EARTHQUAKE ENGINEERING RESEARCH CENTER

MASH
A COMPUTER PROGRAM FOR THE NON-LINEAR ANALYSIS OF VERTICALLY PROPAGATING SHEAR WAVES IN HORIZONTALLY LAYERED DEPOSITS

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16. Abstracts

The computer program MASH is designed to analyze the dynamic response of a deposit of horizontal soil layers subjected to earthquake excitation. The deposit is discretized into a series of one-dimensional constant strain elements and the equations of motion are integrated with respect to time by the cubic inertia method. The soil material may be either visco-elastic or non-linear and modelled into the Davidenkov system of soil property expressions. The program may be used in conjunction with the program APOLLO to perform effective stress response analyses of soil deposits in which pore pressures are generated and dissipated during and following the period of earthquake shaking. An example of this type of analysis, incorporating non-linear soil behavior and pore pressure effects is presented in the report.

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MASH
A COMPUTER PROGRAM FOR THE NON-LINEAR ANALYSIS OF VERTICALLY PROPAGATING SHEAR WAVES IN HORIZONTALLY LAYERED DEPOSITS

by Philippe P. Martin[1] and H. Bolton Seed[2]

1. INTRODUCTION

There are many methods available for the direct integration of the equations of motion of lumped parameter structural systems or continuous systems. Furthermore, several procedures have recently been developed for analyzing the stability and accuracy of direct integration schemes which are governed by linear integration operators [1, 2, 3].

At the present time (1978), all dynamic analyses of complex non-linear structural systems must be performed using step-by-step integration techniques. Within each time step, the structural properties of the system are assumed to be constant, which is equivalent to using a linear integration operator for each step. Accordingly, the conclusions derived from the analysis of linear operators still apply when these operators are used for the study of non-linear systems. More research is needed to develop the concept of non-linear operators and procedures, and to study their properties accordingly.

The nature of the equations governing the dynamic response of a physical system depends on the mathematical representation of this system. If the physical system is modeled as a visco-elastic continuum, the equation of motion is the well-known wave equation. For a one-dimensional problem

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this equation is

$$G \frac{\partial^2 u}{\partial y^2} + \eta \frac{\partial^3 u}{\partial y^2 \partial t} + \rho \frac{\partial^2 u}{\partial t^2} = P(t) \qquad (1)$$

where

G is the shear modulus of the material,

η is the viscosity,

ρ is the mass density,

$u(y,t)$ is the relative particle displacement,

$P(t)$ is the load at time t.

The method of characteristics has been successfully used (4) to solve equation (1) with non-linear soil models.

The second approach is to discretize the physical system into a multi-degree-of-freedom system. For such a representation, the equation of motion is

$$M\ddot{u} + C\dot{u} + Ku = R \qquad (2)$$

where

M is the mass matrix,

C is the damping matrix,

K is the stiffness matrix,

$u, \dot{u}, \ddot{u}$ are displacement, velocity, and acceleration vectors, respectively, and

R is the load vector.

This second approach has been selected to set up a non-linear method for the dynamic analysis of ground response.

The two features of this method are:

1. The step-by-step integration algorithm used to solve equation (2), referred to subsequently as Argyris' 3rd order inertia method [5, 6, 7].
2. The non-linear material model simulating soil behavior under dynamic loading, referred to as the Davidenkov model [8, 9].

2. THE DISCRETIZED SYSTEM

2.1 Linear Operator

The simplest discretization of a continuum is the one-degree-of-freedom oscillator, as shown in Fig. 1a. The role played by this oscillator in linear structural dynamics is most important. Even the most sophisticated multi-degree-of-freedom systems may be considered as a superposition of particular simple damped oscillators.

The equation of motion of the simple damped oscillator is

$$M\ddot{u} + C\dot{u} + Ku = p(t) \tag{3}$$

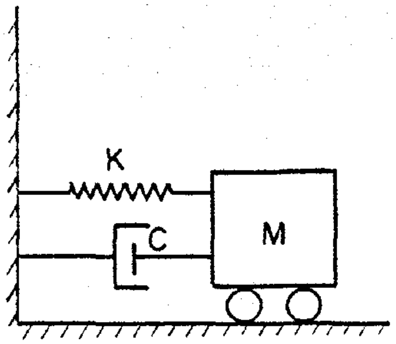
with the same notations as used above.

The use of a step-by-step integration algorithm to solve the equation of motion (3) is equivalent to the application of a linear operator on the unknown quantities of this system. The equation of motion is a second order equation; therefore, the problem is fully described with two initial conditions, e.g., displacement and velocity. A step-by-step integration in the time domain consists of forming a linear operator [L], such as

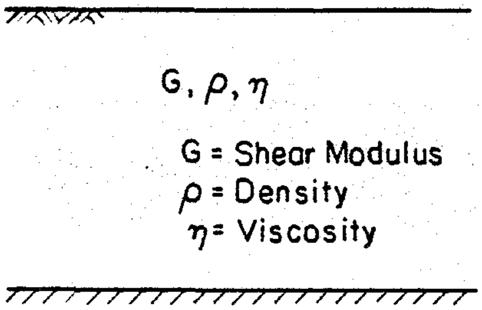
$$\{y\}_1 = [L]\,\{y\}_0 \tag{4}$$

where

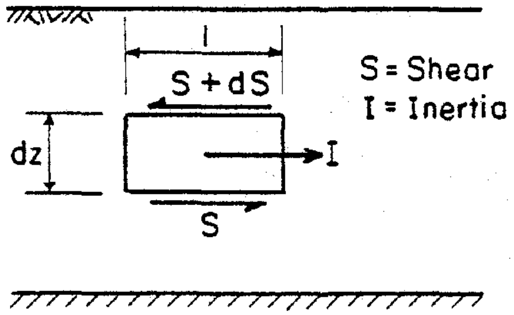
$$\{y\}_1 = \begin{bmatrix} u_1 \\ \dot{u}_1 \end{bmatrix}$$ u_1 and $\dot{u}_1$ are the displacement and velocity, respectively, at the end of the time step;



(a) Simple Damped Oscillator



(b) Continuum Representation



(c) Element Equilibrium

Fig. 1 SYSTEM REPRESENTATION.

$$\{y\}_0 = \begin{bmatrix} u_0 \\ \dot{u}_0 \end{bmatrix}$$ u_0 and $\dot{u}_0$ are the displacement and velocity, respectively, at the beginning of the time step.

2.2 Stability and Accuracy of a Linear Operator

Stability and accuracy are the two criteria which must be fulfilled for any method of integration.

1. Stability.--The stability of a method is directly related to the magnitude of the eigenvalues of its associated operators [2]. Stability is ensured only if the magnitude of the eigenvalues (also called spectral radius) is less than or equal to unity.
2. Accuracy.--In order to check on the accuracy of a given method, a reference solution is needed. As several authors have observed [1, 7], two types of error may occur:
    - a mathematical damping, leading ultimately to the extinction of the response;
    - an increase in the period of oscillation of the response of the system.

The most straightforward solution which gives access to easy reference for checking the accuracy of different methods of integration is the free motion of an undamped linear oscillator. Furthermore, it is important to derive first the exact linear operator for the simple undamped oscillator. It has been shown [9] that all the linear operators associated with the various existing methods of direct integration approximate to a certain degree the exact operator which is derived below.

2.3 The Undamped Linear Oscillator

The equation of motion of the undamped linear oscillator in free oscillation is

$$\ddot{u} + \omega^2 u = 0 \tag{5}$$

where u is the displacement coordinate and each dot above u denotes one order of differentiation with respect to time; ω is the natural frequency of the oscillator.

Let u_1 = u at time $t_1 = t_0 + \Delta t$, and u_0 = u at time t_0. It can be shown that displacement and velocity at time t_1 are related to the same at time t_0 by the equation

$$\begin{bmatrix} u_1 \\ \dot{u}_1 \end{bmatrix} = \begin{bmatrix} \cos\omega\Delta t & \frac{1}{\omega}\sin\omega\Delta t \\ -\omega\sin\omega\Delta t & \cos\omega\Delta t \end{bmatrix} \begin{bmatrix} u_0 \\ \dot{u}_0 \end{bmatrix} \tag{6}$$

It is convenient to define the quantity

$$\theta = \omega\Delta t \tag{7}$$

which when substituted into equation (6) yields the exact linear operator appearing in equation (4):

$$[L]_0 \equiv \begin{bmatrix} \cos\theta & \frac{\sin\theta}{\omega} \\ -\omega\sin\theta & \cos\theta \end{bmatrix} \tag{8}$$

The eigenvalues of $[L]_0$ are

$$\lambda = e^{\pm i\theta} \tag{9}$$

where $\theta = \omega\Delta t$.

Hence, the spectral radius is exactly $|\lambda| = 1$.

It may be noted:

1. The fact that the spectral radius is unity implies that the free motion of such an oscillator is stable and undamped.
2. The fact that the eigenvalues have an imaginary part implies that

the motion is oscillatory, and it can be added that the frequency of oscillation is

$$\omega = \frac{\theta}{\Delta t} \tag{10}$$

This result is of special importance for the study of the period elongations generated by any particular method of integration.

3. CUBIC INERTIA INTEGRATION METHOD (ARGYRIS)

The method presented herein was developed by J. H. Argyris, P. C. Dunne, and T. Angelopoulos [6, 7].

3.1 Basic Approach and Integration Algorithm

The basic assumption is that the relative inertia force, $R = M\ddot{u}$, is considered to vary as a cubic function of time within the time step of integration. Four constants are needed to determine uniquely that cubic. It is natural to use the values of R at the beginning and the end of the time steps as well as the values of its first time derivative at both ends of the time step. Hence,

$$R = H_{00}R_0 + H_{10}\dot{R}_0 + H_{01}R_1 + H_{11}\dot{R}_1 \tag{11}$$

where H_{00}, H_{10}, H_{01}, and H_{11} are the Hermitian polynomials of third order, i.e.,

$$\begin{aligned} H_{00} &= 1 - 3s^2 + 2s^3, \; H_{10} = (s - 2s^2 + s^3)\Delta t \\ H_{01} &= 3s^2 - 2s^3 \;, \quad H_{11} = (-s^2 + s^3)\Delta t \end{aligned} \tag{12}$$

and $t = s\Delta t$, $0 \leq s \leq 1$.

By two successive integrations with respect to time of the equation $M\ddot{u} = R$, it is possible to solve for the increments of relative velocity and relative displacement within the time step.

$$M\Delta\dot{u} = \frac{\Delta t}{12}\,(6R_0 + \Delta t\dot{R}_0 + 6R_1 - \Delta t\dot{R}_1), \tag{13}$$

$$M\Delta u = M\dot{u}_0\Delta t + \frac{\Delta t^2}{60}\,(21R_0 + 3\Delta t\dot{R}_0 + 9R_1 - 2\Delta t\dot{R}_1)\ , \tag{14}$$

where

$$\begin{cases} \Delta\dot{u} = \dot{u}_1 - \dot{u}_0 \\ \Delta u = u_1 - u_0 \end{cases}$$

Equations (13) and (14) are the basic relations of the cubic inertia integration algorithm.

3.2 Application to the Simple Undamped Oscillator

Consider the oscillator shown in Fig. 1a for which the equation of motion is

$$\ddot{u} + \omega^2 u = 0 \quad ,$$

where

$$\omega^2 = \frac{K}{M} \quad .$$

Since $R \equiv M\ddot{u}$ by definition, one can express R and $\dot{R}$ at both ends of the time steps as

$$\begin{aligned} \frac{R_0}{M} &= -\omega^2 u_0 \quad , \qquad \frac{R_1}{M} = -\omega^2 u_1 \\ \frac{\dot{R}_0}{M} &= -\omega^2 \dot{u}_0 \quad , \qquad \frac{\dot{R}_1}{M} = -\omega^2 \dot{u}_1 \quad . \end{aligned} \tag{15}$$

By substituting the relations (15) into (13) and (14), one derives

$$\begin{bmatrix} 1 + \frac{3}{20}\,\theta^2 & -\frac{1}{30}\,\frac{\theta^3}{\omega} \\ \frac{1}{2}\,\omega\theta & 1 - \frac{1}{12}\,\theta^2 \end{bmatrix} \begin{bmatrix} u_1 \\ \dot{u}_1 \end{bmatrix} = \begin{bmatrix} 1 - \frac{7}{20}\,\theta^2 & \frac{\theta}{\omega} - \frac{1}{20}\,\frac{\theta^3}{\omega} \\ -\frac{1}{2}\,\omega\theta & 1 - \frac{1}{12}\,\theta^2 \end{bmatrix} \begin{bmatrix} u_0 \\ \dot{u}_0 \end{bmatrix} \qquad (16)$$

where

$$\theta = \omega \Delta t .$$

The linear relation (16) is of the form

$$[A]\{Y\}_1 = [B]\{Y\}_0$$

or

$$\{Y\}_1 = [L]\{Y\}_0$$

and

$$[L] = \frac{1}{1 + \frac{1}{15}\,\theta^2 + \frac{1}{240}\,\theta^4} \begin{bmatrix} 1 - \frac{13}{30}\theta^2 + \frac{1}{80}\theta^4 & \frac{\theta}{\omega}(1 - \frac{1}{10}\theta^2 + \frac{1}{720}\,\theta^4) \\ -\omega\theta(1 - \frac{1}{10}\,\theta^2) & 1 - \frac{13}{30}\,\theta^2 + \frac{1}{80}\,\theta^4 \end{bmatrix} \qquad (17)$$

The eigenvalues of [L] are roots of the quadratic characteristic equation:

$$(1 - \frac{13}{30}\,\theta^2 + \frac{1}{80}\,\theta^4 - \lambda)^2 + \theta^2(1 - \frac{1}{10}\theta^2)(1 - \frac{1}{10}\,\theta^2 + \frac{1}{720}\,\theta^4) = 0 \qquad (18)$$

It can be shown [9] from equation (18) that

$$\det\,[L] = 1 \qquad (19)$$

and that a necessary and sufficient condition for roots of the form $\lambda = R\,e^{\pm i\phi}$ is that

$$(1 - \frac{1}{10}\,\theta^2)(1 - \frac{1}{10}\,\theta^2 + \frac{1}{720}\,\theta^4) > 0 \quad .$$

That is,

$$\theta^2 < 10 \; . \qquad (20)$$

Then, according to equation (19), $R \equiv 1$.

Accordingly, it may be concluded that:

1. Equation (19) shows that no artificial damping is introduced by the cubic inertia method of Argyris.

2. The method is stable only for time steps which satisfy the relation $\theta^2 < 10$, i.e.,

$$\frac{\omega\Delta t}{2\pi} < 0.50 \ .$$

3. The period elongation is given by

$$PE = (\frac{\theta}{\phi} - 1) \times 100 \qquad (21)$$

in %

where $$\tan\phi = \frac{\theta\sqrt{(1 - \frac{1}{10}\theta^2)(1 - \frac{1}{10}\theta^2 + \frac{1}{720}\theta^4)}}{1 - \frac{13}{30}\theta^2 + \frac{1}{80}\theta^4} \qquad (22)$$

Table 1 shows how the period elongations from the cubic inertia method compare to the linear acceleration method [2]. It is also shown in graphic form in Fig. 2.

For $\Delta t/T = 0.2$, PE = 0.16% by the cubic inertia method compared with PE = 6.0% by the linear acceleration method. Therefore, it appears that even for relatively large values of the time step, the period elongation associated with [L] is kept to a minimum.

4. For small values of θ, it can be shown that the operator [L], defined by equation (17), approximates the exact operator, $[L]_0$, derived in equation (8). By dividing the coefficients of the matrix of equation (17) by the polynomial $1 + \frac{1}{15}\theta^2 + \frac{1}{240}\theta^4$, one finds

Table 1. Period Elongations, PE% = 100($\theta/\phi - 1$), for Different Time-Stepping Algorithms Applied to Simple Undamped Oscillator

$\Delta t/T = \theta/2\pi$	Linear Acceleration	Inertia 3rd Order (Argyris)	Inertia 5th Order (Argyris)
0.01	0.016	0.000	0.000
0.02	0.066	0.000	0.000
0.05	0.408	0.001	0.000
0.10	1.60	0.011	0.000
0.20	5.91	0.159	0.002
0.30	11.7	0.722	0.020
0.40	17.5	1.93	0.099
0.50	20.0	2.18	0.133

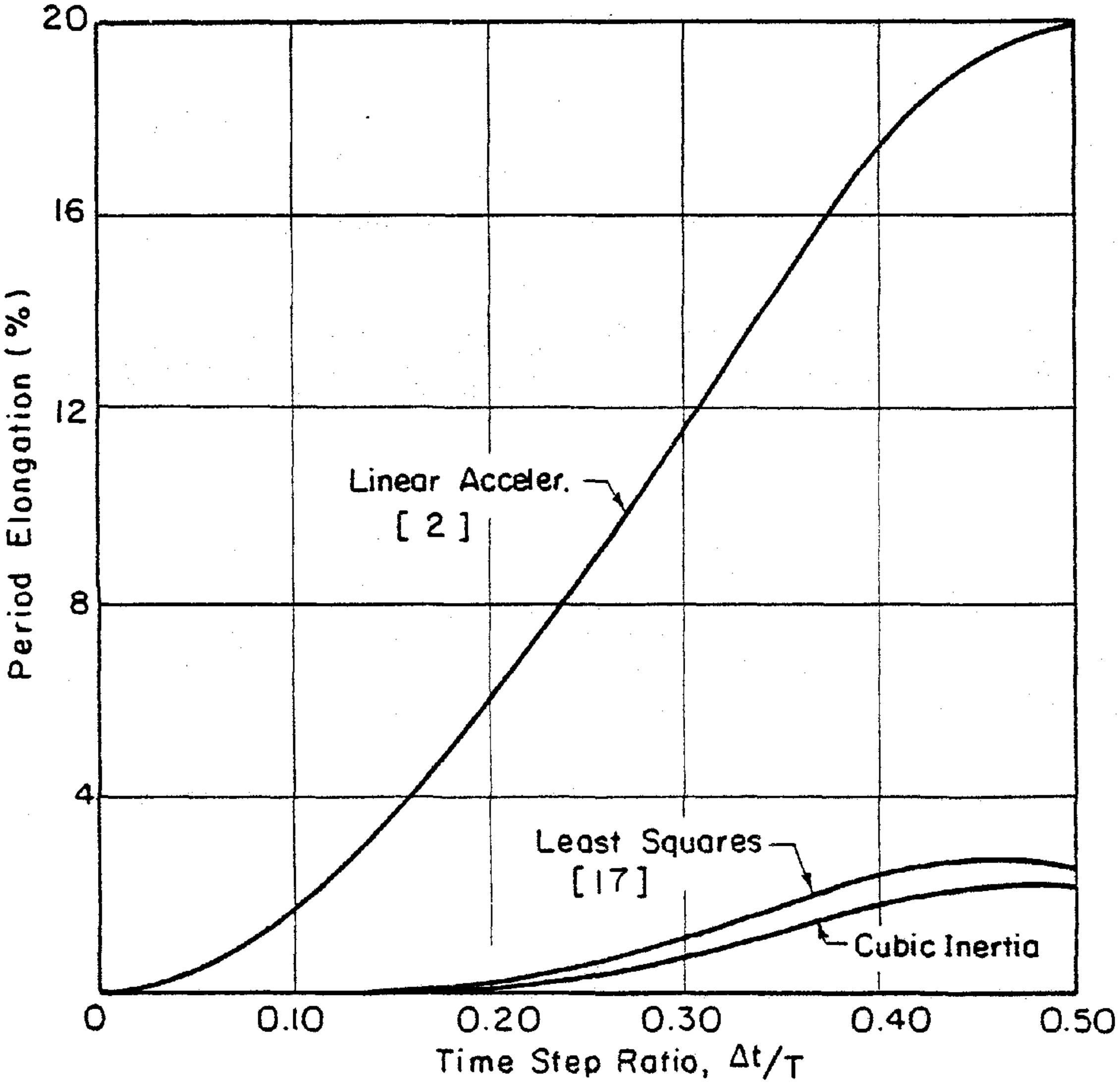


Fig. 2 PERIOD ELONGATIONS OF THE RESPONSE OF A SIMPLE UNDAMPED OSCILLATOR (in Pct.).

$$[L] \simeq \begin{bmatrix} 1 - \frac{\theta^2}{2} + \frac{\theta^4}{24} - \frac{\theta^6}{1440} & \frac{1}{\omega}(\theta - \frac{\theta^3}{6} + \frac{\theta^5}{120} + \frac{\theta^7}{7200} \\ -\omega(\theta - \frac{\theta^3}{6} + \frac{\theta^5}{144}) & 1 - \frac{\theta^2}{2} + \frac{\theta^4}{24} - \frac{\theta^6}{1440} \end{bmatrix}$$

Similarly, for small values of θ, the exact linear operator of the simple undamped oscillator may be written

$$[L]_0 \simeq \begin{bmatrix} 1 - \frac{\theta^2}{2} + \frac{\theta^4}{24} - \frac{\theta^6}{720} & \frac{1}{\omega}(\theta - \frac{\theta^3}{6} + \frac{\theta^5}{120} - \frac{\theta^7}{5040}) \\ -\omega(\theta - \frac{\theta^2}{6} + \frac{\theta^5}{120}) & 1 - \frac{\theta^2}{2} + \frac{\theta^4}{24} - \frac{\theta^6}{720} \end{bmatrix}$$

The error operator is defined as

$$[L]_E = [L] - [L]_0 \quad ,$$

where

$$[L]_E = \begin{bmatrix} \frac{\theta^6}{1440} & \frac{1}{\omega} \frac{17}{50400} \theta^7 \\ -\omega \frac{-\theta^5}{720} & \frac{\theta^6}{1440} \end{bmatrix}$$

Therefore, the operator, $[L]$, approximates the exact operator, $[L]_0$, up to the fourth order inclusive in θ.

Consequently, the cubic inertia method was chosen to study the dynamic response of non-linear discretized systems representing horizontal soil layers. Indeed, as far as undamped simple oscillators are concerned, the cubic inertia method has a better accuracy than the linear acceleration method for the same time step. Furthermore, for multi-degree-of-freedom systems the mass matrix is the only matrix which needs to be inverted in that procedure.

3.3 Implicit Formulation of the Cubic Inertia Method

In this section the method is studied in connection with a finite element approach to solving the problem of the dynamic response of horizontally layered soil deposits.

The finite element model consists of constant strain one-dimensional elements with masses lumped at the nodes. The procedure has been programmed using an implicit formulation of the time-stepping cubic inertia algorithm into a computer program named MASH (Martin/Seed Analysis of Shear waves in Horizontally layered deposits). The structure of the program MASH and its user's manual are presented in Section 5.

An implicit formulation of the time-stepping algorithm was found to be most advantageous when used with non-linear materials. As shown by Argyris et al., the convergence speed in the iterative procedure is a function of the ratio of the time increment to the period of the elements, and also a function of the viscosity of the materials of the deposit. Two studies were made to determine the optimum value of the ratio $\Delta t/T$ to be used in practice and the optimum spatial discretization of a profile into finite elements:

1. a study of the iteration matrix associated with a simple damped oscillator,
2. a study of the accuracy of the computed response of a deposit of visco-linear material with a natural frequency of 2.5 cps to harmonic excitations with frequencies ranging between 1 cps and 10 cps.

