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LASS-II, COMPUTER PROGRAM FOR ANALYSIS OF SEISMIC RESPONSE AND LIQUEFACTION OF HORIZONTALLY LAYERED SANDS

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A new approach to analysis of seismic response and evaluation of the liquefaction potential of saturated sands are presented. Work on the development of a two-phase fluid solid model for quasi-static and dynamic analysis of saturated soils has been extended here by using a nonlinear material model to represent the behavior of solid granular medium. The separate phases of solid granular skeleton and the pore water are modeled individually, and the coupling between these two phases is taken into account. The pore water is allowed to flow with respect to granular solid. This process is assumed to be governed by Darcy flow law with the coefficient of permeability as the material constant. Dynamic analysis of this model allows direct determination of the time histories of pore water pressures and effective stresses. The seismic response of the system to earthquake base acceleration is also determined in the process of dynamic analysis. The material model used is defined in terms of effective stresses. Criteria for the occurrence of initial liquefaction and onset of liquefaction are defined in terms of effective stresses and are included in the material model.

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OF HORIZONTALLY LAYERED SATURATED SANDS

TABLE OF CONTENTS

Page

LASS-II, COMPUTER PROGRAM FOR ANALYSIS OF SEISMIC RESPONSE AND LIQUEFACTION OF HORIZONTALLY LAYERED SATURATED SANDS

1. INTRODUCTION

The problem of liquefaction of saturated soils during earthquakes has attracted considerable attention in recent years and extensive research has already been performed in; understanding the phenomenon; the process of development of liquefaction during earthquakes; and, factors affecting this process. It is not intended here to give a complete literature survey in the area of liquefaction. However, few references cited here (2, 8, 10, 11, 12, 14, 15) represent some of many significant developments and various approaches to the problem. An excellent survey of the state of the art has been presented in a recent paper by Seed (16).

Presented here is a new approach to analysis of seismic response and evaluation of the liquefaction potential of saturated sands. A two phase fluid-solid model has been previously developed for quasi-static and dynamic analysis of saturated soils (3, 4, 5, 6). This work has been extended here by using a nonlinear material model to represent the behavior of solid granular medium.

The separate phases of solid granular skeleton and the pore water are modeled individually and the coupling between these two phases is taken into account. The pore water is allowed to flow with respect to granular solid and this process is assumed to be governed by Darcy flow law with the coefficient of permeability as the material constant. Dynamic analysis of this model allows direct determination of the time histories of pore water pressures and effective stresses. The seismic response of the system to earthquake base acceleration is also determined in the process of dynamic analysis.

The material model used in this study is defined in terms of effective stresses. Criteria for the occurrence of initial liquefaction and onset of liquefaction is defined in terms of effective stresses and are included in the material model. Initial liquefaction is considered as a condition of "near failure". Two different material models are used for the behavior of soil before and after the initial liquefaction. Cyclic effects are included in the material model.

All the material parameters needed for the material model used in this study can be determined from routine laboratory tests and possibly undrained triaxial test under monotonically increasing stress. Cyclic tests are not required for this model. Another feature of the method of analysis presented here is that the damping is not included as an independent parameter. The model inherently includes two effective damping mechanisms; hysteretic damping and dissipative damping. Thus the need for evaluation of damping ratio is eliminated.

2. METHOD OF ANALYSIS

The saturated granular soil system is treated as a two-phase medium with consituent materials being the granular solid skeleton and pore water. The two phases are coupled through volumetric strains. The method is general and has been applied to two dimensional cases in previous studies (3, 5). However, in the previous applications the linearly elastic material properties were used for modeling the behavior of the solid skeleton. With this type of material model the pore water pressures result only from elastic volumetric strains which neglect the reduction in effective pressures and increase in pore water pressure which is caused by dilatency and contractancy of granular soils under shear deformations. An appropriate nonlinear material property has been used in this study which is capable of adequately representing the volumetric deformation under shear strains.

The horizontally layered system of saturated soils is assumed to consist of horizontal layers with specified thicknesses and material properties. Each layer is subdivided into a number of "layer elements" which consist of the medium contained between two horizontal planes a distance h apart. The plane separating two adjacent elements is referred to as "nodal plane". The motion of the system is described by nodal displacement degrees of freedom. In a general case each node has four displacement degrees of freedom; three components of displacement of solid portion, u_x, u_y, u_z, and a vertical displacement of pore water with respect to solid, w_z. A schematic representation of a layered system and a typical layer element are shown in Figures (1) and (2).

