program SHAKE. The following table shows the influence on maximum accelerations through the profile, see page 50 of the original report*.

Depth	Original Max. Acc.	New Max. Acc.
0.0	0.09377	0.09878
7.0	0.09259	0.09758
20.0	0.05934	0.05942
30.0	0.05487	0.05540
42.0	0.05042	0.05037
62.0	0.04666	0.04667
80.0	0.03195	0.03140
100.0	0.02423	0.02364
120.0	0.01793	0.01763

all other differences observed were of similar or smaller relative magnitude.