3.3.1 Convergence and Iteration Matrix

With the usual notations, the equation of motion of a simple damped oscillator is

$$m\ddot{u} + c\dot{u} + ku = p \tag{23}$$

The basic equations of the cubic inertia algorithm have been expressed previously as:

$$\Delta\dot{u} = \frac{\Delta t}{12m}\,(6\,R_o + \Delta t\,\dot{R}_o + 6\,R_1 - \Delta t\,\dot{R}_1) \tag{24}$$

$$\Delta u = \Delta t\dot{u}_o + \frac{\Delta t^2}{60m}\,(21\,R_o + 3\,\Delta t\,\dot{R}_o + 9\,R_1 - 2\,\Delta t\,\dot{R}_1) \tag{25}$$

The implicit algorithm consists of assuming values for R_1 and $\dot{R}_1$ in equations (24) and (25) and computing a new set of values for R_1 and $\dot{R}_1$ by using equation (23) and its first time derivative.

The expressions for $\dot{u}_1$ and u_1 are obtained from equations (24) and (25) as follows:

$$\dot{u}_1 = \frac{\Delta t}{2m}\,R_1 - \frac{\Delta t^2}{12m}\,\dot{R}_1 + F_o \tag{26}$$

$$u_1 = \frac{3\Delta t^2}{20m}\,R_1 - \frac{\Delta t^3}{30m}\,\dot{R}_1 + G_o \quad . \tag{27}$$

And the new expressions for $\dot{R}_1$ and R_1 are obtained then by equation (23):

$$\dot{R}_1 = -C\,\ddot{u}_1 - k\,\dot{u}_1 + \dot{P} \tag{28}$$

$$R_1 = -C\,\dot{u}_1 - k\,u_1 + P \quad . \tag{29}$$

Defining $\omega^2 = k/m$, $2\omega\beta = c/m$ and $\theta = \omega\Delta t$, equations (28) and (29) may be rewritten as

$$\begin{bmatrix} \dot{R}_1 \\ R_1 \end{bmatrix} = [A] \begin{bmatrix} \dot{R}_1 \\ R_1 \end{bmatrix} + \{B\} \tag{30}$$

where [A] is the iteration matrix and {B} a known load vector.

The expression for the iteration matrix [A] is

$$[A] = \begin{bmatrix} \frac{\theta^2}{12} & -\omega(\frac{1}{2}\theta + 2\beta) \\ \frac{1}{\omega}(\frac{1}{30}\theta^3 + \frac{1}{6}\beta\theta^2) & -(\frac{3}{20}\theta^2 + \theta\beta) \end{bmatrix} \tag{31}$$

For an undamped system, the spectral radius of this iteration matrix is

$$|\lambda|_A = 0.6455\ \theta^2 \quad . \tag{32}$$

This value agrees with the findings of Argyris et al. [6] and corresponds to a stability limit of $\theta^2 = 15.5$ for the implicit as compared to the $\theta^2 = 10.0$ limit found for the explicit algorithm in equation (20). This implies that when the ratio $\Delta t/T$ is less than one-half, the spectral radius of equation (32) is less than 0.65, which insures a rapid convergence of the implicit iterative procedure.

Figure 3 shows that the introduction of viscosity into a simple oscillator increases the spectral radius of the iteration matrix. In the figure the variation of $|\lambda|_A$ is plotted at fixed ratios of $\Delta t/T$ versus the normalized viscosity η/GT where T is the natural period of the oscillator. The figure shows that for the time step ratio $\Delta t/T = 0.2$, the implicit algorithm defined by equations (24) and (25) is convergent only if the viscosity satisfies the relation $\eta/GT < 0.4$.

It has been shown [9] that the curves of Fig. 3 did apply approximately to multi-degree-of-freedom systems provided the period T is replaced by the minimum natural period for the discretized sytem whose expression is

$$T_{min} = \frac{\pi h}{v_s} \tag{33}$$

where v_s is the shear wave velocity within each element and h the height of the element.

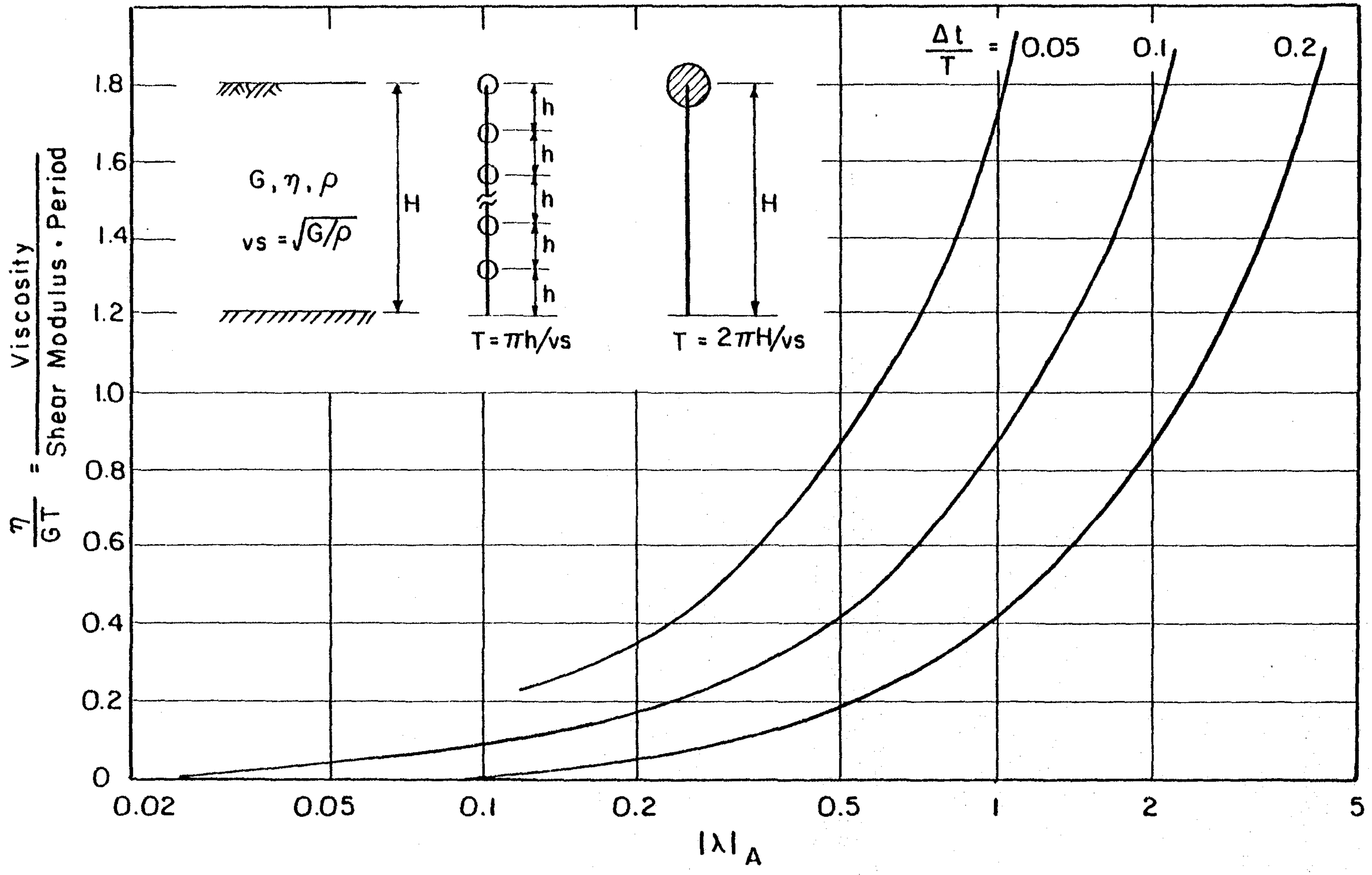


Fig. 3 RADIUS OF ITERATION MATRIX IN CUBIC INERTIA METHOD.

Let N be the number of equal size elements in the profile shown in Fig. 3 and β the fraction of critical viscous damping in that profile. It can be shown that the convergence criterion may be roughly approximated by:

$$\frac{\Delta t}{T_{min}} < \frac{0.2}{\beta N} \tag{34}$$

for viscously damped systems.

As an example, the maximum possible time step ratio to analyze a 100-element profile with $\beta = 5\%$ is approximately $\Delta t/T_{min} = 0.04$.

Argyris et al. have determined a termination criterion for the iterations and computed the corresponding errors on the computed acceleration, velocity, and displacement. The termination criterion is written as

$$\text{Euclidian Norm } ||\dot{R}_1^{n+1} - \dot{R}_1^{n}|| < \dot{\varepsilon} \tag{35}$$

Argyris et al. showed that the norms of the error vectors on acceleration, velocity and displacement may also be written as functions of $\dot{\varepsilon}$:

$$\text{Error }(\ddot{u}) < \frac{\Delta t}{6} ||\, M^{-1} ||\, \dot{\varepsilon}$$

$$\text{Error }(\dot{u}) < \frac{\Delta t^2}{6} ||\, M^{-1} ||\, \dot{\varepsilon}$$

$$\text{Error }(u) < \frac{7}{120} \Delta t^3 \, ||M^{-1}||\, \dot{\varepsilon} \tag{36}$$

where $||M^{-1}||$ is the norm of the inverse of the mass matrix.

In practice, $||M^{-1}|| \simeq \frac{1}{\rho h}$ where h is the height of an element and ρ the density of the material. Using equation (33), an upper bound to the error vector on accelerations is obtained as:

$$\text{Error } (\ddot{u}) < \frac{\Delta t}{T_{min}} \frac{\pi}{6\rho v_s} \dot{\varepsilon} \qquad (37)$$

If $v_s = 1000$ ft/sec and $\gamma = 110$ lbs/cu ft, the inequality (37) leads to the dimensionless relationship

$$\text{Error } (\frac{\ddot{u}}{g}) < 10^{-2} \frac{\Delta t}{T} \dot{\varepsilon} \quad . \qquad (38)$$

When using $\Delta t/T = 0.2$ and $\dot{\varepsilon} = 0.1$, an upper bound on the norm of the error of accelerations is

$$\text{Error } (\frac{\ddot{u}}{g}) < 2 * 10^{-4} \qquad (39)$$

This level of accuracy was considered to be sufficient to analyze the dynamic response of horizontal soil deposits; furthermore, in most cases convergence in terms of the inequality (35) was achieved in less than three iterations.

3.3.2 Element Size and Transmissibility

As shown by Lysmer and Romo [10], the spatial discretization of a profile into a string of elements affects the transmissibility properties of the system. They pointed out that a controlling factor was the ratio of the wavelength of excitation, λ, to the height of the element, h. Results of a study by Martin [9] of the transmissibility properties of a profile with 2.5 cps natural frequency and 7.8% of critical viscous damping are shown in Tables 2 and 3. It can be seen in Table 2 that the response was accurate, i.e., had errors less than 3% for values of the ratio λ/h larger than eight. The response to 10 cps excitation corresponded to $\lambda/h = 4$ and in effect was largely damped, which corroborated earlier findings by Lysmer and Romo on the transmissibility of elements with lumped masses.

Table 2. Forced Response Amplification Spectrum Using 4 Elements

Δt (secs)	λ/h	Excitation Frequency (cps)	Exact Amplification	Frequency Step (cps)	Computed Amplification	Error %
.015625	40	1	1.235	.250	1.234	0.1
.015625	20	2	3.072	.250	3.048	0.8
.01250	8	5	.905	.3125	.874	3.4
.01250	4	10	.401	.3125	.229	43

Table 3. Forced Response at 10 cps

Δt (secs)	Number of Elements	λ/h	T_{min} (secs)	$\frac{\Delta t}{T_{min}}$	$\frac{\eta}{GT_{min}}$	Convergence	Error %
.015625	4	4	.08	.20	.13	Yes	42
.015625	4	4	--	--	--	Yes	42
.015625	8	8	.04	.40	.25	No	
.0078125	8	8	.04	.20	.25	Yes	12
.0078125	8	8	.04	.20	.25	Yes	10
.00390625	20	20	.02	.25	.64	No	
.001953125	20	20	.02	.12	.64	Barely	9
.0009765625	20	20	.02	.06	.64	Yes	3.5

The surface amplification for a 10 cps harmonic excitation at the base of the same profile was also obtained with both 8 and 20 elements in the profile. The results are compiled in Table 3.

It appeared that only large values of the ratio of wavelength to element height, e.g., $\lambda/h = 20$ could reduce the error on computed amplification to less than 4%.

Incidentally, the effects of viscosity on the convergence of the iteration matrix (see Fig. 3) were confirmed by this analysis. Element periods, T_{min}, were computed from equation (33), and convergence of the method was reached only for those time steps, Δt, which satisfied the requirements set forth in Fig. 3 and equation (34).

4.1 A NON-LINEAR SOIL MODEL

The shape of the stress-strain curves in soils under cyclic loading conditions reflects the soil non-linearity and the mechanisms of energy loss. It has been observed [13, 14, 15, 16] that damping in soils is independent of the rate of loading and thus it cannot be exactly accounted for by viscosity effects.

Among the non-linear models with rate independent damping following Masing's rules, the Ramberg-Osgood model has received much attention in the field of structural mechanics [11, 12]. In terms of finite element analyses however, it has the disadvantage of expressing strains as functions of stresses. A non-linear model better suited to these types of analyses is the Davidenkov model [8, 9] where stresses are expressed as functions of strains.

4.1 Basic Equations of the Davidenkov Model

There are two basic equations, one for loading and another for unloading:

$$\begin{aligned} &\text{Loading} \quad \uparrow \frac{d\tau}{d\gamma} = G \left[1 - F(\gamma - \gamma_{min})\right] \quad ; \\ &\text{Unloading} \quad \downarrow \frac{d\tau}{d\gamma} = G \left[1 - F(\gamma_{max} - \gamma)\right] \quad . \end{aligned} \qquad (40)$$

F is defined on the positive interval including zero; G is the shear modulus for low strains and for each reversal of the direction of loading.

Martin [9] has shown that the secant modulus G* defined in Fig. 4 corresponding to the strain amplitude γ_a could be written as

$$G^*(\gamma_a) = G \cdot [1 - H(\gamma_a)] \qquad (41)$$

with

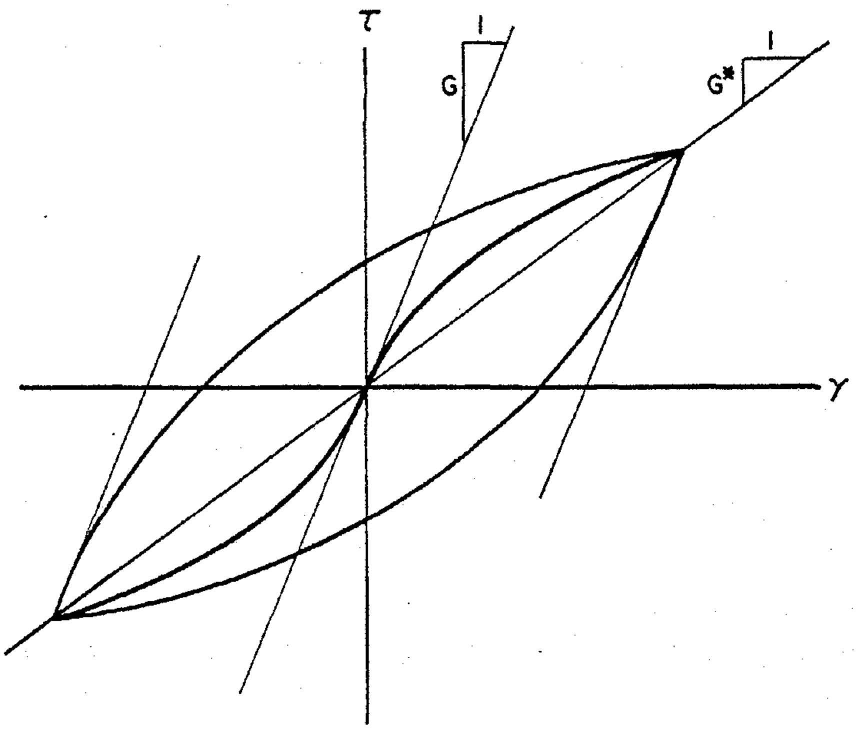
$$H(\gamma) = \frac{1}{\gamma} \int_0 F\ (2\eta)\ d\eta \quad . \qquad (42)$$

In practice, the secant modulus is a soil property easy to determine in laboratory tests. Therefore, it is the function H(γ) which must be determined by running a series of cyclic tests at different strains levels. Once the function H(γ) is known, the function F is obtained by differentiating equation (42):

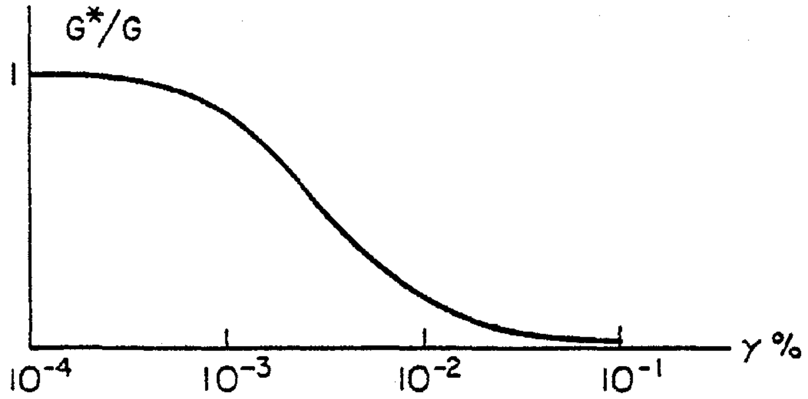
$$F(2\gamma) = H(\gamma) + \gamma \frac{dH(\gamma)}{d\gamma} \qquad (43)$$

By integrating the basic equations (40), the stress-strain relationships for loading and unloading are obtained as:

$$\begin{aligned} &\text{Loading} \quad \uparrow \tau - \tau_{min} = G[\gamma - \gamma_{min}][1 - H\ (\frac{\gamma - \gamma_{min}}{2})] \\ &\text{Unloading} \quad \downarrow \tau - \tau_{max} = -G[\gamma_{max} - \gamma][1 - H\ (\frac{\gamma_{max} - \gamma}{2})] \end{aligned} \qquad (44)$$



(a) Hysteresis Associated With Plastic Strain Damping, Masing's Hypothesis.



(b) Typical Dynamic Stiffness vs. Strain Level Relationship.

Fig. 4

The damping loss ratio, β is by definition [9] expressed as:

$$\beta = \frac{1}{4\pi} \frac{\Delta W}{W} \tag{45}$$

where ΔW is the damping energy, i.e. the area within the hysteresis loop shown in Fig. 4 and W the equivalent linear strain energy defined as

$$W = \frac{1}{2} G^* (\gamma_a)\, \gamma_a^2 \tag{46}$$

The damping energy at the strain amplitude γ_a can be computed with equations (44) as:

$$\Delta W = 8 \int_o^{\gamma_a} [G^*(\eta) - G^*(\gamma_a)]\; \eta d\eta \tag{47}$$

and the damping loss ratio at the strain amplitude γ_a may be expressed as

$$\beta(\gamma_a) \cdot \frac{2}{\pi} \cdot \frac{\int_o^{\gamma_a} 2[G^*(\eta) - G^*(\gamma_a)]\; \eta d\eta}{G^*(\gamma_a) \cdot \gamma_a{}^2} \tag{48}$$

4.2 A Davidenkov Model for Soils

Martin has proposed to define the function $H(\gamma)$ in equation (41) as:

$$H(\gamma) = \left[\frac{[\gamma/\gamma_o]^{2B}}{1 + [\gamma/\gamma_o]^{2B}} \right]^A \tag{49}$$

where A, B and γ_o are three parameters which can be determined by measuring in the laboratory the variation of the secant modulus with cyclic strain amplitude and by obtaining the best fit between the laboratory curve and the model curve.

4.2.1 Sands

It was found that the best set of parameters in terms of reproducing the curve proposed by Seed and Idriss is given by

$$A = 0.9, \quad B = 0.413 \quad \text{and} \quad \gamma_o = 3.16 \times 10^{-2}\,\% \tag{50}$$

The comparison between the experimental curves and the Davidenkov model is shown in Fig. 5. Although the agreement between the modulus curves is excellent, the Davidenkov model tends to overestimate the amount of damping with respect to experimental findings for strain amplitudes larger than about 0.1%. The values of $A = 0.9$ and $B = 0.413$ are to be compared to $A = 1.0$ and $B = 0.5$ which define the hyperbolic stress-strain model used by Finn et al. for which

$$H(\gamma) = \frac{\gamma/\gamma_o}{1 + \gamma/\gamma_o}$$

The agreement in the values of A and B attributed to both models make them very similar.

4.2.2 Clays

It was more difficult to achieve a good agreement in the case of clays. The best compromise was found to be given by the parameters:

$$A = 0.2, \quad B = 0.5 \quad \text{and} \quad \gamma_o = 0.5\% \tag{51}$$

Furthermore, the ratio of shear modulus at low strain, G, to undrained shear strength, S_u, was fixed at

$$\frac{G}{S_u} = 2500 \tag{52}$$

The comparison between the experimental and the model curves is shown in Figure 6.

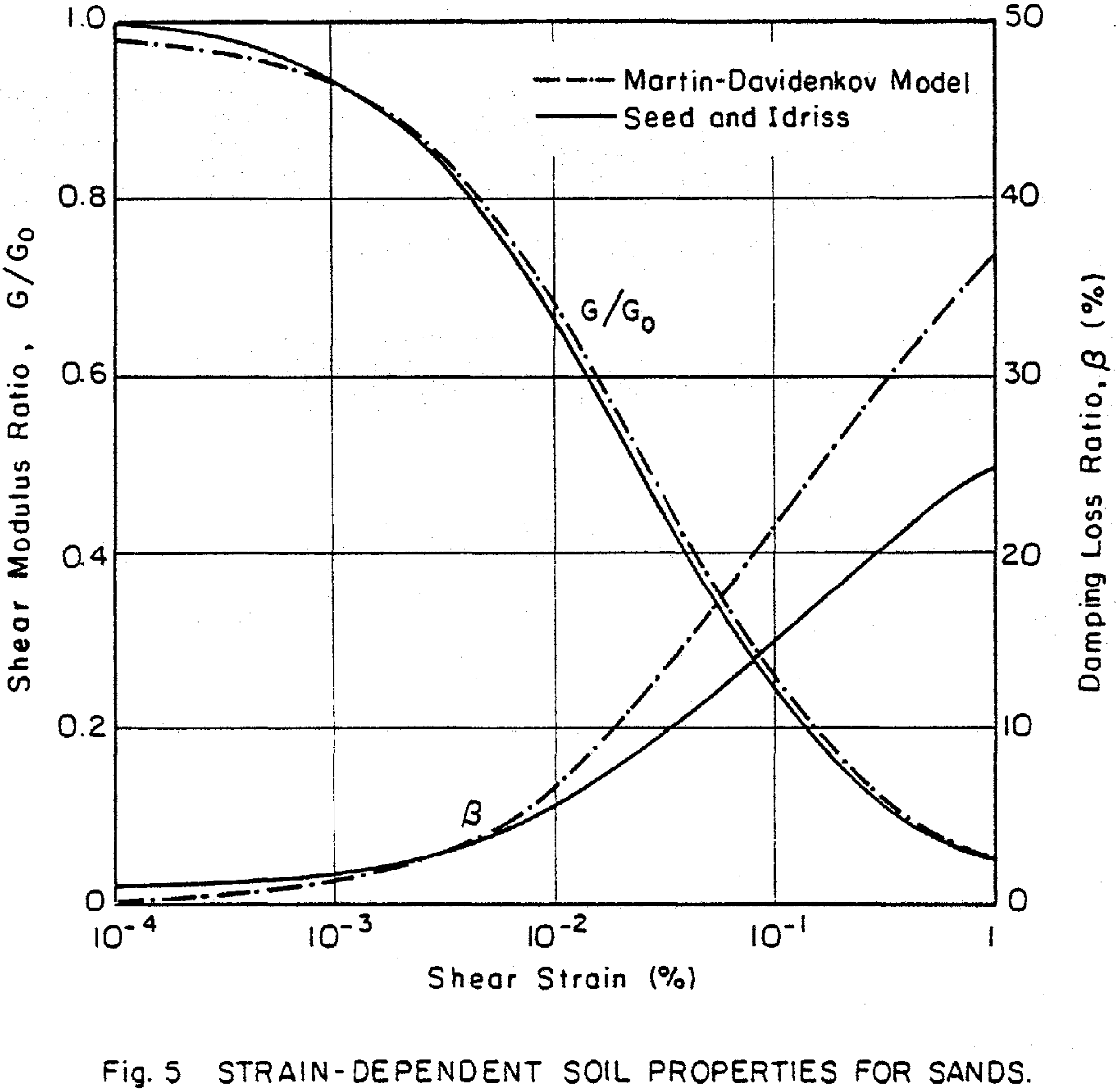


Fig. 5 STRAIN-DEPENDENT SOIL PROPERTIES FOR SANDS.