The nodal planes remain horizontal during the motion of the systems and they can only undergo parallel displacements. Torsional motion of the system is neglected. As a result of these assumptions there are only three non-zero strain components. The strain-displacement relations are:

$$\begin{aligned} \varepsilon_{zz} &= u_{z,\,z} \\ \varepsilon_{xz} &= u_{x,\,z} \\ \varepsilon_{yz} &= u_{y,z} \end{aligned} \tag{1}$$

and the volumetric strain of pore water is given by the following relation:

$$\zeta = w_{z,\,z} \tag{2}$$

For a typical layer element shown in Figure 2 the components of displacement are assumed to vary linearly between the nodal planes i and j. With this assumption on variation of displacements for each element the stiffness matrix, mass matrix, and "dissipation resistance" matrix can be computed. The matrices for the system result from direct assembly of the element matrices.

The matrix equation of motion for the system can be written as follows.

$$\begin{bmatrix} M_s & 0 \\ 0 & M_f \end{bmatrix} \begin{Bmatrix} \ddot{u} \\ \ddot{w} \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & H \end{bmatrix} \begin{Bmatrix} \dot{u} \\ \dot{w} \end{Bmatrix} + \begin{bmatrix} K_{ss} & K_{sf} \\ K_{sf}^T & K_{ff} \end{bmatrix} \begin{Bmatrix} u \\ w \end{Bmatrix} = \begin{Bmatrix} M_s I \\ 0 \end{Bmatrix} \ddot{u}_g \tag{3}$$

The terms of equation 3 are as follows.

u = vector of the displacements of the solid portion

w = vector of the displacements of the pore water with respect to solid

M_s = lumped mass matrix for the bulk of saturated soil

M_f = lumped mass matrix for the fluid portion

H = dissipation resistance matrix. The terms of this matrix are inversely proportional to the coefficient of permeability

K_{ss} = stiffness matrix for the bulk of saturated soil

K_{ff} = stiffness matrix for the fluid portion

K_{sf} = stiffness matrix representing the coupling between solid and fluid portions.

$\ddot{u}_g$ = time history of base acceleration.

Equation 3 is a nonlinear system of equations. The source of nonlinearity is through the sub matrix K_{ss} which contains the nonlinear material behavior of the solid granular skeleton. This nonlinear matrix equation can be written symbolically as follows.

$$M\,\ddot{u}(t) + D\,\dot{u}(t) + K\,u(t) = ML\,\ddot{u}_g(t) \tag{4}$$

in which L is a vector containing ones and zeros at the appropriate locations. Since it is only possible to develope a tangent stiffness matrix, the third term on the left hand side of Equation 4 has to be written in incremental form as follows

$$K\,u(t) = K_t\,\Delta U\,(t) + R\,(t - \Delta t) \tag{5}$$

in which

$$\Delta u(t) = u(t) - u(t - \Delta t) \tag{6}$$

and the vector R (t - Δt) is the vector of internal

resisting forces which is computed from the stresses computed at the end of the previous time step, as follows.

$$R(t - \Delta t) = \Sigma\int_V B^T\ (t- \Delta t)\ dv \tag{7}$$

The matrix B is the strain - displacement matrix and the integration is carried out over each element with the summation sign denoting direct assembly process.

Substitution of Equation (5) into Equation (4) yield the following incremental form of the equation of motion.

$$M\,\ddot{u}(t) + D\,\dot{u}(t) + K_t\,\Delta u(t) = ML\,\ddot{u}_g(t) - R(t - \Delta t) \tag{8}$$

This nonlinear matrix equation of motion is directly integrated in time by a time marching scheme, as described in reference (6).

Two types of energy absorption mechanism or equivalent damping effects are present in the analytical model used here. A hysteretic damping is introduced into the system by using the material model which will be discussed in the next section. The magnitude of energy absorbed with this damping mechanism is dependent on the history of shear strains which develop within each element. Another energy absorption mechanism is provided through the dissipation resistance matrix which represents dissipation of pore water pressure and flow of pore water through granular solid. It is difficult to evaluate these damping effects in terms of other conventional damping mechanisms used in dynamic analysis such as proportional and modal damping. However, the influence of the damping mechanisms used in this study can be shown through their effects on the response of the system. By studying such responses, as will be shown later, it appears that these two damping mechanisms adequately represent the energy absorption in the system.