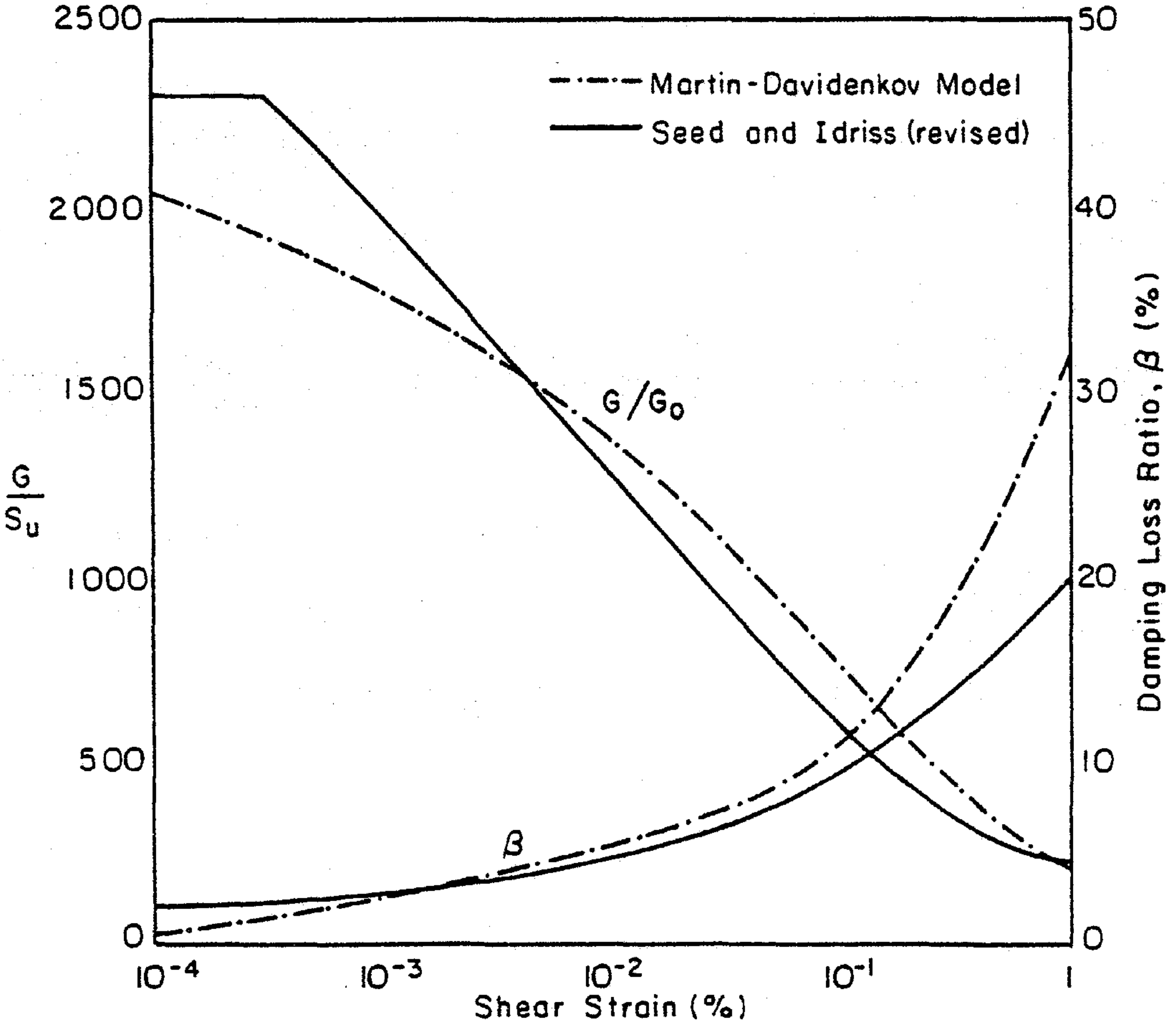


Fig. 6 STRAIN-DEPENDENT SOIL PROPERTIES FOR CLAYS

5. MASH--ANALYSIS OF SHEAR WAVES IN HORIZONTALLY LAYERED DEPOSITS

5.1 Description

The computer program MASH is designed to solve the dynamic response of a deposit of horizontal soil layers. The deposit is discretized into a string of one-dimensional constant strain elements. The equations of motion are integrated with respect to time by the cubic inertia method. The soil material may be either visco-elastic or non-linear and modelled into the Davidenkov system discussed in Section 4.

The equations of motion at any level i in the profile have the form

$$M_i \ddot{u}_i + \tau_i - \tau_{i-1} = -M_i \ddot{u}_b \quad , \tag{1}$$

where M_i is the amount of mass lumped at level i,

τ_i is the stress in element i just below level i,

τ_{i-1} is the stress in element i-1 just above level i,

$\ddot{u}_i$ is the acceleration relative to the base, and

$\ddot{u}_b$ is the base acceleration.

An implicit formulation of the cubic inertia method is used to integrate the equations of motion within a succession of time intervals, Δt. Within each time interval, the computation steps are:

a. Assume a value of the inertia force vector $\{R\}$ and of its first time derivative $\{\dot{R}\}$ at the end of the time interval, say $\{R\}_1$ and $\{\dot{R}\}_1$, respectively. The program assumes

$$\{\dot{R}\}_1 = \{\dot{R}\}_0 \quad , \tag{2}$$

$$\{R\}_1 = \{R\}_0 + \Delta t \, \{\dot{R}\}_0 \quad , \tag{3}$$

where $\{R\}_0 = [M]\{\ddot{u}\}_0$.

b. Compute $\{u\}_1$ and $\{\dot{u}\}_1$ from the basic equations of the algorithm (see Section 3.3.1, equations 24 and 25).

c. Compute the strain and the strain rate in each element at the end of the time interval.

d. Compute the stress in each element assuming that the tangent stiffness is a constant soil property during the time interval. According to the notations of Fig. 7,

$$\tau = \tau_{sec} + G \cdot \gamma \quad , \qquad (4)$$

where the value τ_{sec} has been determined at the end of the previous time interval.

e. Use equation (1) for each element to compute the new values of $\{R\}_1$ and $\{\dot{R}\}_1$. If the convergence criterion defined in Section 3.3.1, equation (35), is not satisfied, another iteration is necessary. In that case, go back to step b and proceed down to step e. When convergence has been reached, the stress is adjusted in order to account for the non-linearity of the material, but the strain is kept unchanged. This adjustment is shown graphically in Fig. 7. Then, by using equation (1), the final values of $\{R\}_1$ and $\{\dot{R}\}_1$ are computed. It was shown in Section 3.3.1 that it was sufficient to use $\dot{\varepsilon} = 10\%$ in equation (35). When using this value, it was found that convergence was reached with less than four cycles of iterations in most cases.

5.2 Structure of the Program

The program MASH consists of a main program, 30 subroutines, and 2 function subprograms.

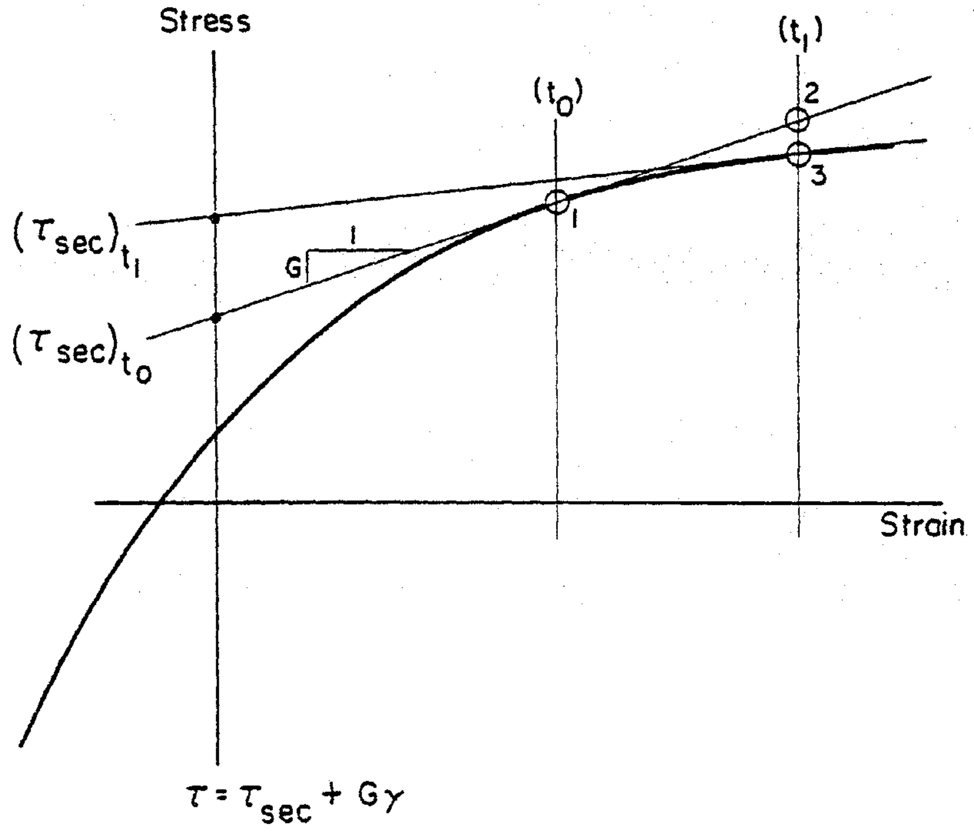


Fig. 7 LINEARIZATION BY MASH OF THE STRESS-STRAIN RELATIONSHIP DURING EACH TIME STEP.

MASH, the main program, includes the user's manual in the form of comment cards. Also it fixes arbitrarily the value of the constant ITMAX, i.e. the maximum number of iterations in the implicit formulation of the cubic inertia method. (It should be set from 5 to 10.)

MASTER reads the constants of the problem necessary to set up the dynamic storage.

ADJUST contains the system subroutines LOCF and MEM which return the central memory location of a specified variable and adjust the size of central memory to the minimum required to run the problem, respectively.

SOILIN is the tree of the program. It calls the different operations in sequence.

UNIT reads the system of units in which the data are input and in which the results are given. The computations within the program are done in dimensionless units.

PROPY reads the soil properties of the profile and prints out all data characteristic of the profile. The natural frequencies at low strain of each element are printed in order for the user to evaluate the discretization of the profile. Indeed, best efficiency in terms of computing time is achieved when all the elements in the profile have approximately the same frequency, because the time step of the analysis is a fraction of the smallest period in the system. The ratio of the time step of the analysis to the smallest period in the system is arbitrarily set at 20% (RATIO = 0.2). It is possible to stop the execution at this stage by setting SWITCH = 2 in the input data.

MASS sets up the lumped mass matrix.

OPTION reads the output options selected for the analysis.

EARQK reads the digitized record of the base acceleration time history and computes its Fourier spectrum. If SWITCH = 0, it does generate and punch out for later use the record of the first time derivative of the acceleration time history. If SWITCH = 1, it reads that record from input data.

XMX computes the absolute maximum value in an array.

LIQUIN reads output data from APOLLO concerning the pore pressure buildup during the earthquake. The use of this program is optional (set LIQFN = 1).

ITR is part of the solution block. It computes the response at each time step by using the implicit formulation of the algorithm of the cubic inertia method.

ERRORS checks whether the convergence criterion is satisfied after each iteration. The parameter (Section 3.3.1, equation 35) is set at $\dot{\varepsilon} = 0.1$.

STIFF computes the stresses and rigidity of the material as functions of strains according to the equations of the Davidenkov model.

REVERS computes the maximum (or minimum) strain at reversal of loading within any element. The procedure is shown in graphic form in Fig. 8.

FUNCTION FF is the function $F(\gamma)$ of the Davidenkov model.

FUNCTION HF is the function $H(\gamma)$ of the Davidenkov model (see Section 4.2).

RECIN stores the acceleration time histories for later filtering (if requested) and the optional output on tapes.

RENEW computes the reduction factor on shear modulus at low strain as pore pressures increase with time.

PROUT prints out the maxima of accelerations, stresses and strains within each element.

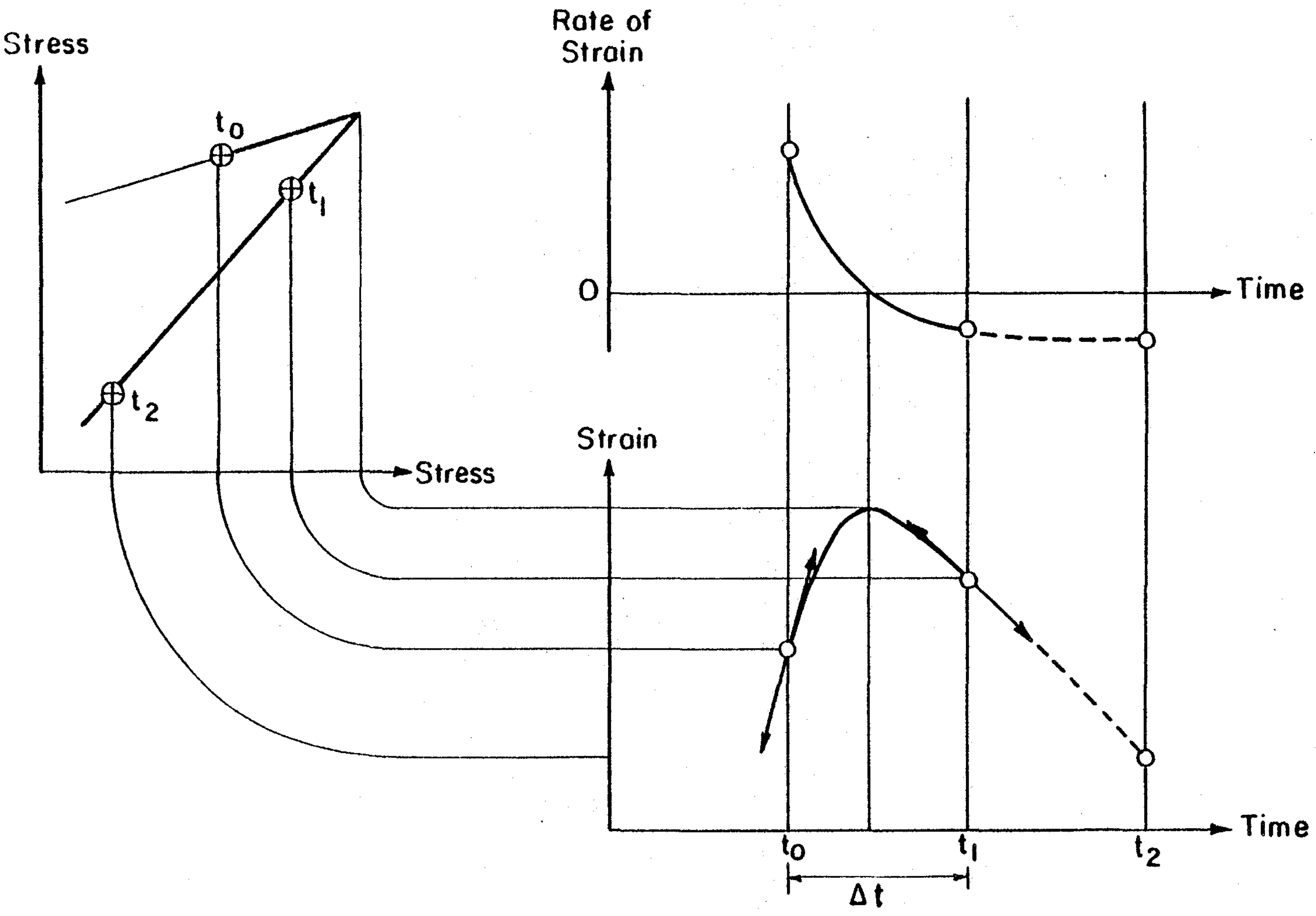


Fig. 8 BILINEAR MODEL, MATHEMATICAL DETERMINATION OF STRAIN REVERSAL.

FILTER retrieves the acceleration time histories of each element from tapes and filters them. Also, it sends the optional output acceleration time histories to be processed.

RECOUT retrieves the optional output information from tapes and sends it to be processed.

RESULT processes the optional output information.

PLT and PLOTX are used for printer-plotting optional output.

PCH is used to punch optional output on cards.

FFT, RFFT, and RFSN are the Fast Fourier transform programs.

SPECTR, SETUP, DRCTSP, CMPMAX and DIVORD are the Response Spectra generation programs.

The subprograms of MASH are listed in Table 4 with a description of the relationship between the programs.

Table 4. Calling Sequence for Subprograms of MASH

Program	Section			Calls	Called by
	Input	Solution	Output		
SMASH	x			MASTER	MASH
MASTER	x			SOILIN	MASTER
ADJUST	x				MASTER
SOILIN	x	x	x	UNIT,PROPY,MASS,OPTION, EARQK,LIQUIN,ITR,RECIN, RENEW,PROUT,FILTER, RECOUT	
UNIT	x				SOILIN
PROPY	x				SOILIN
MASS	x				SOILIN
OPTION	x				SOILIN
EARQK	x			XMX,RFFT,RFSN,PLOTX	SOILIN
LIQUIN	x				SOILIN
ITR		x		ERRORS,STIFF,REVERS	SOILIN
ERRORS		x			ITR
REVERS		x			ITR
STIFF		x		FF,HF	ITR
FF		x			STIFF
HF		x			STIFF
RECIN		x			SOILIN
RENEW		x			SOILIN
PROUT			x		SOILIN
FILTER			x	RFFT,RFSN,XMX,RESULT	SOILIN
RECOUT			x	RESULT	SOILIN
RESULT			x	PLT,PCH,SPECTR	FILTER,RECOUT
PLT			x	PLOTX	RESULT
PCH			x		RESULT
PLOTX			x		PLT,EARQK
SPECTR			x	RFFT,SETUP,XMX	RESULT
SETUP			x	DRCTSP,PLOTM,DIVORD	SPECTR
DRCTSP			x	RFSN,CMPMAX	SETUP
CMPMAX			x		DRCTSP
DIVORD			x		SETUP
RFFT,RFSN,FFT	x		x		EARQK,FILTER, SPECTR,DRCTSP
XMX					EARQK,FILTER, SPECTR

5.3 User's Manual

Input Data

1. Job Identification Card (2I5,I3,I2,I5,10A6)

1-5	NTS	Number of different soil layers in the profile.
6-10	NELM	Number of elements in the profile.
13	RESP	Switch for computation of response spectra = 1 Two response spectra cards are read = 0 No computation of response spectra.
15	LIQFN	Switch for liquefaction study = 1 Effective Stress Analysis--there is allowance for pore pressure change and a liquefaction card is read = 0 Total Stress Analysis--Hydrostatic condition.
16-20	NOUT	Number of elements for which optional output is requested (either time histories or response spectra).
21-80	IDENT	Profile and Job Identification.

2. Response Spectra Cards (Two Cards)--Only if RESP = 1, otherwise skip.

2.1 Control Card No. 1 (6I5)

5	KAV	Switch for computation of response spectra = 0 Absolute Spectral Accelerations are computed only = 1 Relative spectral velocities are computed only = 2 Both absolute spectral accelerations and relative spectral velocities are computed.
10	KFR	Switch for frequencies used in computations = 0 4 steps from 0.25 cps to 0.50 cps 5 steps from 0.50 cps to 1.0 cps 9 steps from 1.0 cps to 10.0 cps = 1 8 steps from 0.25 cps to 0.50 cps 10 steps from 0.50 cps to 1.0 cps 18 steps from 1.0 cps to 10.0 cps = 2 30 steps from 0.2 cps to 0.5 cps 20 steps from 0.5 cps to 1.0 cps 38 steps from 1.0 cps to 20.0 cps = 3 Logarithmic steps increasing from frequency FS to frequency FE, with NSTP steps per log cycle.
11-15	NSTP	Number of steps per log cycle if KFR = 3, otherwise blank--It is recommended to use NSTP = 20 when KFR = 3 has been selected.
20	ND	Number of fractions of critical damping used in the computations of spectra--ND must be less than or equal to 5.

25	KPL	Switch for printed-plotted output = 0 No printer-plotted output = 1 Printer-plotted output of all the computed spectra.
30	KPU	Switch for punched output = 0 No punched output = 1 Punched output of all the computed spectra.

2.2 Control Card No. 2 (8F10.0)

1-10	FS	Lowest frequency (cps) for which response is computed.
11-20	FE	Highest frequency (cps) for which response is computed. Note--FS and FE are required only if KFR = 3, otherwise leave blank.
21-70	DD(ND)	Fractions of critical damping used for response spectra computations--ND values.

3. Effective Stress Analysis Card (2I5)--Only if LIQFN = 1, otherwise skip.

1-5	NTL	Number of lines where a reduction factor time history of the shear modulus at low strain is given.
6-10	NDTL	Number of values in stiffness degradation histories.

4. Time Domain Integration Card (2I5,2F10.0)

1-5	NV	Number of acceleration values in the base motion record.
6-10	NDT	Number of time steps necessary to cover the motion duration (the program automatically adds trailing zeros to achieve NDT = 2**N).
11-20	DT	Time step of the base motion record (secs.)
21-30	FMAX	Filter frequency (cps) for acceleration response--If FMAX blank, all frequencies are kept in the response.

5. Unit System Card (10A6,2F10.0)

1-60	IDT	Identification of the chosen unit system (e.g., SI, CGS, British, etc.)
61-70	GW	Unit weight of water as expressed in the chosen unit system.
71-80	GR	Acceleration of gravity as expressed in the chosen unit system.

6. Profile Constants Card (8F10.0)

1-10	SKO	Coefficient of earth pressure at rest.
11-20	WT	Depth of water table.
21-30	SAT	Depth of saturation line (S = 100%).
31-40	BETA	Average fraction of critical viscous damping for the whole profile.

7. Soil Cards (3I5,F5.0,6F10.0) Total of NTS Cards

1-5	K	Soil number (the soil layers must be numbered in increasing order, starting with 1 at the surface).
6-10	TYPE	1 = Clays or modulus independent of depth 2 = sands or modulus proportional to the square root of depth
11-15	N	Number of elements per soil layer.
16-20	VIS	Coefficient of viscosity of the soil material--no effect if BETA is given a non-zero value.
21-30	DY	Total unit weight of the soil.
31-40	FACT	Modulus Factor Type = 1, FACT is the undrained shear strength of clays Type = 2, FACT represents the effect of denseness FACT = 1+(DR - 75) * 0.01.
41-50	A	First nonlinear parameter Standard Sands A = .9 Clays A = .2
51-60	B	Second nonlinear parameter Standard Sands B = .413 Clays B = .5
61-70	WO	Reference strain for nonlinear model Standard Sands WO = 3.16E-4 Clays WO = 5.00E-3
71-80	TH	Thickness of soil layer.

8. Optional Output Cards--If NOUT = 0, Skip

8.1 Card No. 1 (16I5)

KEY(I)	(I = 1,NOUT)--Numbers of the elements for which optional output is requested (time histories or response spectra).