3. MATERIAL MODEL

Two distinct material behavior models are required to cover the whole range possible during the stress history of an element of soil from insitu stress condition to final liquefaction. The first material model is to represent the soil behavior from insitu stress condition up to the initial liquefaction. After the onset of initial liquefaction the material behavior is quite different than the pre-initial liquefaction. A second material model is required to represent this behavior.

The initial liquefaction here is considered to be a condition of near failure in the soil element. After the initial liquefaction the granular structure of sand changes due to large strains developing in the near failure condition. The material model for the post initial liquefaction range is in effect the representation of the post failure behavior of sand in a cyclic stress environment.

The material model developed here and used in the computer program LASS - II is based on the observations of the soil behavior and the test results reported in literature (1,7,9,13,17).

3.1 PRE-INITIAL - LIQUEFACTION MODEL

The shear stress-strain relation under monotonic loading is represented by following equation and shown in Fig. (3a).

$$\left(\frac{q}{p'}\right) = \frac{\gamma\, G_o\, S_{max}}{\gamma\, G_o + S_{max}} \qquad (9)$$

in which q is the shear stress, p' is the effective pressure and γ is the shear strain. This relation is assumed to applying equally to shear stress in positive or negative direction. The unloading is assumed to take place linearly with the slope G_0 until previous maximum or minimum value of q/p' is reached, whereupon the above stress-strain relation in Equation 9 becomes valid again. The stress-strain relation in shear as represented by the above equation is assumed to remain constant up to the onset of initial liquefaction. This is a reasonable assumption as no significant changes occur in the void ratio of saturated sands during the earthquake prior to liquefaction. In the p'-q plane the shear yield loci (lines of equal shear strain) take the form of straight lines radiating from the origin, Fig. (3b). Within the low effective stress range encountered in earthquake analysis of soil deposits this appears to be a reasonable assumption. The existence of such yield loci for shear deformations has been experimentally verified and reported in References (7, 13). However, it has been shown that for higher values of effective pressure the yield loci approach a state parallel to p'-axis.

Under monotonic shear stress increase with this model the failure will occur as the stress point in p'-q plane approaches a line corresponding to the asymptote of the shear stress-strain relation in Equation 9. This failure line which is also referred to as "critical state" line is given by the following equation

$$f_1 = q - p' \tan \phi = 0 \qquad (10)$$

Initial liquefaction occurs as the stress point approaches the failure line but before reaching this line. Therefore, it is justified to assume that $\tan \phi$ takes a value slightly smaller than Smax.

The initial effective pressures at each depth prior to application of shear stresses are denoted by p'_0. With the application of monotonically increasing shear stresses in undrained conditions, the stress point in p'-q plane follows a path similar to the stress path shown in Fig. (3b) which intersects the failure line at effective pressure p'_f. This stress path has been approximated by a quarter of an ellipse which is given by the following equation.

$$f_2 = (p' - p'_f)^2 + \frac{1}{\lambda^2} q^2 - (p'_o - p'_f)^2 = 0 \qquad (11)$$

The material parameter λ is the ratio of the major and minor axes of the ellipse, as given by the following relation.

$$\lambda = \frac{p'_f}{p'_o - p'_f} \tan \phi \qquad (12)$$

The stress path given in Equation 11 is completely defined by two material parameters λ and ϕ and the insitu effective pressure p'_o. Equation 11 can be written in terms of these parameters as follows.

$$f_2 = q^2 + \lambda^2 \left[p'^2 - \left(\frac{2\lambda}{\lambda + \tan \phi}\right) p' p'_o + \left(\frac{\lambda - \tan \phi}{\lambda + \tan \phi}\right) p'^2_o\right] = 0 \qquad (13)$$

As can be seen from Fig. (3b) under monotonic increase in shear stress the effective pressure p' decreases and as a result the pore water pressure increases in undrained condition. In unloading the effective pressure is assumed to remain constant until the stress path reaches the previous maximum or minimum value of q/p' in p' - q plane. After the stress point has reached the previous maximum or minimum value of q/p', it continues along a stress path given by Equation 13 but computed with a new value of p'_o which is determined such that the stress path goes through the point just reached by the stress path. This process in effect corresponds to successive reduction in the value of initial effective pressure p'_o as a result of cyclic shear stress. When unloading occurs, the value of q/p' just prior to unloading becomes the current value of the so called previous maximum or minimum value of q/p'.

The original concept of the "state boundary surface" has been extended by Ishihara and his co-workers (7,17,18) by introducing the concept of the "multiplicity of state boundary surface" which helps in explaining a number of aspects of the behavior of sands under cyclic shear stress. As a result of this concept it is postulated that the loading stress paths on each side of the p'-axis are independent of the other side. In a cyclic stress situation therefore, at each instant two current values of p_0' exist associated with stress paths for positive and negative values of q.

It is important to relate the model material parameters to relative density which is recognized to be an important factor in determining the liquefaction potential of saturated sands.

The values of λ determined from various reported experimental results are shown in Fig. (4) versus the relative density. The data appears to fall within a narrow band for low and medium densities. The value of λ increases with relative density and the value of $\lambda = 1$ occurs at about 35% relative density. This corresponds to a circular stress path $f_2 = 0$. Below 35% relative density the major axis of f_2 falls along p'-axis and above this relative density the major axis of f_2 is parallel to q-axis. From the data in Figure (4), which are for fairly uniform sands with rounded particles, it appears that λ is only dependent on relative density and the effective pressure has little effect on the value of λ. Data from tests at various effective pressures, $p_0' = 1.0$, 4.0 and 10.0 kg/cm^2 do not differ appreciably. As a result of this observation it can be concluded that, for fairly uniform sands with rounded particles, the shape of the stress path f_2 remains constant and only its size changes with p_0', since λ is independent of p_0'. However, Castro also has reported the results of experiments on two types of sands with angular and subangular particles. The values of λ determined from these results are shown in Figure (5) and it is evident that the effective pressure p_0' has a great deal of influence on λ. Therefore, for these types of sands the shape of the stress path f_2 must also be dependent on the effective pressure. However, at the present there is not sufficient data to justify quantification of this phenomenon and it is not included in computer program LASS-II.

3.2 POST INITIAL LIQUEFACTION BEHAVIOR

After the stress path has reached a level very close to failure line or montonic strain has reached a certain level, it is said that the soil element is at initial liquefaction. When using a strain criteria for initial liquefaction it is important to distinguish between the actual strain in cyclic environment and its monotonic strain equivalent. The later must be used. After initial liquefaction the material behavior of the soil element changes abruptly. Although this material behavior change is gradual in cyclic tests, especially for dense sands, under montonic loading for low relative densities very abrupt material behavior changes have been observed. In any case, for the purpose of material modeling, this material behavior change must be considered an abrupt and discrete phenomenon.

There appears to be very little experimental data to provide insight as to the mechanism of post initial liquefaction behavior of saturated sands. Limited experimental data does point to certain general material behavior characteristics for this range. However, development of accurate material postulates based on acceptable material mechanism must await further experimental evidence. Ishihara, et al. (8) have used a specific stress path for post initial liquefaction behavior which appears justified based on limited experimental data. This specified stress path is sufficient for the type of application reported in Ref. (8). However, a general material model needed for a systematic dynamic stress analysis requires information as to the deformational characteristics of sand at post initial liquefaction range. Sufficient experimental data for development of such a material model does not exist at the present.

All sands do not lose their strength after the initial liquefaction. It appears that only at very loose states and low densities complete liquefaction almost instantaneously follows the initial liquefaction; the effective stress point in p'-q plane instantaneously follows the failure line down to origin. At higher values of relative densities, additional stress cycles are required to further reduce the effective pressure and achieve complete liquefaction. It appears reasonable to assume that shear loading and unloading characteristic does not change appreciably after initial liquefaction. From cyclic tests it seems that the pore pressures and effective pressures start oscillating after initial liquefaction, which is due to the fact that the stress point must move up along failure line upon loading which reduces pore pressure and upon unloading the pore pressure increases The magnitude of pore pressure increase in each cycle of loading will depend on relative density of sand and the highest magnitude of the shear stress in that cycle. It seems the higher shear stresses after initial liquefaction cause an interlocking of particles resulting in higher effective pressure which upon unloading is transferred to pore pressures. A possible mechanism for explaining this phenomenon is a change in compressibility of solid skeleton.

4. POST EARTHQUAKE ANALYSIS

After the completion of the earthquake analysis excess pore water pressures are computed throughout the layered system. This excess pore water pressure dissipates with time after the termination of the earthquake strong shaking. In the process, the excess pore pressure distribution through the depth changes which may cause some unliquefied portions to liquify. Some significant ground settlements may result after the dissipation of the excess pore water pressure.