8.2 Card No. 2 (16I5)

KEY(I+NOUT)	(I = 1,NOUT) Optional output requested in a condensed form for an element. In a field I5, from left to right: First column = Stress Second column = Strain Third column = Relative displacement Fourth column = relative velocity Fifth column = absolute acceleration Code = 0 No action taken 1 Printer-plot only 2 punch only 3 printer-plot and punch

8.3 Card No. 3 (16I5) Only if RESP = 1, otherwise skip

KEY(i+2*NOUT)	(i = 1,NOUT) Switch for computation of response spectra in an element = 0 No spectra computation = 1 Computation of response spectra is performed in this element.

9. Base Motion Control Card (I5,F5.0,F10.0,10A6)

= 0 Only base motion is read (NV values)--its first time derivative record is generated and punched (NDT values).

= 1 Both the base motion and the record of its first time derivative are read (NV values in each record).

= 2 Stop execution before reading motion--This option should be used to set up the discretized model of the profile and check it out.

6-10	FMAX	Filter frequency for base motion (cps).
11-20	AMAX	Maximum acceleration at the base of the profile.
21-80	IDNT	Base motion identification.

10. Acceleration Cards (8F9.6,I7)--Total of NCARDS

1-72	EQK	Acceleration values, $\ddot{u}_g(t)$.
73-79	N	Card number (Cards must be in sequence). Note--NCARDS = (NV - 1)/8 + 1.

11. First Time Derivative Cards (8F9.6,I7) - Total of NCARDS if SWITCH = 1, otherwise skip.

1-12	EQKD	$d\ddot{u}_g(t)/dt$
73-79	N	Card Number (cards must be in sequence).

12. Effective Stress Analysis Cards--only if LIQFN = 1, otherwise skip

12.1 Card No. 1 (10A6)

1-80	IDENT	Identification from APOLLO run.

12.2 Card No. 2 (10A6)

1-80	IDT	Header for time values at which information is given.

12.3 Card No. 3 (8F10.0)

TIMLIQ	Time in seconds at which information is given--NDTL values.

12.4 Card No. 4 (10A6)

1-80	IDW	Header for water table rise values.

12.5 Card No. 5 (8F10.0)

RISE	Water table rise with time--NDTL values.

12.6 Set of Stiffness Degradation History--NTL sets

Card No. 1 (3A6,I5,3X,1A6,F8.1,3X,4A6,F13.3). Identification card from APOLLO for each line where reduction factor time history is applied.

Card No. 2 (10A6) Header.

Card No. 3 (8F10.0) Reduction factor time histories for the corresponding line--NDTL values.

<u>NOTE</u>--The entire set of effective stress analysis cards can be obtained from APOLLO by requesting the punched output of the effective stress ratio time histories at different levels in the profile.

5.4 Example Problem

In order to illustrate the use of the program, an effective stress analysis of the ground response of the soil profiles shown in Fig. 9 was performed for a 1.6 second earthquake motion scaled to 0.1g maximum acceleration.

The profile was divided into 2 soil layers and 11 elements. Soil No. 1 and Soil No. 2 are identical; the purpose of artificially layering the soil profile was to have elements with approximately the same natural frequency. The A, B and γ_o-parameters of the non-linear soil model were chosen as A = 1.0, B = 0.5 and $\gamma_o = 0.75\%$ which represents the hyperbolic model developed by Finn et al. 1977; furthermore, an amount of 2% of critical viscous damping was introduced in the soil profile.

The input data required to solve this problem and the output may be found in Appendix A.

5.5 Run Time

On the CDC 6400 computer, run time to solve the equations of motion in the time domain is approximately 5 seconds of central processor per layer and per thousand time steps.

These time increments are generally smaller than the time step in which the base motion is digitized--the total number of steps is printed in the output.

Variable additional time should be included in this estimate to account for processing the input-output options of the case under study.

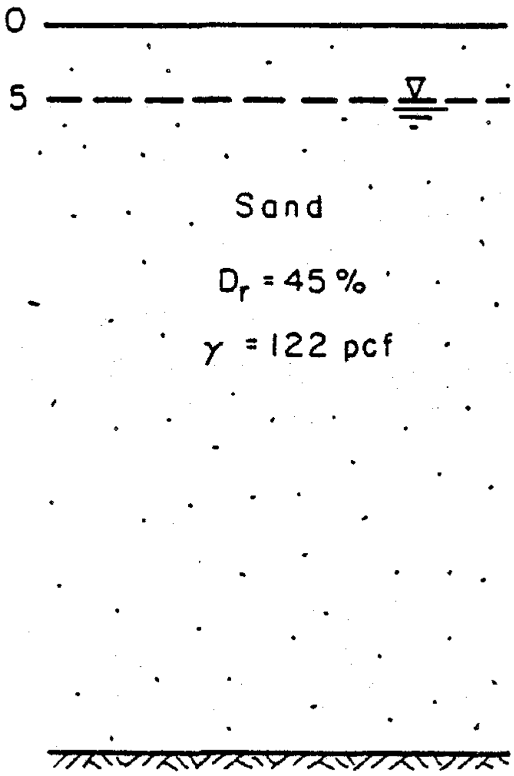


Fig. 9 SOIL PROFILE IN EXAMPLE PROBLEM.

ACKNOWLEDGEMENT

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REFERENCES

1. Bathe, K. J. and Wilson, E. L. (1973) "Stability and Accuracy Analysis of Direct Integration Methods," Journal of Earthquake Engineering and Structural Dynamics, Vol. 1, pp. 283-291.

2. Goudreau, G. L. and Taylor, R. L. (1973) "Evaluation of Numerical Integration Methods in Elastodynamics," Journal of Computer Methods in Applied Mechanics and Engineering, Vol. 2, pp. 69-97.

3. Wilson, E. L., Farhoomand, I. and Bathe, K. J. (1973) "Nonlinear Dynamic Analysis of Complex Structures," Journal of Earthquake Engineering and Structural Dynamics, Vol. 1, pp. 241-252.

4. Streeter, V. L., Wylie, E. B. and Richart, F. E. Jr. (1974) "Soil Motion Computations by Characteristics Method," Journal of the Geotechnical Engineering Division, ASCE, Vol. 100, No. GT3, March.

5. Argyris, J. H. and Chan, A.S.L. (1972) "Applications of Finite Elements in Space and Time," Ingenieur-Archiv 41, pp. 235-257.

6. Argyris, J. H., Dunne, P. C. and Angelopoulos, T. (1973a) "Dynamic Response by Large Step Integration," Journal of Earthquake Engineering and Structural Dynamics, Vol. 2, pp. 185-203.

7. Argyris, J. H., Dunne, P. C. and Angelopoulos, T. (1973b) "Non-linear Oscillations Using the Finite Element Technique," Journal of Computer Methods in Applied Mechanics and Engineering, Vol. 2, pp. 203-250.

8. Lazan, B. J. (1968) "Damping of Materials and Members in Structural Mechanics," Pergamon Press.

9. Martin, Philippe P. (1975) "Non-linear Methods for Dynamic Analysis of Ground Response," Ph.D. dissertation, Department of Civil Engineering, University of California, Berkeley.

10. Lysmer, J. and Romo-Organista, M. (1974) Personal communication.

11. Papadakis, C. N., Streeter, V. L. and Wylie, E. B. (1974) "Bedrock Motions Computed from Surface Seismograms," Journal of the Geotechnical Engineering Division, ASCE, Vol. 100, No. GT10, October.

12. Constantopoulos, I. V., Roesset, J. M. and Christian, J. T. (1973) "A Comparison of Linear and Exact Non-linear Analyses of Soil Amplification," Fifth World Conference on Earthquake Engineering, Rome.

13. Hardin, B. O. (1965) "The Nature of Damping in Sands," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 91, No. SM1, January.

14. Hardin, B. O. and Drnevich, P. V. (1972) "Shear Modulus and Damping in Soils: Measurement and Parameter Effects," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 98, No. SM6, June.

15. Hardin, B. O. and Drnevich, P. V. (1972) "Shear Modulus and Damping in Soils: Design Equations and Curves," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 98, No. SM7, July.

16. Seed, H. B. and Idriss, I. M. (1970) "Soil Moduli and Damping Factors for Dynamic Response Analysis," University of California, Earthquake Engineering Research Center, Report No. EERC 70-10, December.

17. Zienkiewicz, O. C. and Lewis, R. W. (1973) "An Analysis of Various Time-stepping Schemes for Initial Value Problems," Journal of Earthquake Engineering and Structural Dynamics, Vol. 1, pp. 407-408.

APPENDIX A

EXAMPLE PROBLEM

A.1 INPUT DATA

```
  2    11   1 1      2WASH--TEST--RESPONSE SPECTRA
  2     3   20     1     1     1
 .05        25.        .05
  9   103
 30   128    .02        10.
UNIT SYSTEM FEET AND POUNDS                                                         62.         32.2
 0.44        5.         0.         0.02
  1      2     3 0.      122.      0.735       1.0        0.5        0.00075     10.
  2      2     3 0.0     122.      0.735       1.0        0.5        0.00075     40.
  1      6
  322
  1      1
  1 25.     0.1     EL CENTRO SITE IMPERIAL VALLEY IRRIGATION DISTRICT COMP S00E
 -.00143  -.01102  -.01030  -.00808  -.00969  -.01224  -.01448  -.01306      1
 -.01122  -.00867  -.00867  -.01336  -.01795  -.01979  -.01652  -.01469      2
 -.01102  -.00836  -.00428  -.00673  -.01336  -.01938  -.01999  -.00673      3
  .00306   .01438  -.00590  -.01306  -.01469  -.02070  -.02652  -.03315      4
 -.03121  -.01754  -.02009  -.01663  -.01673  -.00683   .00255   .01530      5
  .02407   .02570   .03427   .04722   .05018   .04274   .03662   .02764      6
  .02397   .03458   .04202   .05406   .06517   .07466   .06650   .05109      7
  .04080   .04030   .00645  -.05253  -.08027  -.06150  -.04937  -.02550      8
 -.00602   .01367   .03141   .05090   .07242   .10148   .12433   .15595      9
  .14779   .11780   .09537   .09098   .09445   .08557   .09190   .10128     10
  .32851   .35928  -.26018   .11161  -.02755   .26032  -.07618  -.02022      1
 -.18078  -.04098   .07031   .33879   .11523   .02018  -.24860  -.00442      2
 -.30236  -.02158  -.28542   .50362   .09548   .51964  -.64075  -.37358      3
 -.86452   .29405  1.00461  -.00005   .21565   .35223   .23075   .33367      4
 -.71656  -.29832   .05048  -.12369  -.14509  -.62187  -.44639  -.70925      5
 -.14369  -.16740  -.67186  -.46262   .15923   .45628   .21911   .62443      6
 -.42009  -.35587  -.59022  -.44599  -.30012   .13922   .18990   .82079      7
  .52164   .30551  2.88602  2.56341  -.07650 -1.03441  -.63258 -1.40429      8
 -.72906 -1.11776  -.77535 -1.08382 -1.24194 -1.36489 -1.30344 -1.16550      9
 1.66842  1.10290  1.05077  -.55738   .52755  -.09469  -.19334 -1.18526     10
APOLLO--EXAMPLE PROBLEM--CDC 6400                                  --     PERIOD NO.    1
TIME IN SECONDS
  0.          .10000      .25000      .35000      .45000      .55000      .65000      .75000
  .85000      .95000     1.05000     1.15000     1.25000     1.35000     1.45000     1.55000
 1.65000     1.75000     1.85000     1.95000     2.05000     2.15000     2.25000     2.35000
 2.45000     2.55000     2.65000     2.75000     2.35000     2.95000     3.05000     3.15000
 3.25000     3.35000     3.45000     3.55000     3.65000     3.75000     3.85000     3.95000
 4.05000     4.15000     4.25000     4.35000     4.45000     4.55000     4.65000     4.75000
 4.85000     4.95000     5.05000     5.15000     5.25000     5.35000     5.45000     5.55000
 5.65000     5.75000     5.85000     5.95000     6.05000     6.15000     6.25000     6.35000
 6.45000     6.55000     6.65000     6.75000     6.85000     6.95000     7.05000     7.15000
 7.25000     7.35000     7.45000     7.55000     7.65000     7.75000     7.85000     7.95000
 8.05000     8.15000     8.25000     8.35000     8.45000     8.55000     8.65000     8.75000
 8.85000     8.95000     9.05000     9.15000     9.25000     9.35000     9.45000     9.55000
 9.65000     9.75000     9.85000     9.95000
WATER TABLE RISE HISTORY
 5.00000     5.00000     5.00000     5.00000     5.00000     5.00000     5.00000     5.00000
 5.00000     5.00000     5.00000     4.99035     4.95404     4.89904     4.82668     4.73598
 4.62320     4.47895     4.27470     3.99999     3.99990     3.99980     3.99969     3.99957
 3.99944     3.99931     3.99917     3.99902     3.99887     3.99872     3.99856     3.99843
 3.99830     3.99817     3.99804     3.99792     3.99779     3.99766     3.99753     3.99740
 3.99727     3.99713     3.99700     3.99687     3.99673     3.99659     3.99646     3.99632
 3.99618     3.99604     3.99590     3.99575     3.99561     3.99546     3.99532     3.99517
```

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  3.99502   3.99487   3.99472   3.99457   3.99441   3.99427   3.99412   3.99398
  3.99384   3.99369   3.99355   3.99341   3.99326   3.99312   3.99298   3.99283
  3.99269   3.99255   3.99240   3.99226   3.99211   3.99197   3.99182   3.99168
  3.99153   3.99139   3.99124   3.99108   3.99094   3.99079   3.99064   3.99050
  3.99035   3.99020   3.99006   3.98991   3.98977   3.98962   3.98947   3.98933
  3.98918   3.98903   3.98889   3.98874
BOTTOM OF LAYER NO    5   DEPTH      15.0   INITIAL EFFECTIVE STRESS     1210.000
    EFFECTIVE STRESS RATIO = EFFECTIVE STRESS / INITIAL EFFECTIVE STRESS
  1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000
  1.00000   1.00000   1.00000    .99000    .97679    .96478    .95292    .94078
   .92800    .91400    .89726    .87722    .87151    .85545    .83075    .80772
   .78586    .76483    .74443    .72452    .70497    .68569    .66661    .65409
   .64802    .64197    .63593    .62989    .62386    .61784    .61181    .60579
   .59976    .59373    .58769    .58165    .57559    .56952    .56344    .55734
   .55123    .54509    .53893    .53275    .52654    .52030    .51402    .50772
   .50137    .49498    .48855    .48207    .47555    .47141    .46971    .46802
   .46633    .46465    .46297    .46129    .45962    .45795    .45628    .45462
   .45296    .45130    .44964    .44799    .44633    .44468    .44302    .44137
   .43971    .43704    .43334    .42961    .42740    .42673    .42607    .42542
   .42477    .42412    .42349    .42285    .42223    .42161    .42099    .42038
   .41977    .41917    .41857    .41798
BOTTOM OF LAYER NO    6   DEPTH      20.0   INITIAL EFFECTIVE STRESS     1510.000
    EFFECTIVE STRESS RATIO = EFFECTIVE STRESS / INITIAL EFFECTIVE STRESS
  1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000
  1.00000   1.00000   1.00000    .98823    .97319    .95997    .94727    .93462
   .92165    .90785    .89197    .87356    .86672    .84726    .81726    .78928
   .76266    .73701    .71205    .68758    .66345    .63953    .61571    .60017
   .59290    .58562    .57833    .57101    .56367    .55631    .54891    .54149
   .53403    .52654    .51900    .51142    .50380    .49611    .48833    .48058
   .47272    .46478    .45677    .44868    .44050    .43223    .42386    .41537
   .40677    .39804    .38917    .38016    .37098    .36536    .36344    .36151
   .35958    .35764    .35569    .35373    .35176    .34979    .34781    .34582
   .34382    .34181    .33979    .33777    .33573    .33368    .33163    .32956
   .32748    .32376    .31835    .31285    .30980    .30928    .30875    .30823
   .30771    .30719    .30667    .30616    .30564    .30513    .30462    .30411
   .30360    .30309    .30259    .30209
BOTTOM OF LAYER NO    7   DEPTH      25.0   INITIAL EFFECTIVE STRESS     1810.000
    EFFECTIVE STRESS RATIO = EFFECTIVE STRESS / INITIAL EFFECTIVE STRESS
  1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000
  1.00000   1.00000   1.00000    .98697    .97060    .95649    .94315    .93008
   .91690    .90315    .88778    .87038    .86270    .84076    .80685    .77519
   .74499    .71580    .68729    .65924    .63143    .60370    .57589    .55772
   .54935    .54094    .53250    .52401    .51547    .50688    .49823    .48951
   .48072    .47186    .46290    .45385    .44470    .43544    .42606    .41655
   .40639    .39708    .38710    .37693    .36656    .35597    .34513    .33402
   .32260    .31085    .29871    .28613    .27306    .26515    .26281    .26044
   .25806    .25565    .25322    .25075    .24828    .24578    .24325    .24069
   .23810    .23548    .23283    .23014    .22743    .22467    .22188    .21905
   .21618    .21049    .20174    .19256    .18757    .18717    .18676    .18636
   .18596    .18557    .18518    .18479    .18441    .18403    .18366    .18328
   .18292    .18255    .18219    .18183
BOTTOM OF LAYER NO    8   DEPTH      30.0   INITIAL EFFECTIVE STRESS     2110.000
    EFFECTIVE STRESS RATIO = EFFECTIVE STRESS / INITIAL EFFECTIVE STRESS
  1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000
  1.00000   1.00000   1.00000    .98621    .96907    .95446    .94082    .92758
   .91438    .90080    .88591    .86935    .86119    .83771    .80139    .76745
```

```
  .73505     .70369     .67301     .64273     .61262     .58247     .55209     .52227
  .52329     .51425     .50514     .49596     .48669     .47734     .46790     .45834
  .44868     .43889     .42897     .41890     .40867     .39326     .38766     .37685
  .36581     .35451     .34293     .33103     .31877     .30610     .29298     .27934
  .26508     .25011     .23428     .21740     .19920     .18798     .18495     .18186
  .17371     .17550     .17222     .16887     .16545     .16195     .15836     .15462
  .15091     .14703     .14303     .13892     .13467     .13027     .12570     .12095
  .11600     .10499     .08564     .06030     .04226     .04239     .04251     .04263
  .04276     .04288     .04301     .04313     .04325     .04338     .04350     .04362
  .04375     .04387     .04399     .04412
BOTTOM OF LAYER NO    9   DEPTH       32.5   INITIAL EFFECTIVE STRESS     2260.000
      EFFECTIVE STRESS RATIO = EFFECTIVE STRESS / INITIAL EFFECTIVE STRESS
 1.00000    1.00000    1.00000    1.00000    1.00000    1.00000    1.00000    1.00000
 1.00000    1.00000    1.00000     .98622     .96913     .95459     .94104     .92794
  .91491     .90155     .88700     .87092     .86270     .83912     .80266     .76854
  .73595     .70438     .67348     .64298     .61264     .58225     .55161     .53157
  .52241     .51322     .50397     .49466     .48527     .47580     .46624     .45658
  .44680     .43690     .42687     .41668     .40633     .39580     .38507     .37412
  .36293     .35148     .33973     .32764     .31519     .30232     .28896     .27505
  .26050     .24519     .22895     .21159     .19277     .18112     .17795     .17472
  .17143     .16806     .16463     .16112     .15753     .15386     .15009     .14621
  .14223     .13813     .13339     .12952     .12498     .12026     .11534     .11019
  .10478     .09251     .06984     .03446    0.                     .00017     .00052     .00085
  .00119     .00151     .00184     .00216     .00247     .00278     .00308     .00339
  .00368     .00397     .00426     .00455
BOTTOM OF LAYER NO   10   DEPTH       35.0   INITIAL EFFECTIVE STRESS     2410.000
      EFFECTIVE STRESS RATIO = EFFECTIVE STRESS / INITIAL EFFECTIVE STRESS
 1.00000    1.00000    1.00000    1.00000    1.00000    1.00000    1.00000    1.00000
 1.00000    1.00000    1.00000     .98624     .96924     .95485     .94147     .92853
  .91580     .90274     .88859     .87302     .86484     .84126     .80481     .77077
  .73829     .70685     .67611     .64577     .61562     .58543     .55501     .53520
  .52625     .51723     .50813     .49896     .48970     .48034     .47089     .46134
  .45166     .44187     .43193     .42185     .41161     .40120     .39059     .37977
  .36373     .35742     .34584     .33394     .32169     .30905     .29595     .28234
  .26813     .25323     .23748     .22071     .20257     .19158     .18860     .18557
  .13248     .17933     .17612     .17284     .16949     .16606     .16256     .15897
  .15529     .15151     .14762     .14363     .13951     .13525     .13084     .12627
  .12152     .11100     .09276     .06987     .03383    0.         0.         0.
 0.         0.         0.         0.         0.          .00001     .00002     .00003
  .00005     .00006     .00008     .00010
BOTTOM OF LAYER NO   11   DEPTH       40.0   INITIAL EFFECTIVE STRESS     2710.000
      EFFECTIVE STRESS RATIO = EFFECTIVE STRESS / INITIAL EFFECTIVE STRESS
 1.00000    1.00000    1.00000    1.00000    1.00000    1.00000    1.00000    1.00000
 1.00000    1.00000    1.00000     .98708     .97109     .95755     .94497     .93284
  .92084     .90861     .89541     .88095     .87308     .85075     .81630     .78406
  .75331     .72354     .69444     .66577     .63733     .60895     .58046     .56173
  .55292     .54409     .53524     .52635     .51742     .50844     .49941     .49032
  .48116     .47193     .46261     .45320     .44368     .43406     .42431     .41442
  .40439     .39419     .38382     .37325     .36247     .35144     .34016     .32857
  .31666     .30438     .29168     .27849     .26475     .25640     .25391     .25140
  .24883     .24633     .24377     .24119     .23858     .23596     .23331     .23063
  .22793     .22520     .22244     .21965     .21683     .21397     .21109     .20815
  .20519     .19919     .18989     .18011     .16974     .15862     .14678     .13405
  .12015     .10459     .08642     .06341     .02409    0.         0.         0.
 0.         0.         0.         0.
BOTTOM OF LAYER NO   12   DEPTH       45.0   INITIAL EFFECTIVE STRESS     3010.000
```

```
    EFFECTIVE STRESS RATIO = EFFECTIVE STRESS / INITIAL EFFECTIVE STRESS
 1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000
 1.00000   1.00000   1.00000    .98711    .97127    .95795    .94567    .93389
  .92231    .91058    .89803    .88440    .87673    .85452    .82024    .78832
  .75796    .72870    .70019    .67219    .64450    .61694    .58935    .57158
  .55371    .55579    .54783    .53982    .53175    .52363    .51544    .50719
  .49887    .49048    .48200    .47344    .46479    .45603    .44717    .43820
  .42910    .41987    .41049    .40096    .39126    .38138    .37130    .36100
  .35046    .33966    .32857    .31715    .30537    .29851    .29683    .29514
  .29343    .29169    .28994    .28816    .28636    .28454    .28270    .28084
  .27895    .27705    .27512    .27317    .27120    .26921    .26719    .26516
  .26310    .25864    .25166    .24450    .23713    .22952    .22167    .21353
  .20507    .19625    .18700    .17726    .16691    .15579    .14392    .13111
  .11704    .10116    .08238    .05786
BOTTOM OF LAYER NO  13   DEPTH     50.0   INITIAL EFFECTIVE STRESS      3310.000
    EFFECTIVE STRESS RATIO = EFFECTIVE STRESS / INITIAL EFFECTIVE STRESS
 1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000
 1.00000   1.00000   1.00000    .98844    .97420    .96218    .95106    .94038
  .92985    .91917    .90773    .89529    .88825    .86826    .83746    .80376
  .78147    .75517    .72960    .70453    .67982    .65532    .63091    .61498
  .60753    .60009    .59264    .58519    .57773    .57026    .56276    .55524
  .54770    .54012    .53251    .52436    .51716    .50941    .50161    .49375
  .48582    .47782    .46974    .46158    .45333    .44499    .43654    .42797
  .41929    .41047    .40151    .39240    .38312    .37747    .37558    .37370
  .37182    .36994    .36807    .36620    .36434    .36247    .36060    .35874
  .35687    .35500    .35314    .35126    .34939    .34751    .34563    .34374
  .34185    .33832    .33307    .32775    .32235    .31685    .31126    .30557
  .29976    .29385    .28730    .28163    .27531    .26883    .26218    .25533
  .24828    .24098    .23341    .22551
```

A.2 PRINTED OUTPUT