The differential equation governing the dissipation of excess pore pressure is as follows.

$$k \frac{\partial^2 \pi}{\partial z^2} = c_v \frac{\partial \pi}{\partial t} \tag{14}$$

in which π is the excess pore pore pressure, k is the coefficient of permeability and c_v is the coefficient of compressibility. The discrete form of the dissipation equation for the same mesh as used during the earthquake analysis is as follows.

$$[A] \{\pi\} + [B] \{\overset{\circ}{\pi}\} = 0 \tag{15}$$

in which $\{\pi\}$ is the vector of excess pore pressures and the matrices [A] and [B] are obtained from direct assembly of element matrices $[A_m]$ and $[B_m]$, respectively. For the one-dimensional elements used here, it is assumed that the excess pore pressure varies linearly between the nodal values of excess pore pressure. The element matrices are as follows.

$$[A_m] = \frac{k}{L} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \tag{16}$$

$$[B_m] = \frac{C_v L}{6} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \qquad (17)$$

The matrix equation of dissipation, Equation 15, is integrated in time using Crank-Nicolson (mid-differnece) scheme which reduces Equation 15 to the following form.

$$[D] \{\pi_n\} = [E] \{\pi_{n-1}\} \qquad (18)$$

in which $\{\pi_n\}$ is the vector of excess pore pressures at time $n\Delta t$ and Δt is the integration time step. The matrices D and E are computed from the matricies A and B as follows.

$$[D] = \frac{1}{\Delta t} [B] + \frac{1}{2} [A] \qquad (19)$$

$$[E] = \frac{1}{\Delta t} [B] - \frac{1}{2} [A] \qquad (20)$$

Equation 18 is applied successively to compute the time history of the excess pore pressures. The starting vector (initial conditions) contains the value of excess pore pressures computed at the termination of the earthquake analysis.

Due to the logarithmic nature of variation of excess pore pressure with time, usually a smaller time step is used at the beginning of the analysis and later the value of the time step is increased. The time integration method used is unconditionally stable and therefore there is no restriction on the size of the time step for stability considerations.

5. EFFECTIVE DAMPING

Two types of energy absorbing mechanisms which act as effective damping are available in the method of analysis presented in this report. These damping mechanisms are as follows.

1. Hysteretic damping which is inherent in the material model used in this study.
2. Dissipative damping which is the result of modeling the two phase nature of the soil and is caused by flow of pore water with respect to the granular solid.

The first damping mechanism is independent of the velocity whereas the second is a velocity dependent damping mechanism.

The magnitude of the effect of these two damping mechanisms are determined automatically in the process of analyses by the behavior of the system. This eliminates the need for determining the damping ratio which is one, the most critical, at the same time difficult, steps in a dynamic analysis. The hysteretic damping at each point in the system is dependent on the effective pressure and the level of cyclic shear stresses. This can be seen from shear stress-strain diagrams shown in Fig. 11.

In order to study the influence of these damping mechanisms the following three cases were analyzed.

Case 1. The soil is modeled as one phase solid with linearly elastic material property. No damping is present in this case.

Case 2. The soil is modeled as one phase solid. But in this case nonlinear material properties are used. This case has only the hysteretic damping.

Case 3. The soil is modeled as two phase medium and nonlinear material properties are used. In this case both damping mechanisms are present.

For all the cases 100 ft layer was assumed and all the properties, except those which were mentioned above, were the same. The El Centro earthquake record was used as the base motion. The response spectra at ground surface for these three cases are shown in Fig. 6. The effect of the two damping mechanisms is quite clear from this figure. In Case 1, in absence of any damping, very high peak spectral velocities are present at the natural frequencies of the system. Hysteretic type damping has considerably reduced the surface response spectrum of case 2. The differences between surface response spectra of cases 2 and 3 is solely due to dissipative types damping which appears to be considerable. Furthermore, the hysteretic damping appears to be almost uniformly effective over the whole frequency range whereas the dissipative damping has little effect in the low frequency range but is very effective in the high frequency range.

The observations made in this section appear to confirm the authors belief that close modeling of the behavior and physical make up of soil to a great degree eliminates the need for specifying the damping as an additional material property.