```
*** PROGRAM  MASH  CDC 6400 ***
BLANK COMMON LENGTH IN PHASE ONE    =       1777
BLANK COMMON LENGTH IN PHASE TWO    =       1978
BLANK COMMON LENGTH IN PHASE THREE  =       1221
TOTAL AVAILABLE BLANK COMMON LENGTH=       13893
TEMPORARY STORAGE CAPACITY          =      12672
TIME HISTORIES STORAGE CAPACITY     =         99
```

```
UNIT SYSTEM FEET AND POUNDS
UNIT WEIGHT OF WATER_____________62.0000
ACCELERATION OF GRAVITY          32.2000


*****************************************************************************************
*                 *                 *                 *                 *                 *
* ACCEL. OF GRAVITY *      M/SEC2     *      CM/SEC2     *      FT/SEC2    *      FT/SEC2    *
*                 *                 *                 *                 *                 *
*****************************************************************************************
*                 *                 *                 *                 *                 *
* UNIT WT. OF WATER *      KN/M3      *      KGF/CM3     *     KIPS/CUFT   *     LBS/CUFT    *
*                 *                 *                 *                 *                 *
*****************************************************************************************
*                 *                 *                 *                 *                 *
*      LENGTH     *        M        *        CM       *        FT       *        FT       *
*                 *                 *                 *                 *                 *
*****************************************************************************************
*                 *                 *                 *                 *                 *
*      FORCE      *        KN       *       KGF       *       KIPS      *       LBS       *
*                 *                 *                 *                 *                 *
*****************************************************************************************
*                 *                 *                 *                 *                 *
*      STRESS     *      KN/M2      *      KGF/CM2     *     KIPS/SQFT   *     LBS/SQFT    *
*                 *                 *                 *                 *                 *
*****************************************************************************************
```

```
*OVF*
                    MASH--TEST--RESPONSE SPECTRA

                   NUMBER OF SOILS                       2
                   NUMBER OF ELEMENTS                   11
                   NUMBER OF TIME STEPS                640
                   TIME STEP (IN SECS.)          .00400000
                   MIN. PERIOD (SECS.)           .02031374
                   FUNDAMENTAL PERIOD(SECS)          .3259

                   COEFFICIENT K0                    .4400
                   DEPTH OF WATER TABLE             5.0000
                   DEPTH TO FULL SATURATION     0.
                   DEPTH TO BEDROCK                50.0000
                   FILTER FREQUENCY(HZ)               9.77


 ELEMENT   SOIL    THICKNESS    TOTAL UNIT  COEFFT.OF    SHEAR MODULUS   ELEMENT FREQ.        A         B         WO
 NUMBER    NUMBER                 WEIGHT    VISCOSITY    AT LOW STRAIN   AT LOW STRAIN     COEFFT.   COEFFT.   COEFFT.
    1        1       3.3333     122.000    1486.366       716359.376        41.523          1.000     .500     .75E-03
    2        1       3.3333     122.000    1813.003       873783.700        45.859          1.000     .500     .75E-03
    3        1       3.3333     122.000    2089.182      1006888.843        49.228          1.000     .500     .75E-03
    4        2       5.0000     122.000    2389.938      1151839.463        35.101          1.000     .500     .75E-03
    5        2       5.0000     122.000    2707.093      1304693.430        37.358          1.000     .500     .75E-03
    6        2       5.0000     122.000    2990.802      1441428.369        39.267          1.000     .500     .75E-03
    7        2       5.0000     122.000    3249.338      1566271.541        40.932          1.000     .500     .75E-03
    8        2       5.0000     122.000    3489.699      1681873.163        42.416          1.000     .500     .75E-03
    9        2       5.0000     122.000    3714.101      1790024.618        43.758          1.000     .500     .75E-03
   10        2       5.0000     122.000    3925.695      1892003.946        44.987          1.000     .500     .75E-03
   11        2       5.0000     122.000    4126.456      1988760.853        46.123          1.000     .500     .75E-03
```

```
*OVN*

      STORAGE OF ACCELERATION TIME HISTORIES
            11   IN TAPE 1

      ELEMENT    ACCELERATION     TAPE          VELOCITY   DISPLACEMENT    STRAIN      STRESS      TAPE
      NUMBER         CODE        NUMBER           CODE         CODE          CODE        CODE       NUMBER
        1**           3             1               0            0             0           0           0

        6**           4             1               0            0             2           2           2


       CODE SIGNIFICATION     0 = NO ACTION TAKEN
                              1 = PRINTER-PLOT ONLY
                              2 = PUNCH ONLY
                              3 = PRINTER-PLOT AND PUNCH
                              4 = STORAGE ON TAPE
                             ** = RESPONSE SPECTRUM COMPUTATION


      STORAGE OF TIME HISTORIES IN OPTION
             2   IN TAPE 2
```

```
EL CENTRO SITE IMPERIAL VALLEY IRRIGATION DISTRICT COMP SOOE
NUMBER OF ACCELERATION VALUES           80
TIME INTERVAL (IN SECS.)           .020000
CUTOFF FREQUENCY (IN HZ.)        24.609375

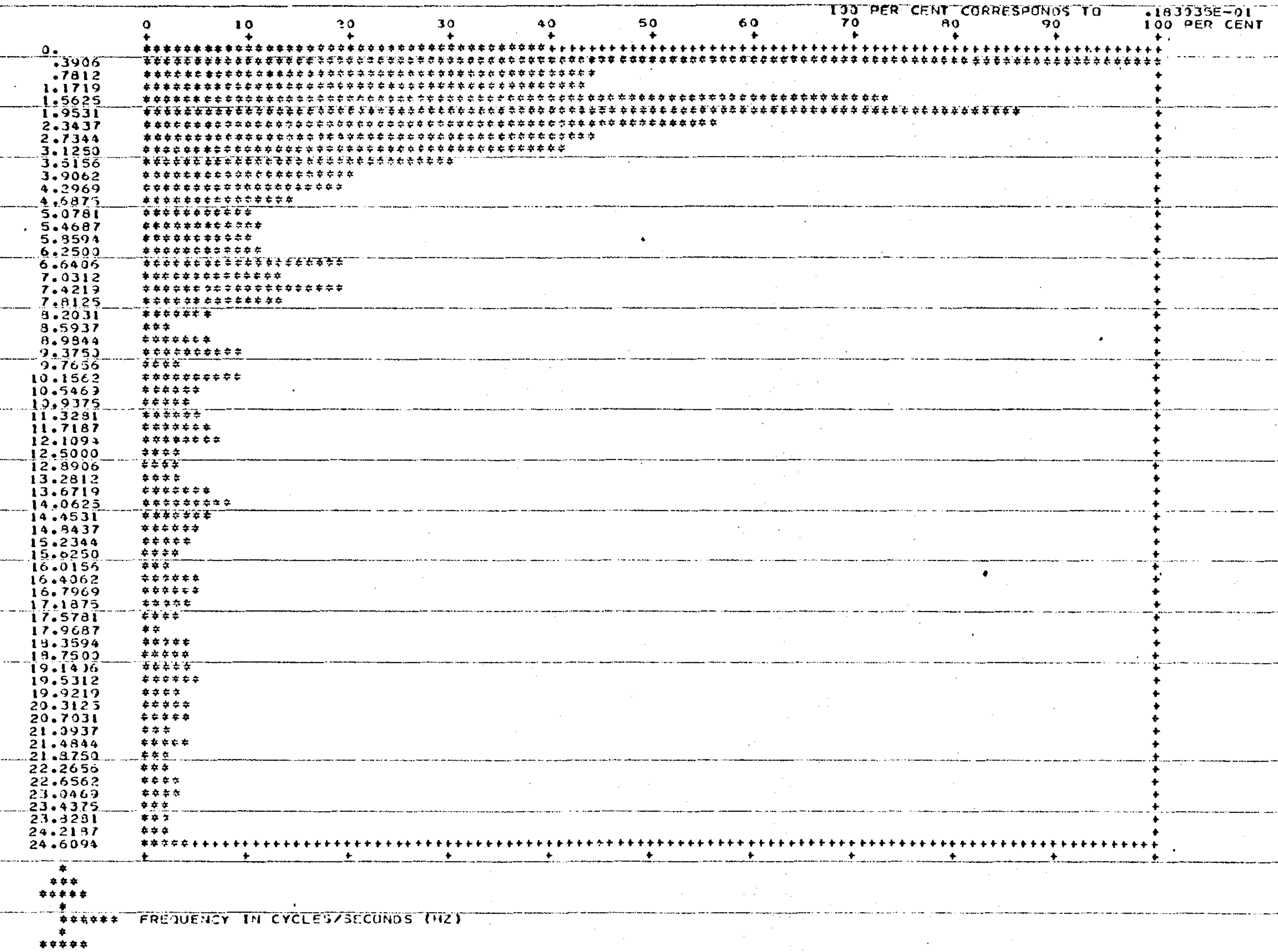
EARTHQUAKE MOTION

  1      -.001430     -.011020     -.010300     -.003980     -.009690     -.012240     -.014430     -.013060
  2      -.011220     -.008670     -.008670     -.013360     -.017950     -.019790     -.016520     -.014690
  3      -.011020     -.008360     -.004280     -.006730     -.013360     -.019390     -.019990     -.006730
  4       .003060      .014380     -.005000     -.013060     -.014690     -.020700     -.026520     -.033150
  5      -.031210     -.017540     -.020090     -.016630     -.016730     -.006830      .002550      .015300
  6       .024070      .025700      .034270      .047220      .050190      .042740      .036620      .027640
  7       .023970      .034580      .042020      .054060      .065170      .074660      .066500      .061090
  8       .040800      .040800      .006430     -.052530     -.080270     -.061500     -.049370     -.025500
  9      -.006020      .013670      .031410      .050900      .072420      .101480      .124330      .155950
 10       .147790      .117800      .095370      .090980      .094450      .085570      .091900      .101280
```

```
   FIRST TIME DERIVATIVE OF EARTHQUAKE MOTION IN G/SEC

 1      .328510      .359290     -.260180      .111610     -.027550      .260320     -.076180     -.020220
 2     -.180780     -.040980      .070310      .338790      .115230      .020180     -.248600     -.004420
 3     -.302360     -.021580     -.285420      .503620      .095480      .519640     -.640750     -.373580
 4     -.864520      .294050     1.004610     -.000050      .215650      .352230      .230750      .383670
 5     -.716560     -.208320      .050480     -.123690     -.145090     -.621870     -.446390     -.709250
 6     -.143690     -.167400     -.671860     -.462520      .159230      .456280      .219110      .624480
 7     -.420090     -.355870     -.590220     -.445990     -.800120      .199220      .139900      .820790
 8      .521640      .305510     2.885020     2.563410     -.076500    -1.034410     -.632580    -1.404290
 9     -.729060    -1.117760     -.775350    -1.083820    -1.241040    -1.364890    -1.303440    -1.165500
10     1.663420     1.102900     1.050770     -.557380      .527550     -.094690     -.193340    -1.185260
```

```
*OVF*
CURVE 1  -  FOURIER SPECTRUM OF EARTHQUAKE MOTION
            *EVERY    1    POINT IS PLOTTED*
```



```
         CURVE                              TABLE OF FUNCTION VALUES (ALL POINTS INCLUDED)

 0.        1    .7163E-02  .1930E-01  .8114E-02  .7814E-02  .1341E-01  .1569E-01  .1024E-01  .8029E-02  .7525E-02  .5572E-02
 3.9062    1    .3741E-02  .3393E-02  .2479E-02  .1761E-02  .1350E-02  .1860E-02  .2013E-02  .3392E-02  .2329E-02  .3462E-02
 7.8125    1    .2330E-02  .1057E-02  .4138E-03  .1068E-02  .1622E-02  .5027E-03  .1581E-02  .9686E-03  .7559E-03  .8869E-03
11.7187    1    .1156E-02  .1312E-02  .5920E-03  .4706E-03  .6290E-03  .1132E-02  .1513E-02  .1152E-02  .8337E-03  .7016E-03
15.6250    1    .5497E-03  .4551E-03  .8807E-03  .9817E-03  .6773E-03  .4679E-03  .2412E-03  .7909E-03  .8203E-03  .6571E-03
19.5312    1    .9551E-03  .5050E-03  .6710E-03  .6936E-03  .3886E-03  .7290E-03  .3153E-03  .4517E-03  .4696E-03  .6235E-03
23.4375    1    .3719E-03  .3707E-03  .3985E-03  .7318E-03


        MAXIMUM BASE ACCELERATION BEFORE FILTERING          .100
        MAXIMUM BASE ACCELERATION AFTER FILTERING           .100
              WHEN USING A FILTER FREQUENCY OF          24.609   CPS
```

```
*OVF*

      LIQUEFACTION DATA

      APOLLO--EXAMPLE PROBLEM--CDC 6400

      BOTTOM OF LAYER NO    5    DEPTH       15.0    INITIAL EFFECTIVE STRESS      1210.000
      BOTTOM OF LAYER NO    6    DEPTH       20.0    INITIAL EFFECTIVE STRESS      1510.000
      BOTTOM OF LAYER NO    7    DEPTH       25.0    INITIAL EFFECTIVE STRESS      1810.000
      BOTTOM OF LAYER NO    8    DEPTH       30.0    INITIAL EFFECTIVE STRESS      2110.000
      BOTTOM OF LAYER NO    9    DEPTH       32.5    INITIAL EFFECTIVE STRESS      2260.000
      BOTTOM OF LAYER NO   10    DEPTH       35.0    INITIAL EFFECTIVE STRESS      2410.000
      BOTTOM OF LAYER NO   11    DEPTH       40.0    INITIAL EFFECTIVE STRESS      2710.000
      BOTTOM OF LAYER NO   12    DEPTH       45.0    INITIAL EFFECTIVE STRESS      3010.000
      BOTTOM OF LAYER NO   13    DEPTH       50.0    INITIAL EFFECTIVE STRESS      3310.000

      TIME IN SECONDS

   0.        .10       .25       .35       .45       .55       .65       .75       .85       .95      1.05      1.15      1.25      1.35      1.45
  1.55      1.65      1.75      1.85      1.95      2.05      2.15      2.25      2.35      2.45      2.55      2.65      2.75      2.85      2.95
  3.05      3.15      3.25      3.35      3.45      3.55      3.65      3.75      3.85      3.95      4.05      4.15      4.25      4.35      4.45
  4.55      4.65      4.75      4.85      4.95      5.05      5.15      5.25      5.35      5.45      5.55      5.65      5.75      5.85      5.95
  6.05      6.15      6.25      6.35      6.45      6.55      6.65      6.75      6.85      6.95      7.05      7.15      7.25      7.35      7.45
  7.55      7.65      7.75      7.85      7.95      8.05      8.15      8.25      8.35      8.45      8.55      8.65      8.75      8.85      8.95
  9.05      9.15      9.25      9.35      9.45      9.55      9.65      9.75      9.85      9.95     -0.       -0.       -0.

      WATER TABLE RISE HISTORY

 5.000     5.000     5.000     5.000     5.000     5.000     5.000     5.000     5.000     5.000     5.000     4.990     4.954     4.899     4.827
 4.736     4.623     4.479     4.275     4.000     4.000     4.000     4.000     4.000     3.999     3.999     3.999     3.999     3.999     3.999
 3.999     3.998     3.998     3.998     3.998     3.998     3.998     3.998     3.998     3.997     3.997     3.997     3.997     3.997     3.997
 3.997     3.996     3.996     3.996     3.996     3.996     3.996     3.996     3.995     3.995     3.995     3.995     3.995     3.995     3.995
 3.994     3.994     3.994     3.994     3.994     3.994     3.994     3.993     3.993     3.993     3.993     3.993     3.993     3.993     3.992
 3.992     3.992     3.992     3.992     3.992     3.992     3.991     3.991     3.991     3.991     3.991     3.991     3.990     3.990     3.990
 3.990     3.990     3.990     3.990     3.989     3.989     3.989     3.989     3.989     3.989    -0.       -0.       -0.
```

```
                 STRESS REDUCTION FACTOR FOR LINE NO     1

   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000    .9900    .9768    .9648    .9529
    .9408    .9280    .9140    .8973    .8772    .8715    .8555    .8307    .8077    .7859    .7648    .7444    .7245    .7050    .6857
    .6666    .6541    .6480    .6420    .6359    .6299    .6239    .6178    .6118    .6058    .5998    .5937    .5877    .5816    .5756
    .5695    .5634    .5573    .5512    .5451    .5390    .5328    .5265    .5203    .5140    .5077    .5014    .4950    .4886    .4821
    .4756    .4714    .4697    .4680    .4663    .4647    .4630    .4613    .4596    .4580    .4563    .4546    .4530    .4513    .4496
    .4480    .4463    .4447    .4430    .4414    .4397    .4370    .4333    .4296    .4274    .4267    .4261    .4254    .4248    .4241
    .4235    .4229    .4222    .4216    .4210    .4204    .4198    .4192    .4186    .4180 -0.      -0.      -0.

                 STRESS REDUCTION FACTOR FOR LINE NO     2

   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000    .9882    .9732    .9600    .9473
    .9346    .9216    .9078    .8920    .8736    .8667    .8473    .8173    .7893    .7627    .7370    .7121    .6876    .6635    .6395
    .6157    .6002    .5929    .5856    .5783    .5710    .5637    .5563    .5489    .5415    .5340    .5265    .5190    .5114    .5038
    .4961    .4884    .4806    .4727    .4648    .4568    .4487    .4405    .4322    .4239    .4154    .4068    .3980    .3892    .3802
    .3710    .3654    .3634    .3615    .3596    .3576    .3557    .3537    .3518    .3498    .3478    .3458    .3438    .3418    .3398
    .3378    .3357    .3337    .3316    .3296    .3275    .3238    .3184    .3128    .3098    .3093    .3087    .3082    .3077    .3072
    .3067    .3062    .3056    .3051    .3046    .3041    .3036    .3031    .3026    .3021 -0.      -0.      -0.

                 STRESS REDUCTION FACTOR FOR LINE NO     3

   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000    .9870    .9706    .9565    .9431
    .9301    .9169    .9032    .8873    .8704    .8627    .8408    .8069    .7752    .7450    .7158    .6873    .6592    .6314    .6037
    .5759    .5577    .5494    .5409    .5325    .5240    .5155    .5069    .4982    .4895    .4807    .4719    .4629    .4538    .4447
    .4354    .4261    .4166    .4069    .3971    .3871    .3769    .3666    .3560    .3451    .3340    .3226    .3109    .2987    .2861
    .2731    .2652    .2628    .2604    .2581    .2556    .2532    .2508    .2483    .2458    .2432    .2407    .2381    .2355    .2329
    .2301    .2274    .2247    .2219    .2191    .2162    .2105    .2017    .1926    .1876    .1872    .1868    .1864    .1860    .1856
    .1852    .1848    .1844    .1840    .1837    .1833    .1829    .1825    .1822    .1818 -0.      -0.      -0.

                 STRESS REDUCTION FACTOR FOR LINE NO     4

   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000    .9862    .9691    .9545    .9408
    .9276    .9144    .9008    .8859    .8694    .8612    .8377    .8014    .7675    .7351    .7037    .6730    .6427    .6126    .5825
    .5521    .5323    .5233    .5143    .5051    .4960    .4867    .4773    .4679    .4583    .4487    .4389    .4290    .4189    .4087
    .3983    .3877    .3768    .3658    .3545    .3429    .3310    .3188    .3061    .2930    .2793    .2651    .2501    .2343    .2174
    .1992    .1880    .1849    .1819    .1787    .1755    .1722    .1689    .1654    .1620    .1584    .1547    .1509    .1470    .1430
    .1389    .1347    .1303    .1257    .1210    .1160    .1050    .0856    .0603    .0423    .0424    .0425    .0426    .0428    .0429
    .0430    .0431    .0433    .0434    .0435    .0436    .0437    .0439    .0440    .0441 -0.      -0.      -0.

                 STRESS REDUCTION FACTOR FOR LINE NO     5

   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000    .9862    .9691    .9546    .9410
    .9279    .9149    .9016    .8870    .8709    .8627    .8391    .8027    .7685    .7359    .7044    .6735    .6430    .6126    .5822
    .5516    .5316    .5224    .5132    .5040    .4947    .4853    .4758    .4662    .4566    .4468    .4369    .4269    .4167    .4063
    .3958    .3851    .3741    .3629    .3515    .3397    .3276    .3152    .3023    .2890    .2751    .2605    .2452    .2290    .2116
    .1928    .1811    .1780    .1747    .1714    .1681    .1646    .1611    .1575    .1539    .1501    .1462    .1422    .1381    .1339
    .1295    .1250    .1203    .1153    .1102    .1048    .0925    .0698    .0345  0.          .0002    .0005    .0009    .0012    .0015
    .0018    .0022    .0025    .0028    .0031    .0034    .0037    .0040    .0043    .0045 -0.      -0.      -0.
```

```
          STRESS REDUCTION FACTOR FOR LINE NO      6

   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000     .9862     .9692     .9549     .9415
    .9286     .9159     .9027     .8896     .8730     .8648     .8413     .8048     .7708     .7383     .7068     .6761     .6459     .6156     .5854
    .5550     .5352     .5263     .5172     .5081     .4990     .4897     .4803     .4709     .4613     .4517     .4419     .4319     .4218     .4116
    .4012     .3906     .3798     .3687     .3574     .3458     .3339     .3217     .3090     .2959     .2823     .2681     .2532     .2375     .2207
    .2027     .1916     .1886     .1856     .1825     .1793     .1761     .1728     .1695     .1661     .1626     .1590     .1553     .1515     .1476
    .1436     .1395     .1353     .1308     .1263     .1215     .1110     .0928     .0699     .0338        0.        0.        0.        0.        0.
       0.        0.        0.     .0000     .0000     .0000     .0000     .0001     .0001     .0001       -0.       -0.       -0.

          STRESS REDUCTION FACTOR FOR LINE NC      7

   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000     .9871     .9711     .9576     .9450
    .9328     .9208     .9086     .8954     .8809     .8731     .8508     .8163     .7841     .7533     .7235     .6944     .6658     .6373     .6090
    .5805     .5617     .5529     .5441     .5352     .5264     .5174     .5084     .4994     .4903     .4812     .4719     .4626     .4532     .4437
    .4341     .4243     .4144     .4044     .3942     .3838     .3733     .3625     .3514     .3402     .3286     .3167     .3044     .2917     .2785
    .2647     .2564     .2539     .2514     .2489     .2463     .2438     .2412     .2386     .2360     .2333     .2306     .2279     .2252     .2224
    .2196     .2168     .2140     .2111     .2081     .2052     .1992     .1899     .1801     .1697     .1586     .1469     .1341     .1202     .1046
    .0364     .0634     .0241        0.        0.        0.        0.        0.        0.        0.       -0.       -0.       -0.

          STRESS REDUCTION FACTOR FOR LINE NO      8

   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000     .9871     .9713     .9580     .9457
    .9339     .9223     .9106     .8980     .8844     .8767     .8545     .8202     .7883     .7580     .7287     .7002     .6722     .6445     .6169
    .5893     .5716     .5637     .5558     .5478     .5398     .5317     .5236     .5154     .5072     .4989     .4905     .4820     .4734     .4648
    .4560     .4472     .4382     .4291     .4199     .4105     .4010     .3913     .3814     .3713     .3610     .3505     .3397     .3286     .3171
    .3054     .2985     .2968     .2951     .2934     .2917     .2899     .2882     .2864     .2845     .2827     .2808     .2790     .2770     .2751
    .2732     .2712     .2692     .2672     .2652     .2631     .2586     .2517     .2445     .2371     .2295     .2217     .2135     .2051     .1963
    .1870     .1773     .1669     .1553     .1439     .1311     .1170     .1012     .0824     .0579       -0.       -0.       -0.

          STRESS REDUCTION FACTOR FOR LINE NC      9

   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000     .9884     .9742     .9622     .9511
    .9404     .9298     .9192     .9077     .8953     .8882     .8633     .8375     .8088     .7815     .7552     .7296     .7045     .6793     .6553
    .6309     .6150     .6075     .6001     .5925     .5852     .5777     .5703     .5628     .5552     .5477     .5401     .5325     .5249     .5172
    .5094     .5016     .4938     .4858     .4778     .4697     .4616     .4533     .4450     .4365     .4280     .4193     .4105     .4015     .3924
    .3831     .3775     .3756     .3737     .3718     .3699     .3681     .3662     .3643     .3625     .3606     .3587     .3569     .3550     .3531
    .3513     .3494     .3475     .3456     .3437     .3419     .3383     .3331     .3277     .3224     .3169     .3113     .3056     .2998     .2939
    .2878     .2816     .2753     .2688     .2622     .2553     .2433     .2410     .2334     .2255       -0.       -0.       -0.
```

```
*OVN*

CP TIME FOR SETTING UP PROBLEM                      6.91300   SECS

CP TIME FOR SOLUTION IN TIME DOMAIN                25.71000   SECS
TOTAL ELAPSED CP TIME                              32.62300   SECS
```

```
*OVF*

MAXIMUM STRESS      MAXIMUM STRAIN        MAXIMUM ACC.        TIME OF MAX. ACC.      DEPTH      ELT
                       IN PCT.          BEFORE FILTERING

   .4429E+02          .6683E-02             .2178                1.532000             0.          1
   .1324E+03          .1853E-01             .2169                1.532000             3.33        2
   .2193E+03          .2960E-01             .2140                1.528000             6.67        3
   .3253E+03          .4282E-01             .2095                1.524000            10.00        4
   .4461E+03          .5792E-01             .1996                1.520000            15.00        5
   .5570E+03          .7143E-01             .1842                1.516000            20.00        6
   .6551E+03          .8211E-01             .1629                1.512000            25.00        7
   .7383E+03          .8935E-01             .1392                1.496000            30.00        8
   .8071E+03          .9303E-01             .1204                1.472000            35.00        9
   .8637E+03          .9330E-01             .1030                1.456000            40.00       10
   .9097E+03          .9245E-01             .1014                1.428000            45.00       11
```

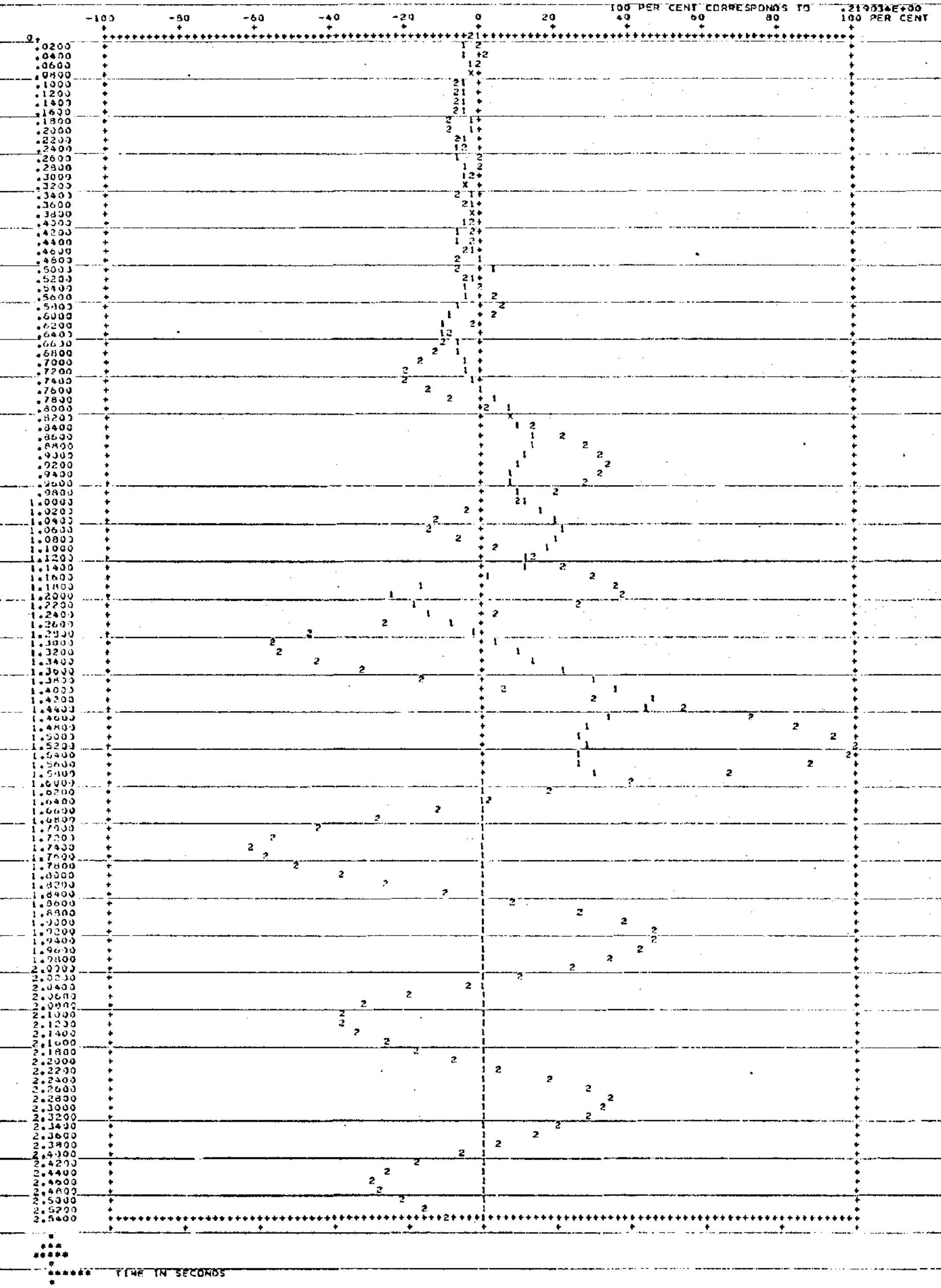
```
*OVN*

     CP TIME TO REWIND  2 TAPES                              .20500   SECS
     TOTAL ELAPSED CP TIME                                 32.82800   SECS
```

```
*DVE*

*****************************  ELEMENT NO      1   ******************************

CURVE 1  -   EARTHQUAKE ACCELERATION  (G)
CURVE 2  -  ACCELERATION TIME HISTORY  (G)
             *EVERY    1    POINT IS PLOTTED*
                                                                    100 PER CENT CORRESPONDS TO    .219034E+00
```



```
         CURVE                              TABLE OF FUNCTION VALUES (ALL POINTS INCLUDED)

  0.       1   -.9170E-03 -.7066E-02 -.6605E-02 -.3758E-02 -.6214E-02 -.7949E-02 -.9295E-02 -.8374E-02 -.7195E-02 -.5559E-02
           2   -.6039E-02  .1713E-02  .4261E-02 -.1623E-03 -.6127E-02 -.1106E-01 -.1377E-01 -.1295E-01 -.1240E-01 -.1071E-01
   .2000   1   -.5559E-02 -.8367E-02 -.1151E-01 -.1269E-01 -.1059E-01 -.9420E-02 -.7066E-02 -.5361E-02 -.2744E-02 -.4315E-02
           2   -.1719E-01 -.1516E-01 -.7240E-02 -.3282E-03  .2158E-02 -.2647E-02 -.8076E-02 -.1143E-01 -.9053E-02 -.6468E-02
   .4000   1   -.9567E-02 -.1243E-01 -.1282E-01 -.4315E-02  .1962E-02  .9221E-02 -.3206E-02 -.8374E-02 -.9420E-02 -.1327E-01
           2   -.4365E-02 -.5649E-02 -.6553E-02 -.9261E-02 -.1156E-01 -.1421E-01 -.1077E-01 -.1923E-02  .1040E-01  .1524E-01
   .6000   1   -.1731E-01 -.2176E-01 -.2001E-01 -.1127E-01 -.1289E-01 -.1966E-01 -.1073E-01 -.4390E-02  .1675E-02  .9811E-02
           2    .1024E-01 -.1492E-02 -.1545E-01 -.2376E-01 -.2836E-01 -.3567E-01 -.4174E-01 -.4278E-01 -.3222E-01 -.1562E-01
   .8000   1    .1543E-01  .1644E-01  .3107E-01  .3028E-01  .3213E-01  .2741E-01  .2344E-01  .1772E-01  .1537E-01  .2217E-01
           2    .2777E-02  .1711E-01  .3194E-01  .4716E-01  .6313E-01  .7230E-01  .7435E-01  .6879E-01  .5994E-01  .4172E-01
  1.0000   1    .2694E-01  .3466E-01  .4179E-01  .4787E-01  .4264E-01  .3917E-01  .2616E-01  .2616E-01  .4123E-02 -.3368E-01
           2    .2043E-01 -.7970E-02 -.2753E-01 -.3016E-01 -.1316E-01  .1005E-01  .3213E-01  .4847E-01  .6545E-01  .7950E-01
  1.2000   1   -.5147E-01 -.3944E-01 -.3166E-01 -.1615E-01 -.3863E-02  .3766E-02  .2014E-01  .3264E-01  .4644E-01  .6507E-01
           2    .8192E-01  .5710E-01  .6721E-02 -.5529E-01 -.1025E+00 -.1216E+00 -.1177E+00 -.7841E-01 -.7014E-01 -.3514E-01
  1.4000   1    .7977E-01  .1003E+00  .9477E-01  .7554E-01  .6115E-01  .5934E-01  .6056E-01  .5497E-01  .5893E-01  .6494E-01
           2    .1226E-01  .6342E-01  .1168E+00  .1559E+00  .1349E+00  .2052E+00  .2190E+00  .2160E+00  .1906E+00  .1427E+00
  1.6000   1    .6088E-11  .1873E-09 -.8732E-11 -.1766E-09  .8677E-11  .1120E-09 -.3765E-11 -.8115E-10  .8664E-11  .6320E-10
           2    .4383E-01  .4174E-01  .5771E-02 -.2577E-01 -.5949E-01 -.9633E-01 -.1239E+00 -.1351E+00 -.1771E+00 -.1092E+00
  1.8000   1   -.3707E-11 -.5131E-10  .8640E-11  .4303E-10 -.8625E-11 -.3687E-10  .8673E-11  .3206E-10 -.8644E-11 -.2818E-10
           2   -.8532E-01 -.5844E-01 -.2375E-01  .1534E-01  .5481E-01  .8369E-01  .9932E-01  .9954E-01  .9048E-01  .7313E-01
  2.0000   1    .8773E-11  .2530E-10 -.8672E-11 -.2260E-10  .8634E-11  .2009E-10 -.8773E-11 -.1806E-10  .8676E-11  .1633E-10
           2    .5153E-01  .2323E-01 -.8226E-02 -.4166E-01 -.6904E-01 -.8348E-01 -.8329E-01 -.7340E-01 -.5710E-01 -.3986E-01
  2.2000   1   -.8663E-11 -.1457E-10  .8660E-11  .1279E-10 -.8784E-11 -.1140E-10  .8547E-11  .9486E-11 -.8707E-11 -.7559E-11
           2   -.1773E-01  .4827E-02  .3927E-01  .6271E-01  .7453E-01  .7072E-01  .5935E-01  .4419E-01  .2927E-01  .9566E-02
  2.4000   1    .8693E-11  .4994E-11 -.8646E-11 -.1013E-11  .8767E-11 -.6427E-11 -.8550E-11  .3020E-10
           2   -.1364E-01 -.3914E-01 -.5743E-01 -.3578E-01 -.6137E-01 -.5031E-01 -.3451E-01 -.1976E-01
```

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*OVF*
RESPONSE SPECTRUM CALCULATIONS

PROGRAM CONTROL INFORMATION:

   NO. OF ACCELERATION VALUES --------- NV    =  128
   NUMBER OF TERMS USED IN FFT -------- NF    =  128
   NUMBER OF DAMPING VALUES USED ------ ND    =    1
   SWITCH FOR FREQUENCIES USED -------- KFR   =    3
   NO. OF FREQU. STEPS IN 1 LOG. CYCLE  NS    =   20
   SWITCH FOR PRINTER-PLOTTED OUTPUT -- KPL   =    1
   SWITCH FOR PUNCHED OUTPUT ---------- KPU   =    1
   SWITCH FOR COMPUTATION OF SPECTRA -- KAV   =    2
   POINT FOR WHICH RESPONSE IS COMPUTED KV    =    1

   TIME STEP BETWEEN ACC. VALUES ------ DT    =     .020 SEC
   FIRST FREQU. FOR RESPONSE COMP. ---- FS    =     .050 C/SEC
   LAST FREQU. FOR RESPONSE COMP. ----- FF    =   25.000 C/SEC
   DAMPING VALUES USED ---------------- DD( )=     .050

   MAX. ACC. IN INPUT MOTION ---------- AMAX =   .219034 G
   TIME AT WHICH MAX. ACC. OCCURS ----- TMAX = 1.520 SEC
```

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RESPONSE SPECTRUM ANALYSIS -- MASH--TEST--RESPONSE SPECTRA                                  --TOP ELEMENT NO.     1

  TIMES AT WHICH MAX. SPECTRAL VALUES OCCUR FOR DAMPING RATIO = .05

  FREQ =   .050     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4000      PER =20.000    DT = .040    KUG =    63
  FREQ =   .056     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =17.825    DT = .040    KUG =    63
  FREQ =   .063     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =15.887    DT = .040    KUG =    63
  FREQ =   .071     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =14.159    DT = .040    KUG =    63
  FREQ =   .079     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =12.619    DT = .040    KUG =    63
  FREQ =   .089     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =11.247    DT = .040    KUG =    63
  FREQ =   .100     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =10.024    DT = .040    KUG =    63
  FREQ =   .112     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =  8.934   DT = .040    KUG =    63
  FREQ =   .126     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =  7.962   DT = .040    KUG =    63
  FREQ =   .141     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =  7.096   DT = .040    KUG =    63
  FREQ =   .158     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =  6.325   DT = .040    KUG =    63
  FREQ =   .177     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =  5.637   DT = .040    KUG =    63
  FREQ =   .199     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4400      PER =  5.024   DT = .040    KUG =    63
  FREQ =   .223     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4000      PER =  4.477   DT = .040    KUG =    63
  FREQ =   .251     TIMES FOR MAXIMA --    TD =   2.4000    TV =   1.6000    TA =   2.3600      PER =  3.991   DT = .040    KUG =    63
  FREQ =   .281     TIMES FOR MAXIMA --    TD =   2.1600    TV =   1.6000    TA =   2.0800      PER =  3.557   DT = .040    KUG =    63
  FREQ =   .315     TIMES FOR MAXIMA --    TD =   2.1200    TV =   1.6000    TA =   2.0400      PER =  3.170   DT = .040    KUG =    63
  FREQ =   .354     TIMES FOR MAXIMA --    TD =   2.0800    TV =   1.6000    TA =   2.0400      PER =  2.825   DT = .040    KUG =    63
  FREQ =   .397     TIMES FOR MAXIMA --    TD =   2.0400    TV =   1.6000    TA =   2.0000      PER =  2.518   DT = .040    KUG =    63
  FREQ =   .446     TIMES FOR MAXIMA --    TD =   1.7600    TV =   1.6000    TA =   1.7200      PER =  2.244   DT = .040    KUG =    63
  FREQ =   .500     TIMES FOR MAXIMA --    TD =   1.7600    TV =   1.5600    TA =   1.7200      PER =  2.000   DT = .040    KUG =    63
  FREQ =   .561     TIMES FOR MAXIMA --    TD =   1.7400    TV =   2.2000    TA =   1.7200      PER =  1.783   DT = .020    KUG =   127
  FREQ =   .629     TIMES FOR MAXIMA --    TD =   1.7200    TV =   2.1800    TA =   1.7000      PER =  1.589   DT = .020    KUG =   127
  FREQ =   .706     TIMES FOR MAXIMA --    TD =   1.7200    TV =   1.8600    TA =   1.7000      PER =  1.416   DT = .020    KUG =   127
  FREQ =   .792     TIMES FOR MAXIMA --    TD =   1.7200    TV =   1.8400    TA =   1.7000      PER =  1.262   DT = .020    KUG =   127
  FREQ =   .889     TIMES FOR MAXIMA --    TD =   1.7200    TV =   1.6000    TA =   1.7000      PER =  1.125   DT = .020    KUG =   127
  FREQ =   .998     TIMES FOR MAXIMA --    TD =   1.7400    TV =   1.6000    TA =   1.7200      PER =  1.002   DT = .020    KUG =   127
  FREQ =  1.119     TIMES FOR MAXIMA --    TD =   1.7400    TV =   1.6000    TA =   1.7200      PER =   .893   DT = .020    KUG =   127
  FREQ =  1.256     TIMES FOR MAXIMA --    TD =   1.7200    TV =   1.6000    TA =   1.7000      PER =   .796   DT = .020    KUG =   127
  FREQ =  1.409     TIMES FOR MAXIMA --    TD =   1.7000    TV =   1.8400    TA =   1.7000      PER =   .710   DT = .020    KUG =   127
  FREQ =  1.581     TIMES FOR MAXIMA --    TD =   1.6800    TV =   1.8200    TA =   1.6800      PER =   .632   DT = .020    KUG =   127
  FREQ =  1.774     TIMES FOR MAXIMA --    TD =   1.9000    TV =   1.7800    TA =   1.9000      PER =   .564   DT = .020    KUG =   127
  FREQ =  1.991     TIMES FOR MAXIMA --    TD =   1.8600    TV =   1.9800    TA =   1.8600      PER =   .502   DT = .020    KUG =   127
  FREQ =  2.233     TIMES FOR MAXIMA --    TD =   2.0600    TV =   2.1600    TA =   2.0400      PER =   .448   DT = .020    KUG =   127
  FREQ =  2.506     TIMES FOR MAXIMA --    TD =   2.2200    TV =   2.3000    TA =   2.2000      PER =   .399   DT = .020    KUG =   127
  FREQ =  2.812     TIMES FOR MAXIMA --    TD =   2.1600    TV =   2.2400    TA =   2.3400      PER =   .356   DT = .020    KUG =   127
  FREQ =  3.155     TIMES FOR MAXIMA --    TD =   1.5600    TV =   1.6400    TA =   1.5600      PER =   .317   DT = .020    KUG =   127
  FREQ =  3.540     TIMES FOR MAXIMA --    TD =   1.5200    TV =   1.5000    TA =   1.5200      PER =   .283   DT = .020    KUG =   127
  FREQ =  3.972     TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.4200    TA =   1.4800      PER =   .252   DT = .020    KUG =   127
  FREQ =  4.456     TIMES FOR MAXIMA --    TD =   1.4600    TV =   1.4000    TA =   1.4600      PER =   .224   DT = .020    KUG =   127
  FREQ =  5.000     TIMES FOR MAXIMA --    TD =   1.3200    TV =   1.3800    TA =   1.3200      PER =   .200   DT = .020    KUG =   127
  FREQ =  5.610     TIMES FOR MAXIMA --    TD =   1.5600    TV =   1.6200    TA =   1.5500      PER =   .178   DT = .010    KUG =   255
  FREQ =  6.295     TIMES FOR MAXIMA --    TD =   1.5500    TV =   1.6100    TA =   1.5400      PER =   .159   DT = .010    KUG =   255
  FREQ =  7.063     TIMES FOR MAXIMA --    TD =   1.5300    TV =   1.3600    TA =   1.5200      PER =   .142   DT = .010    KUG =   255
  FREQ =  7.924     TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.2700    TA =   1.4000      PER =   .126   DT = .010    KUG =   255
  FREQ =  8.891     TIMES FOR MAXIMA --    TD =   1.4700    TV =   1.6000    TA =   1.4700      PER =   .112   DT = .010    KUG =   255
  FREQ =  9.976     TIMES FOR MAXIMA --    TD =   1.5400    TV =   1.2400    TA =   1.5300      PER =   .100   DT = .010    KUG =   255
  FREQ =11.194      TIMES FOR MAXIMA --    TD =   1.5300    TV =   1.2400    TA =   1.5300      PER =   .089   DT = .010    KUG =   255
  FREQ =12.559      TIMES FOR MAXIMA --    TD =   1.5300    TV =   1.2400    TA =   1.5200      PER =   .080   DT = .010    KUG =   255
  FREQ =14.092      TIMES FOR MAXIMA --    TD =   1.5200    TV =   1.2400    TA =   1.5200      PER =   .071   DT = .010    KUG =   255
  FREQ =15.811      TIMES FOR MAXIMA --    TD =   1.5200    TV =   1.2400    TA =   1.5200      PER =   .063   DT = .010    KUG =   255
  FREQ =17.741      TIMES FOR MAXIMA --    TD =   1.5200    TV =   1.2400    TA =   1.5200      PER =   .056   DT = .010    KUG =   255
  FREQ =19.905      TIMES FOR MAXIMA --    TD =   1.5200    TV =   1.2400    TA =   1.5200      PER =   .050   DT = .010    KUG =   255
  FREQ =22.334      TIMES FOR MAXIMA --    TD =   1.5200    TV =   1.2400    TA =   1.5200      PER =   .045   DT = .010    KUG =   255

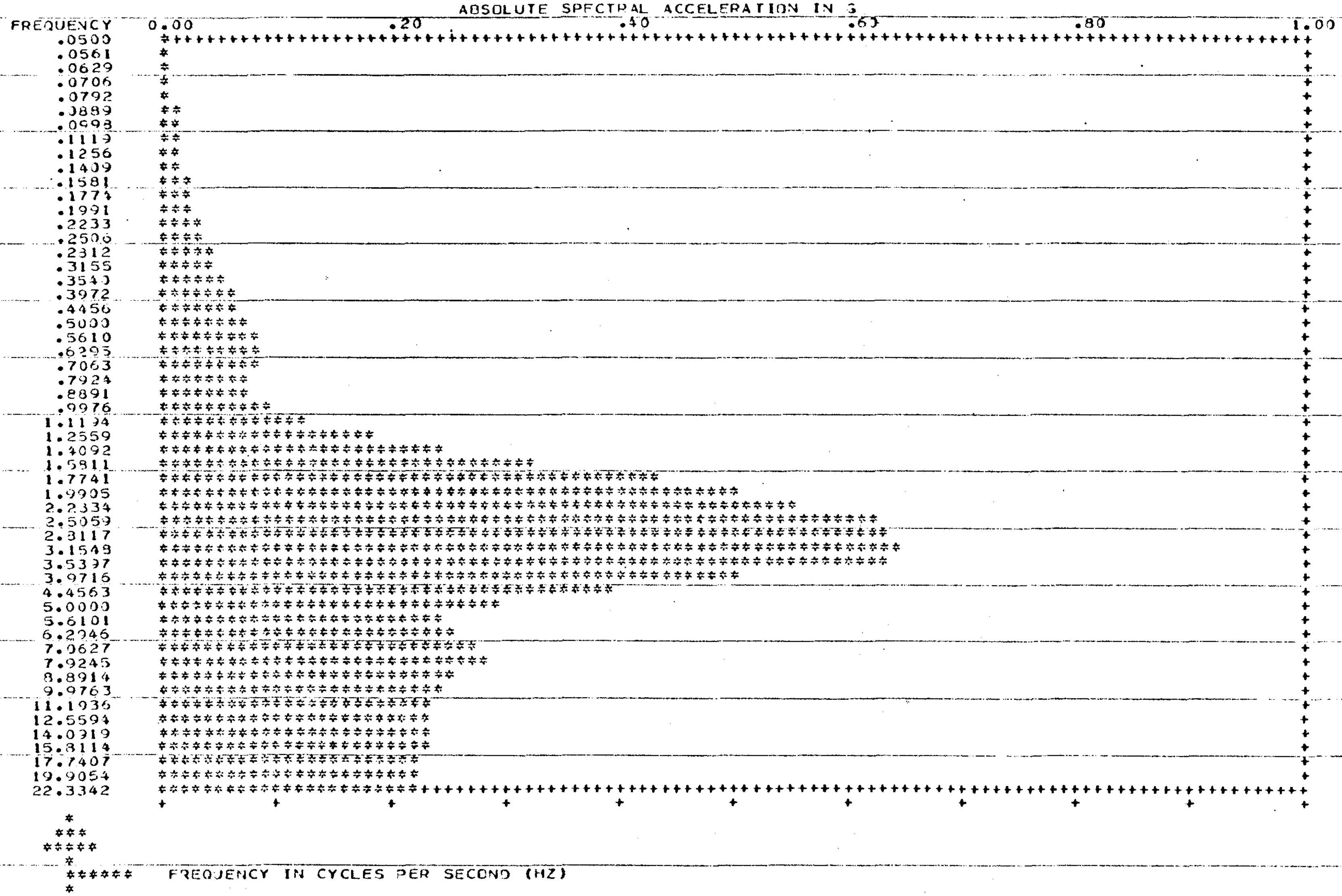
  NOTE:  TD = TIME FOR MAX. RELATIVE DISP.,  TV = TIME FOR MAX. RELATIVE VEL.,  TA = TIME FOR MAX. ABSOLUTE ACC.
```

TABLE OF SPECTRAL VALUES FOR DAMPING RATIO = .05

NO.	FREQCY C/SEC.	REL. DISP. FT.	REL. VEL. FT./SEC.	PSU.REL.VEL. FT./SEC.	ABS. ACC. G.	PSU.ABS.ACC. G.	PERIOD SEC.
1	.050	.55392	.92087	.17402	.00217	.00170	20.000
2	.056	.55407	.92277	.19530	.00266	.00214	17.825
3	.063	.55423	.92511	.21920	.00326	.00269	15.897
4	.071	.55437	.92800	.24601	.00402	.00339	14.159
5	.079	.55442	.93153	.27605	.00495	.00427	12.619
6	.089	.55422	.93580	.30962	.00611	.00537	11.247
7	.100	.55357	.94092	.34700	.00754	.00675	10.024
8	.112	.55210	.94697	.38830	.00930	.00849	8.934
9	.125	.54925	.95398	.43343	.01146	.01062	7.962
10	.141	.54416	.96192	.48181	.01406	.01325	7.096
11	.158	.53561	.97059	.53211	.01715	.01642	6.325
12	.177	.52187	.97953	.58172	.02070	.02014	5.637
13	.199	.50065	.98796	.62515	.02474	.02432	5.024
14	.223	.46937	.99454	.65825	.02914	.02869	4.477
15	.251	.42996	.99723	.67698	.03346	.03310	3.991
16	.281	.38455	.99311	.67936	.03779	.03727	3.557
17	.315	.35911	.97834	.71182	.04441	.04392	3.170
18	.354	.32602	.94834	.72510	.05066	.05008	2.825
19	.397	.28390	.89850	.70847	.05532	.05491	2.518
20	.446	.25300	.82573	.70839	.06240	.06160	2.244
21	.500	.22814	.73999	.71673	.07099	.06993	2.000
22	.561	.19688	.73310	.69399	.07697	.07597	1.783
23	.629	.15940	.63544	.63045	.07853	.07744	1.589
24	.706	.12135	.55525	.53852	.07519	.07422	1.416
25	.792	.08961	.52411	.44620	.06993	.06930	1.262
26	.889	.07202	.48997	.40233	.07072	.06980	1.125
27	.998	.07116	.58795	.44694	.08809	.08683	1.002
28	1.119	.08027	.70361	.56452	.12493	.12330	.893
29	1.256	.09060	.80132	.71497	.17594	.17522	.796
30	1.409	.09841	.99109	.87133	.24142	.23960	.710
31	1.581	.10335	1.20792	1.02673	.31822	.31677	.632
32	1.774	.11039	1.32087	1.23698	.43260	.42790	.564
33	1.991	.10271	1.38461	1.28462	.50441	.49896	.502
34	2.233	.08914	1.30905	1.25086	.55078	.54513	.448
35	2.505	.07928	1.28625	1.24831	.61939	.61040	.399
36	2.812	.06507	1.10553	1.14962	.62964	.63073	.356
37	3.155	.05201	.92350	1.03092	.63699	.63463	.317
38	3.540	.04102	.70446	.91229	.63412	.63013	.283
39	3.972	.02569	.47371	.64109	.49728	.49683	.252
40	4.456	.01566	.32643	.43840	.38651	.38121	.224
41	5.000	.00944	.23172	.29646	.28745	.28924	.200
42	5.610	.00618	.14031	.21777	.23845	.23839	.178
43	6.295	.00522	.10987	.20659	.25471	.25374	.159
44	7.063	.00436	.08009	.19334	.26695	.26646	.142
45	7.924	.00357	.07023	.17758	.27571	.27460	.126
46	8.891	.00255	.06380	.14246	.24823	.24717	.112
47	9.976	.00199	.04667	.12451	.24166	.24238	.100
48	11.194	.00151	.02829	.10641	.23240	.23242	.089
49	12.559	.00118	.02012	.09321	.22834	.22842	.080
50	14.092	.00093	.01501	.08231	.22658	.22634	.071
51	15.811	.00073	.01144	.07293	.22512	.22499	.063
52	17.741	.00058	.00882	.06468	.22396	.22390	.056
53	19.905	.00046	.00686	.05742	.22305	.22302	.050
54	22.334	.00036	.00536	.05102	.22233	.22233	.045

CVF

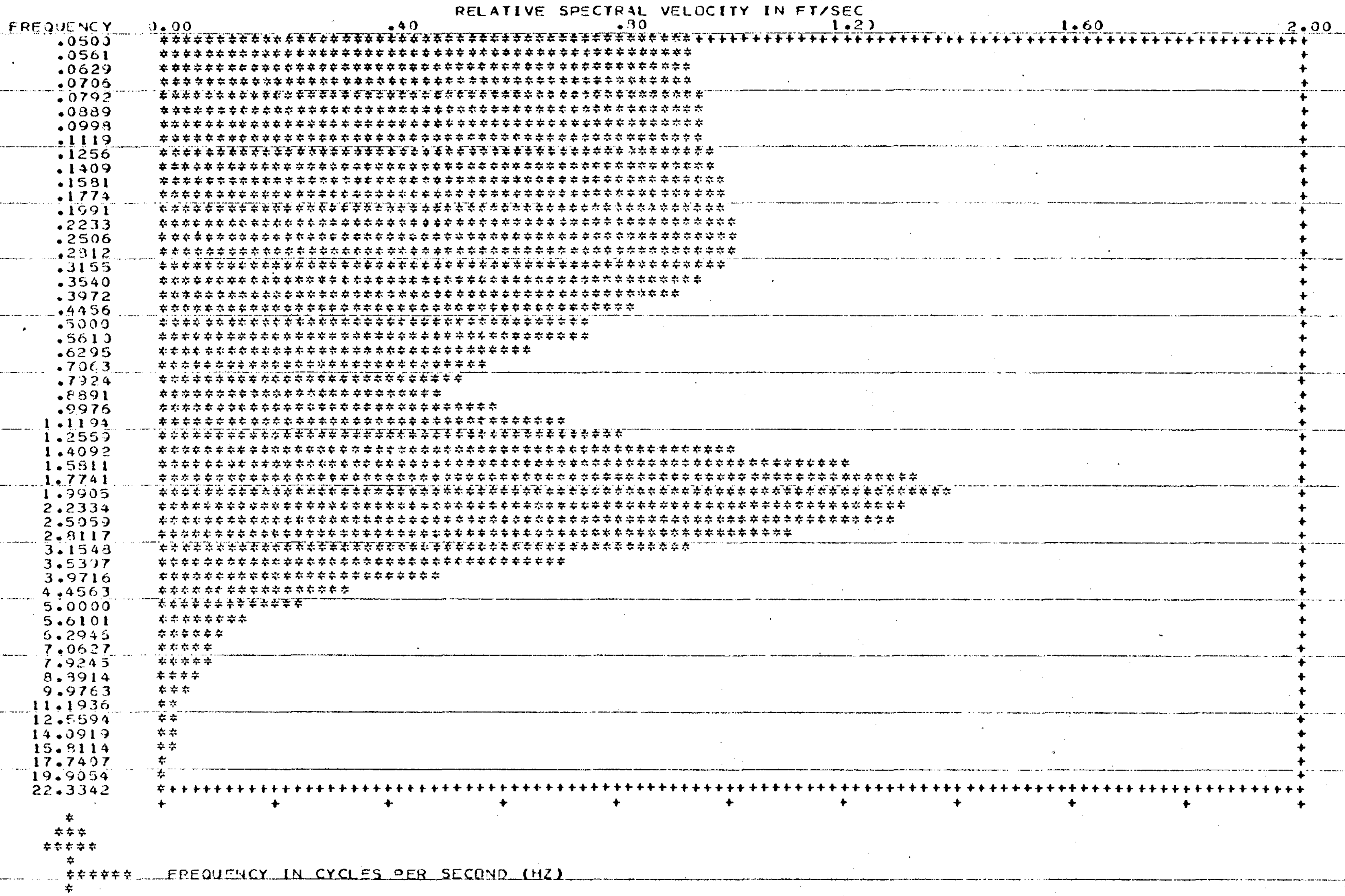
```
PLOT OF ACCELERATION SPECTRA FOR:MASH--TEST--RESPONSE SPECTRA                                --TOP ELEMENT NO.    1
                    CURVE 1 : DAMPING = .05 , MAX. ABS. SPECTRAL ACC. =  .637 G AT FREQUENCY =  3.155 C/SEC
```



```
          CURVE                                  TABLE OF FUNCTION VALUES (ALL POINTS INCLUDED)

  .0500     1     .2173E-02  .2656E-02  .3263E-02  .4016E-02  .4950E-02  .6108E-02  .7539E-02  .9301E-02  .1146E-01  .1406E-01
  .1581     1     .1715E-01  .2070E-01  .2474E-01  .2914E-01  .3345E-01  .3779E-01  .4441E-01  .5066E-01  .5532E-01  .6240E-01
  .5000     1     .7090E-01  .7699E-01  .7853E-01  .7518E-01  .6993E-01  .7072E-01  .8809E-01  .1249E+00  .1750E+00  .2414E+00
 1.5811     1     .3182E+00  .4326E+00  .5044E+00  .5508E+00  .6194E+00  .6296E+00  .6370E+00  .6341E+00  .4973E+00  .3865E+00
 5.0000     1     .2974E+00  .2335E+00  .2547E+00  .2669E+00  .2757E+00  .2483E+00  .2417E+00  .2324E+00  .2283E+00  .2266E+00
15.8114     1     .2251E+00  .2240E+00  .2230E+00  .2223E+00
```

```
IT OF VELOCITY SPECTRA FOR:MASH--TEST--RESPONSE SPECTRA                          --TOP ELEMENT NO.    1
             CURVE I : DAMPING = .05 , MAX. REL. SPECTRAL VEL. = 1.395 FT/SEC AT FREQUENCY =  1.991 C/SEC
```



```
            CURVE                              TABLE OF FUNCTION VALUES (ALL POINTS INCLUDED)

   .0500      1     .9209E+00  .9228E+00  .9251E+00  .9280E+00  .9315E+00  .9358E+00  .9409E+00  .9470E+00  .9540E+00  .9619E+00
   .1581      1     .9706E+00  .9795E+00  .9880E+00  .9945E+00  .9972E+00  .9931E+00  .9783E+00  .9483E+00  .8995E+00  .8257E+00
   .5000      1     .7400E+00  .7331E+00  .6354E+00  .5553E+00  .5241E+00  .4900E+00  .5990E+00  .7036E+00  .8013E+00  .9911E+00
  1.5811      1     .1208E+01  .1321E+01  .1385E+01  .1309E+01  .1286E+01  .1106E+01  .9235E+00  .7045E+00  .4737E+00  .3264E+00
  5.0000      1     .2317E+00  .1403E+00  .1099E+00  .8009E-01  .7023E-01  .6380E-01  .4667E-01  .2829E-01  .2012E-01  .1501E-01
 15.8114      1     .1144E-01  .8823E-02  .6856E-02  .5358E-02

TIME REQUIRED FOR COMPUTATION OF RESPONSE SPECTRA      4.251 SEC.
```

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*OVF*
RESPONSE SPECTRUM CALCULATIONS

PROGRAM CONTROL INFORMATION:

  NO. OF ACCELERATION VALUES ---------- NV   =  128
  NUMBER OF TERMS USED IN FFT --------- NF   =  128
  NUMBER OF DAMPING VALUES USED ------ ND   =    1
  SWITCH FOR FREQUENCIES USED --------- KFR  =    3
  NO. OF FREQU. STEPS IN 1 LOG. CYCLE  NS   =   20
  SWITCH FOR PRINTER-PLOTTED OUTPUT -- KPL  =    1
  SWITCH FOR PUNCHED OUTPUT ----------- KPU  =    1
  SWITCH FOR COMPUTATION OF SPECTRA -- KAV  =    2
  POINT FOR WHICH RESPONSE IS COMPUTED KV   =    6

  TIME STEP BETWEEN ACC. VALUES ------ DT   =     .020 SEC
  FIRST FREQU. FOR RESPONSE COMP. ---- FS   =     .050 C/SEC
  LAST FREQU. FOR RESPONSE COMP. ----- FE   =   25.000 C/SEC
  DAMPING VALUES USED ---------------- DD( )=     .050

  MAX. ACC. IN INPUT MOTION ---------- AMAX =  .183163 G
  TIME AT WHICH MAX. ACC. OCCURS ----- TMAX = 1.520 SEC
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RESPONSE SPECTRUM ANALYSIS -- MASH--TEST--RESPONSE SPECTRA                                          --TOP ELEMENT NC.      6

  TIMES AT WHICH MAX. SPECTRAL VALUES OCCUR FOR DAMPING RATIO = .05

  FREQ =   .050     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =20.000    DT = .040    KUG =    63
  FREQ =   .056     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.5000    TA =   2.4800      PER =17.825    DT = .040    KUG =    63
  FREQ =   .063     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =15.887    DT = .040    KUG =    63
  FREQ =   .071     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.5000    TA =   2.4800      PER =14.159    DT = .040    KUG =    63
  FREQ =   .079     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER =12.619    DT = .040    KUG =    63
  FREQ =   .089     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4900      PER =11.247    DT = .040    KUG =    63
  FREQ =   .100     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.5000    TA =   2.4800      PER =10.024    DT = .040    KUG =    63
  FREQ =   .112     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4800      PER = 8.934    DT = .040    KUG =    63
  FREQ =   .126     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.5000    TA =   2.4800      PER = 7.962    DT = .040    KUG =    63
  FREQ =   .141     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.5000    TA =   2.4800      PER = 7.096    DT = .040    KUG =    63
  FREQ =   .158     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.5000    TA =   2.4800      PER = 6.325    DT = .040    KUG =    63
  FREQ =   .177     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.5000    TA =   2.4800      PER = 5.637    DT = .040    KUG =    63
  FREQ =   .199     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4400      PER = 5.024    DT = .040    KUG =    63
  FREQ =   .223     TIMES FOR MAXIMA --    TD =   2.4800    TV =   1.6000    TA =   2.4000      PER = 4.477    DT = .040    KUG =    63
  FREQ =   .251     TIMES FOR MAXIMA --    TD =   2.4000    TV =   1.6000    TA =   2.3600      PER = 3.991    DT = .040    KUG =    63
  FREQ =   .291     TIMES FOR MAXIMA --    TD =   2.1600    TV =   1.6000    TA =   2.0800      PER = 3.557    DT = .040    KUG =    63
  FREQ =   .315     TIMES FOR MAXIMA --    TD =   2.1200    TV =   1.6000    TA =   2.0800      PER = 3.170    DT = .040    KUG =    63
  FREQ =   .354     TIMES FOR MAXIMA --    TD =   2.0800    TV =   1.6000    TA =   2.0400      PER = 2.825    DT = .040    KUG =    63
  FREQ =   .397     TIMES FOR MAXIMA --    TD =   2.0000    TV =   1.6000    TA =   2.0000      PER = 2.518    DT = .040    KUG =    63
  FREQ =   .446     TIMES FOR MAXIMA --    TD =   1.8000    TV =   1.6000    TA =   1.7600      PER = 2.244    DT = .040    KUG =    63
  FREQ =   .500     TIMES FOR MAXIMA --    TD =   1.7600    TV =   2.2000    TA =   1.7200      PER = 2.000    DT = .040    KUG =    63
  FREQ =   .561     TIMES FOR MAXIMA --    TD =   1.7400    TV =   2.1800    TA =   1.7200      PER = 1.783    DT = .020    KUG =   127
  FREQ =   .629     TIMES FOR MAXIMA --    TD =   1.7200    TV =   2.1600    TA =   1.7000      PER = 1.589    DT = .020    KUG =   127
  FREQ =   .706     TIMES FOR MAXIMA --    TD =   1.7200    TV =   1.8600    TA =   1.7000      PER = 1.416    DT = .020    KUG =   127
  FREQ =   .792     TIMES FOR MAXIMA --    TD =   1.7200    TV =   1.8400    TA =   1.7000      PER = 1.262    DT = .020    KUG =   127
  FREQ =   .889     TIMES FOR MAXIMA --    TD =   1.7200    TV =   1.6000    TA =   1.7000      PER = 1.125    DT = .020    KUG =   127
  FREQ =   .998     TIMES FOR MAXIMA --    TD =   1.7400    TV =   1.6000    TA =   1.7200      PER = 1.002    DT = .020    KUG =   127
  FREQ =  1.119     TIMES FOR MAXIMA --    TD =   1.7400    TV =   1.5000    TA =   1.7200      PER =   .893    DT = .020    KUG =   127
  FREQ =  1.256     TIMES FOR MAXIMA --    TD =   1.7200    TV =   1.5000    TA =   1.7000      PER =   .796    DT = .020    KUG =   127
  FREQ =  1.409     TIMES FOR MAXIMA --    TD =   1.7000    TV =   1.8400    TA =   1.7000      PER =   .710    DT = .020    KUG =   127
  FREQ =  1.581     TIMES FOR MAXIMA --    TD =   1.6800    TV =   1.8200    TA =   1.6600      PER =   .632    DT = .020    KUG =   127
  FREQ =  1.774     TIMES FOR MAXIMA --    TD =   1.9000    TV =   1.7800    TA =   1.9000      PER =   .564    DT = .020    KUG =   127
  FREQ =  1.991     TIMES FOR MAXIMA --    TD =   1.8600    TV =   1.9800    TA =   1.8600      PER =   .502    DT = .020    KUG =   127
  FREQ =  2.233     TIMES FOR MAXIMA --    TD =   2.0400    TV =   2.1600    TA =   2.0400      PER =   .448    DT = .020    KUG =   127
  FREQ =  2.506     TIMES FOR MAXIMA --    TD =   2.2000    TV =   2.3000    TA =   2.2000      PER =   .399    DT = .020    KUG =   127
  FREQ =  2.812     TIMES FOR MAXIMA --    TD =   2.1600    TV =   2.2400    TA =   1.9600      PER =   .356    DT = .020    KUG =   127
  FREQ =  3.155     TIMES FOR MAXIMA --    TD =   1.5600    TV =   1.6400    TA =   1.5600      PER =   .317    DT = .020    KUG =   127
  FREQ =  3.540     TIMES FOR MAXIMA --    TD =   1.5200    TV =   1.5000    TA =   1.5200      PER =   .283    DT = .020    KUG =   127
  FREQ =  3.972     TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.4200    TA =   1.4800      PER =   .252    DT = .020    KUG =   127
  FREQ =  4.456     TIMES FOR MAXIMA --    TD =   1.4800    TV =   1.4000    TA =   1.4600      PER =   .224    DT = .020    KUG =   127
  FREQ =  5.000     TIMES FOR MAXIMA --    TD =   1.4600    TV =   1.3800    TA =   1.4600      PER =   .200    DT = .020    KUG =   127
  FREQ =  5.610     TIMES FOR MAXIMA --    TD =   1.5100    TV =   1.2400    TA =   1.5000      PER =   .178    DT = .010    KUG =   255
  FREQ =  6.295     TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.8600    TA =   1.4900      PER =   .159    DT = .010    KUG =   255
  FREQ =  7.063     TIMES FOR MAXIMA --    TD =   1.4800    TV =   1.8500    TA =   1.4800      PER =   .142    DT = .010    KUG =   255
  FREQ =  7.924     TIMES FOR MAXIMA --    TD =   1.5400    TV =   1.4000    TA =   1.5400      PER =   .126    DT = .010    KUG =   255
  FREQ =  8.891     TIMES FOR MAXIMA --    TD =   1.5300    TV =   1.8300    TA =   1.5200      PER =   .112    DT = .010    KUG =   255
  FREQ =  9.976     TIMES FOR MAXIMA --    TD =   1.5100    TV =   1.8100    TA =   1.5100      PER =   .100    DT = .010    KUG =   255
  FREQ =11.194      TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.6300    TA =   1.5000      PER =   .089    DT = .010    KUG =   255
  FREQ =12.559      TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.6300    TA =   1.5000      PER =   .080    DT = .010    KUG =   255
  FREQ =14.092      TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.6200    TA =   1.5000      PER =   .071    DT = .010    KUG =   255
  FREQ =15.811      TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.6200    TA =   1.5000      PER =   .063    DT = .010    KUG =   255
  FREQ =17.741      TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.6200    TA =   1.5000      PER =   .056    DT = .010    KUG =   255
  FREQ =19.905      TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.6200    TA =   1.5000      PER =   .050    DT = .010    KUG =   255
  FREQ =22.334      TIMES FOR MAXIMA --    TD =   1.5000    TV =   1.6200    TA =   1.5000      PER =   .045    DT = .010    KUG =   255

  NOTE:  TD = TIME FOR MAX. RELATIVE DISP.,  TV = TIME FOR MAX. RELATIVE VEL.,  TA = TIME FOR MAX. ABSOLUTE ACC.
```
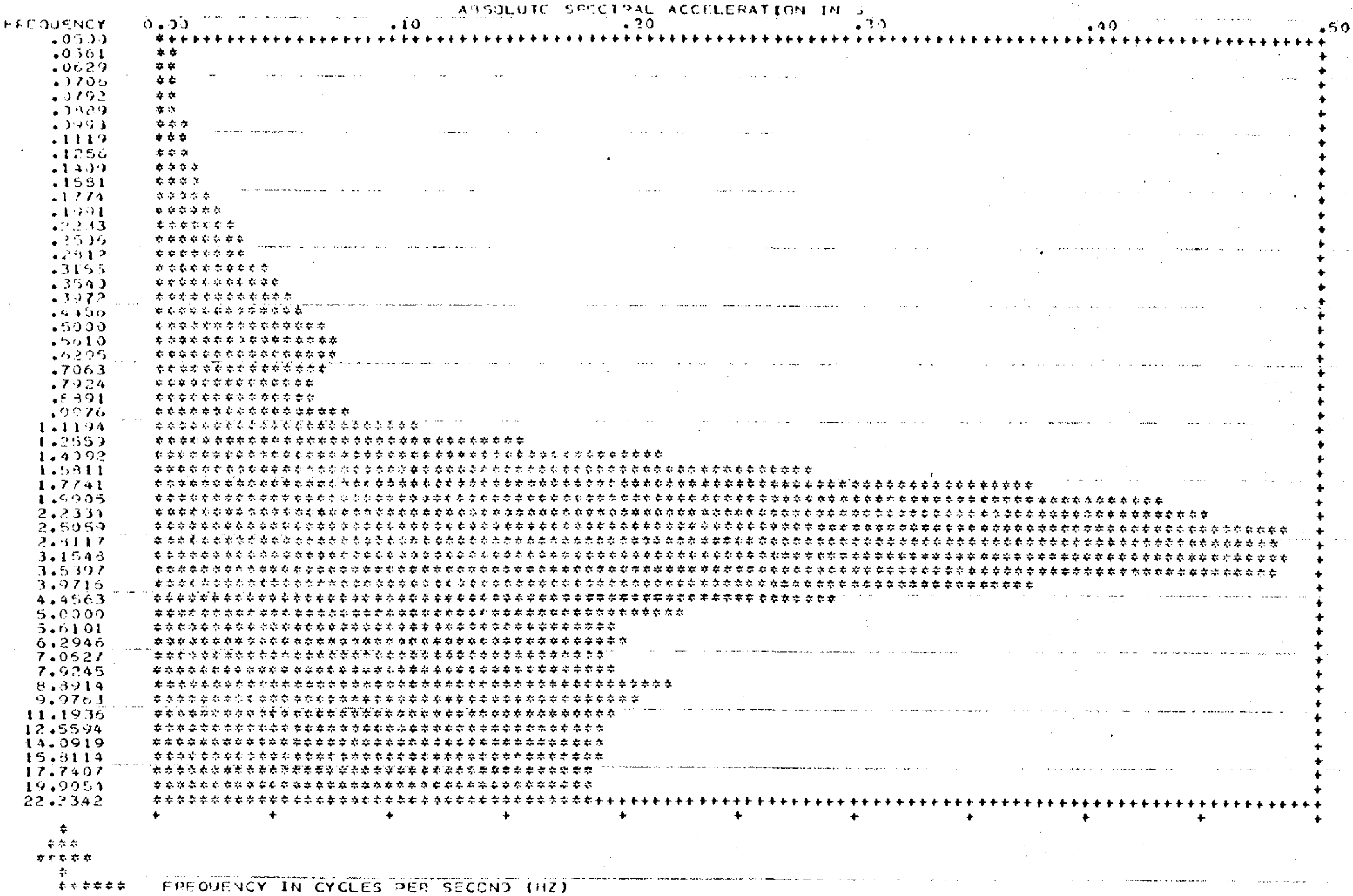

TABLE III SPECTRAL VALUES FOR DAMPING RATIO = .05

NO.	FREQCY C/SEC.	REL. DISP. FT.	REL. VEL. FT./SEC.	PSU.REL.VEL. FT./SEC.	ABS. ACC. G.	PSU.ABS.ACC. G.	PERIOD SEC.
1	.050	.55150	.86498	.17326	.00217	.00169	20.000
2	.056	.55164	.86686	.19445	.00266	.00213	17.825
3	.063	.55131	.86918	.21824	.00327	.00268	15.887
4	.071	.55105	.87204	.24493	.00402	.00339	14.159
5	.079	.55199	.87552	.27484	.00495	.00425	12.619
6	.089	.55179	.87974	.30827	.00611	.00535	11.247
7	.100	.55113	.88479	.34547	.00754	.00673	10.024
8	.112	.54965	.89076	.38657	.00930	.00844	8.934
9	.126	.54676	.89767	.43147	.01144	.01057	7.962
10	.141	.54164	.90547	.47958	.01404	.01319	7.096
11	.158	.53303	.91394	.52954	.01712	.01634	6.325
12	.177	.51921	.92265	.57875	.02065	.02003	5.637
13	.199	.49786	.93076	.62267	.02460	.02419	5.024
14	.223	.46514	.93692	.65414	.02887	.02851	4.477
15	.251	.42665	.93905	.67178	.03314	.03285	3.991
16	.281	.38237	.93422	.67551	.03745	.03706	3.557
17	.315	.35574	.91855	.70515	.04385	.04341	3.170
18	.354	.32195	.88743	.71604	.04992	.04946	2.825
19	.397	.28117	.83628	.70164	.05456	.05438	2.518
20	.446	.24993	.76204	.69994	.06148	.06096	2.244
21	.500	.22385	.69724	.70323	.06950	.06861	2.000
22	.561	.19155	.69421	.67520	.07478	.07391	1.783
23	.629	.15381	.59542	.60833	.07556	.07472	1.589
24	.706	.11551	.50272	.51261	.07137	.07064	1.416
25	.792	.08368	.46396	.41666	.06519	.06443	1.262
26	.889	.06593	.41576	.36833	.06463	.06390	1.125
27	.998	.06431	.50628	.40309	.07951	.07847	1.002
28	1.119	.07216	.61030	.50749	.11223	.11085	.893
29	1.256	.08091	.69328	.63845	.15730	.15647	.796
30	1.400	.08737	.86133	.77358	.21315	.21272	.710
31	1.581	.09128	1.04691	.90679	.28049	.27977	.632
32	1.774	.09647	1.14367	1.07530	.37529	.37224	.564
33	1.991	.08772	1.16934	1.09706	.42798	.42611	.502
34	2.233	.07294	1.06576	1.02358	.45159	.44608	.448
35	2.506	.06250	1.00577	.98411	.48694	.48121	.399
36	2.812	.04903	.83917	.86616	.48029	.47522	.356
37	3.155	.03977	.69779	.78836	.48280	.48531	.317
38	3.540	.03125	.50296	.69506	.48010	.48009	.283
39	3.972	.01931	.32824	.48196	.37673	.37351	.252
40	4.456	.01187	.21438	.33234	.28837	.28899	.224
41	5.000	.00727	.13549	.22824	.22297	.22268	.200
42	5.610	.00511	.08439	.18007	.19717	.19713	.178
43	6.295	.00409	.06067	.16158	.19861	.19846	.159
44	7.063	.00314	.06152	.13928	.19175	.19194	.142
45	7.924	.00251	.05344	.12506	.19390	.19337	.126
46	8.891	.00223	.04806	.12731	.22150	.22087	.112
47	9.975	.00169	.02886	.10570	.20540	.20576	.100
48	11.194	.00128	.01916	.08987	.19672	.19629	.089
49	12.559	.00099	.01386	.07830	.19213	.19188	.080
50	14.092	.00073	.01058	.06888	.18961	.18941	.071
51	15.811	.00061	.00819	.06089	.18802	.18786	.063
52	17.741	.00043	.00639	.05395	.18691	.18678	.056
53	19.905	.00033	.00501	.04788	.18611	.18599	.050
54	22.334	.00030	.00394	.04254	.18551	.18540	.045

OVF

```
PLOT OF ACCELERATION SPECTRA FOR:MASH--TEST--RESPONSE SPECTRA                           --TOP ELEMENT NO.    6
                        CURVE 1 : DAMPING = .05 , MAX. ABS. SPECTRAL ACC. =  .497 G AT FREQUENCY =  2.506 C/SEC
```



```
         CURVE                         TABLE OF FUNCTION VALUES (ALL POINTS INCLUDED)

  .0500    1    .2174E-02  .2664E-02  .3270E-02  .4022E-02  .4955E-02  .5110E-02  .7534E-02  .9296E-02  .1134E-01  .1404E-01
  .1581    1    .1712E-01  .2255E-01  .2460E-01  .2837E-01  .3314E-01  .3745E-01  .4383E-01  .4992E-01  .5456E-01  .6148E-01
  .5000    1    .6950E-01  .7478E-01  .7556E-01  .7137E-01  .6519E-01  .6463E-01  .7951E-01  .1122E+00  .1573E+00  .2132E+00
 1.5911    1    .2805E+00  .3753E+00  .4280E+00  .4516E+00  .4869E+00  .4803E+00  .4929E+00  .4801E+00  .3767E+00  .2834E+00
 5.0000    1    .2230E+00  .1972E+00  .1986E+00  .1918E+00  .1939E+00  .2215E+00  .2054E+00  .1967E+00  .1921E+00  .1906E+00
15.8114    1    .1880E+00  .1869E+00  .1861E+00  .1855E+00
```

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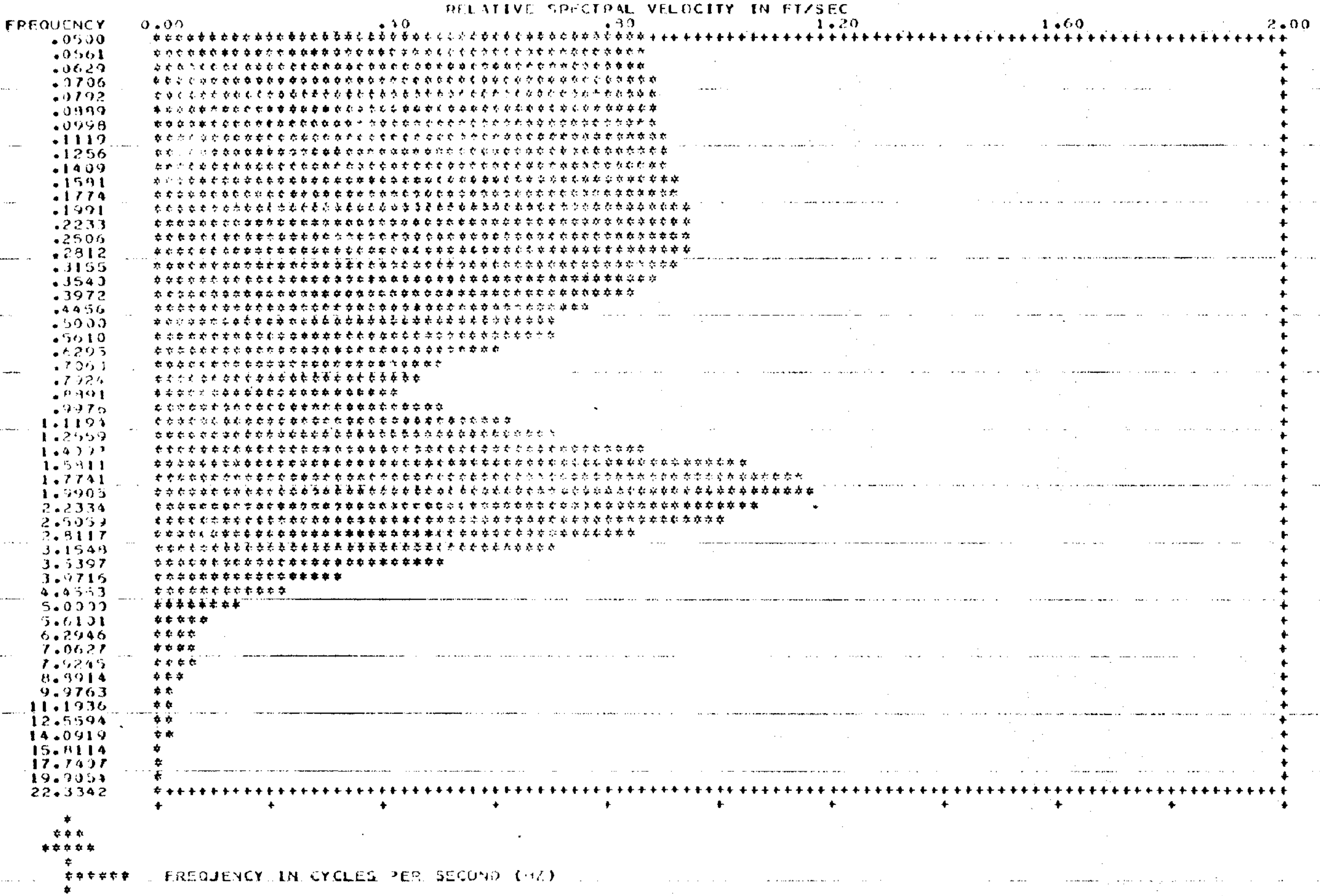
.OT OF VELOCITY SPECTRA FOR:MASH--TEST--RESPONSE SPECTRA                    --TOP ELEMENT NO.    6
                   CURVE 1 : DAMPING = .05 , MAX. REL. SPECTRAL VEL. = 1.170 FT/SEC AT FREQUENCY =  1.991 C/SEC
```



```
        CURVE                                  TABLE OF FUNCTION VALUES (ALL POINTS INCLUDED)

  .0500   1    .8650E+00  .8669E+00  .8692E+00  .8720E+00  .8755E+00  .8797E+00  .8843E+00  .8904E+00  .8977E+00  .9055E+00
  .1581   1    .9130E+00  .9226E+00  .9306E+00  .9369E+00  .9391E+00  .9342E+00  .9185E+00  .8874E+00  .8363E+00  .7620E+00
  .5000   1    .6972E+00  .6242E+00  .5955E+00  .5027E+00  .4640E+00  .4158E+00  .5063E+00  .6103E+00  .6933E+00  .8613E+00
 1.5811   1    .1047E+01  .1143E+01  .1170E+01  .1066E+01  .1006E+01  .8392E+00  .6978E+00  .5030E+00  .3282E+00  .2144E+00
 5.0000   1    .1355E+00  .8439E-01  .6067E-01  .5152E-01  .5346E-01  .4806E-01  .2886E-01  .1916E-01  .1386E-01  .1058E-01
15.8114   1    .8187E-02  .6387E-02  .5007E-02  .3939E-02

TIME REQUIRED FOR COMPUTATION OF RESPONSE SPECTRA      4.267 SEC.
```

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*OVF*

MAXIMUM STRESS        MAXIMUM STRAIN        MAXIMUM ACC.        TIME OF MAX. ACC.        DEPTH        ELT
                          IN PCT.          AFTER  FILTERING

   .4429E+02            .5683E-02             .2190              1.520000              0.            1
   .1324E+03            .1853E-01             .2179              1.520000              3.33          2
   .2193E+03            .2960E-01             .2148              1.520000              6.67          3
   .3253E+03            .4282E-01             .2100              1.520000             10.00          4
   .4461E+03            .5792E-01             .1993              1.520000             15.00          5
   .5570E+03            .7143E-01             .1832              1.520000             20.00          6
   .6551E+03            .8211E-01             .1626              1.500000             25.00          7
   .7333E+03            .8935E-01             .1403              1.500000             30.00          8
   .8071E+03            .9303E-01             .1130              1.490000             35.00          9
   .8637E+03            .9330E-01             .1063              1.440000             40.00         10
   .9097E+03            .9245E-01             .0997              1.440000             45.00         11
```

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*UVN*

CP TIME TO FILTER    11 ACCELERATION TIME HISTORIES           11.82400  SECS
TOTAL ELAPSED CP TIME                                        44.55200  SECS
```

A.3 PUNCHED OUTPUT

```
MASH--TEST--RESPONSE SPECTRA                                               ELEMENT NO     1
ACCELERATION TIME HISTORY  (G)
  -.00604    .00171    .00426   -.00036   -.00633   -.01196   -.01277   -.01285        1
  -.01280   -.01601   -.01719   -.01516   -.00725   -.00053    .00216   -.00265        2
  -.00808   -.01143   -.00905   -.00647   -.00437   -.00565   -.00655   -.00926        3
  -.01156   -.01421   -.01077   -.00192    .01040    .01524    .01028   -.00348        4
  -.01545   -.02376   -.02836   -.03567   -.04174   -.04278   -.03222   -.01562        5
   .00278    .01711    .03194    .04716    .06313    .07220    .07434    .06879        6
   .05998    .04372    .02048   -.00797   -.02753   -.03016   -.01336    .01005        7
   .03213    .04847    .06545    .07950    .08192    .05710    .00672   -.05520        8
  -.10255   -.12356   -.11772   -.09841   -.07034   -.03514    .01226    .06542        9
   .11682    .15586    .18480    .20517    .21903    .21598    .19060    .14275       10
   .08868    .04074    .00577   -.02577   -.05940   -.09633   -.12386   -.13511       11
  -.12710   -.10925   -.08532   -.05844   -.02375    .01534    .05491    .08368       12
   .09932    .09954    .09048    .07313    .05150    .02323   -.00823   -.04166       13
  -.06804   -.08348   -.08329   -.07340   -.05710   -.03986   -.01770    .00883       14
   .03927    .06291    .07458    .07072    .05935    .04419    .02927    .00957       15
  -.01364   -.03914   -.05743   -.06578   -.06137   -.05031   -.03451   -.01976       16
MASH--TEST--RESPONSE SPECTRA
  54 SA-VALUES AT    5.0 PERCENT DAMPING--TOP OF ELEMENT     1
 .2173E-02 .2656E-02 .3263E-02 .4016E-02 .4950E-02 .6108E-02 .7539E-02 .9301E-02
 .1146E-01 .1406E-01 .1715E-01 .2070E-01 .2474E-01 .2914E-01 .3346E-01 .3779E-01
 .4441E-01 .5066E-01 .5532E-01 .6240E-01 .7099E-01 .7699E-01 .7853E-01 .7518E-01
 .6998E-01 .7072E-01 .8809E-01 .1249E+00 .1759E+00 .2414E+00 .3182E+00 .4326E+00
 .5044E+00 .5503E+00 .6194E+00 .6296E+00 .6370E+00 .6341E+00 .4973E+00 .3865E+00
 .2874E+00 .2335E+00 .2547E+00 .2669E+00 .2757E+00 .2483E+00 .2417E+00 .2324E+00
 .2283E+00 .2266E+00 .2251E+00 .2240E+00 .2230E+00 .2223E+00
MASH--TEST--RESPONSE SPECTRA
  54 SV-VALUES AT    5.0 PERCENT DAMPING--TOP OF ELEMENT     1
 .9209E+00 .9228E+00 .9251E+00 .9280E+00 .9315E+00 .9358E+00 .9409E+00 .9470E+00
 .9540E+00 .9619E+00 .9706E+00 .9795E+00 .9880E+00 .9945E+00 .9972E+00 .9931E+00
 .9783E+00 .9483E+00 .8985E+00 .8257E+00 .7400E+00 .7331E+00 .6354E+00 .5553E+00
 .5241E+00 .4900E+00 .5880E+00 .7036E+00 .8013E+00 .9911E+00 .1208E+01 .1321E+01
 .1385E+01 .1309E+01 .1286E+01 .1106E+01 .9235E+00 .7045E+00 .4737E+00 .3264E+00
 .2317E+00 .1403E+00 .1099E+00 .8009E-01 .7023E-01 .6380E-01 .4667E-01 .2829E-01
 .2012E-01 .1501E-01 .1144E-01 .8823E-02 .6856E-02 .5358E-02
MASH--TEST--RESPONSE SPECTRA
  54 SA-VALUES AT    5.0 PERCENT DAMPING--TOP OF ELEMENT     6
 .2174E-02 .2664E-02 .3270E-02 .4022E-02 .4955E-02 .6110E-02 .7538E-02 .9296E-02
 .1144E-01 .1404E-01 .1712E-01 .2065E-01 .2460E-01 .2887E-01 .3314E-01 .3745E-01
 .4385E-01 .4992E-01 .5456E-01 .6148E-01 .6950E-01 .7478E-01 .7556E-01 .7137E-01
 .6519E-01 .6463E-01 .7951E-01 .1122E+00 .1573E+00 .2132E+00 .2805E+00 .3753E+00
 .4280E+00 .4516E+00 .4869E+00 .4803E+00 .4828E+00 .4801E+00 .3767E+00 .2884E+00
 .2230E+00 .1972E+00 .1986E+00 .1918E+00 .1939E+00 .2215E+00 .2054E+00 .1967E+00
 .1921E+00 .1896E+00 .1880E+00 .1869E+00 .1861E+00 .1855E+00
MASH--TEST--RESPONSE SPECTRA
  54 SV-VALUES AT    5.0 PERCENT DAMPING--TOP OF ELEMENT     6
 .8650E+00 .8669E+00 .8692E+00 .8720E+00 .8755E+00 .8797E+00 .8848E+00 .8909E+00
 .8977E+00 .9055E+00 .9139E+00 .9226E+00 .9308E+00 .9369E+00 .9391E+00 .9342E+00
 .9185E+00 .8874E+00 .8363E+00 .7620E+00 .6972E+00 .6942E+00 .5954E+00 .5027E+00
 .4640E+00 .4158E+00 .5063E+00 .6103E+00 .6933E+00 .8613E+00 .1047E+01 .1144E+01
 .1170E+01 .1066E+01 .1006E+01 .8392E+00 .6978E+00 .5030E+00 .3282E+00 .2144E+00
 .1355E+00 .8439E-01 .6067E-01 .6152E-01 .5344E-01 .4806E-01 .2886E-01 .1916E-01
 .1386E-01 .1058E-01 .8187E-02 .6387E-02 .5007E-02 .3939E-02
MASH--TEST--RESPONSE SPECTRA                                               ELEMENT NO     6
STRAIN TIME HISTORY  (PCT)
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0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
0.             0.             0.             0.             0.             0.             0.             0.
MASH--TEST--RESPONSE SPECTRA                                                                  ELEMENT NO     6
STRESS TIME HISTORY
 0.              .105E-07       .904E-04       .353E-02       .170E-01       .310E-01       .424E-01       .458E-01
  .461E-01       .491E-01       .515E-01       .515E-01       .515E-01       .515E-01       .515E-01       .894E-02
  .245E-01       .320E-01       .321E-01       .321E-01       .191E-01       .218E-01       .259E-01       .290E-01
  .345E-01       .392E-01       .393E-01       .393E-01       .393E-01      -.380E-01      -.223E-01       .101E-01
  .433E-01       .687E-01       .956E-01       .123E+00       .138E+00       .139E+00       .139E+00       .139E+00
  .139E+00       .139E+00       .139E+00       .139E+00       .139E+00       .139E+00       .139E+00      -.262E+00
 -.232E+00      -.174E+00      -.930E-01      -.106E-01       .448E-01       .537E-01       .587E-01       .587E-01
  .587E-01       .587E-01       .587E-01       .587E-01      -.270E+00      -.197E+00      -.385E-01       .161E+00
  .343E+00       .453E+00       .476E+00       .476E+00       .476E+00       .476E+00       .476E+00       .476E+00
  .476E+00       .476E+00       .476E+00       .476E+00       .476E+00      -.115E+01      -.107E+01      -.918E+00
 -.724E+00      -.516E+00      -.324E+00      -.117E+00       .115E+00       .324E+00       .488E+00       .586E+00
  .604E+00       .604E+00       .604E+00       .604E+00       .604E+00       .604E+00       .604E+00       .604E+00
  .604E+00      -.373E+00      -.346E+00      -.291E+00      -.210E+00      -.102E+00       .273E-01       .164E+00
  .278E+00       .348E+00       .366E+00       .366E+00       .366E+00       .366E+00       .366E+00       .366E+00
  .366E+00       .366E+00       .366E+00      -.241E+00      -.211E+00      -.160E+00      -.942E-01      -.137E-01
  .796E-01       .173E+00       .246E+00       .283E+00       .286E+00       .286E+00       .286E+00       .286E+00
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