6. CASE STUDIES

In this section the results of the application of the method of analysis described in previous sections to two cases are presented and discussed. The first case studied is a 100 ft layer of sand with water table at 2 ft below ground surface. This layer is subjected to N-S component of El Centro earthquake of May 1940 as horizontal base acceleration. The material properties used in this analysis are shown in Fig. 7. It is assumed that the initial shear modulus increases with depth. Other parameters are constant through the depth.

Shown in Fig. 8 are the time histories of excess pore pressures and effective stresses normalized with respect to in situ effective stresses. It can be seen that major pore pressure increases occur within the first 2.5 seconds of the earthquake. Initial liquefaction occurs when the excess pore pressures have reached a value of about 60 % of the in situ effective pressure. After the initial liquefaction the material properties change to a post failure condition causing the excess pore pressures to oscillate according to shear stresses. The oscillations in the excess pore pressure continue until final liquefaction has occurred, whereupon the pore pressures remain constant with time. The first element liquefies at 2.7 seconds. The liquefaction of other elements follow and the liquefied zone increases with time. The pattern of development of liquefaction with time is shown in Fig. 9. It can be seen that the last element has liquefied at 6.0 seconds. The zone of liquefaction extends from the water table to a depth of 20 feet below ground surface and the zone of liquefaction does not expand after 6 seconds. The variation of excess pore pressure with depth is shown in Fig. 10 at various times. It can be seen that before liquefaction the excess pore pressure, as a percentage of in situ effective pressure, has the highest value near the ground surface. The time rate of increase of this pore pressure ratio is also much higher near the ground surface and it rapidly decreases with depth. Below a depth of 60 feet the excess pore pressures vary between 20 to 35 per cent of the in situ effective pressures.

Shown in Fig. 11 are typical shear stress-strain plots at several depths. It is evident from this figure that the increase in effective pressure with depth has a great deal of influence on the maximum shear stresses, equivalent shear moduli and the hysteretic damping.

The dynamic analysis due to earthquake base motion was carried out for 30 seconds. The excess pore pressure ratios at the end of 30 seconds of earthquake are shown in Fig. 12. Also shown in this figure are the pore pressure ratios at different elapsed times after the earthquake. The dissipation of excess pore pressure after the earthquake are obtained by post-earthquake analysis.

The second case studied here is a soil profile similar to Niigata sites where extensive liquefaction occurred during the June 16, 1964 earthquake. No attempt is made here to directly model the Niigata site. The properties used in this analysis, as shown in Fig. 13, are chosen to coincide with those used by Seed and Idriss in Ref. (14). The initial shear modulus is assumed to increase linearly with depth. The relative densities and the corresponding values for λ are also shown in Fig. 13. The depth of the layer used in the analysis is 250 feet. Below 100 feet the rate of increase of shear moduli with depth was gradually reduced and a constant relative density of 0.9 was used.

Two base motions were used in the analysis; the El Centro earthquake record with half the amplitude; and, a sine wave with an amplitude of 0.15 g and a period of 0.5 seconds. The pattern of the development of liquefaction for these two cases are shown in Figures 14 and 16 and the variation of excess pore pressures with depth are shown in Figures 15 and 17. It can be seen that the pattern of the development of liquefaction for both the base motions is very similar and the main differences are in the fact that for sine wave base motion liquefaction occurs earlier and also a larger zone liquefies. However, in both cases liquefaction starts in the second layer which is assigned the lowest relative density of 40 percent.

The sine wave base motion is probably the most severe condition from liquefaction point of view, since the soil is subjected to sustained levels of cyclic shear stress, whereas, when earthquake record is used as the base motion, only a few cycles of high shear stresses occur. It is reasonable to conclude that the peak acceleration and earthquake duration play a more important role in the liquefaction potential than other properties of any earthquake.

In summary, it is observed that for base accelerations used, with peak values typical of Niigata earthquake and regardless of earthquake type, the method shows that liquefaction does occur in the upper 30 feet of the soil profile used in this analysis.

7. CONCLUDING REMARKS

Presented in this report is a general method for analysis of seismic response and liquefaction of horizontally layered saturated soils. The saturated soil below water table is modeled as a coupled two phase medium with solid granular skeleton and pore water as the constituent materials. Above the water table soil is modeled as a one phase solid. A nonlinear material model was used in the analysis which includes yielding, failure, volume change characteristics, cyclic effects and criteria for initial and final liquefaction.

Under cyclic shear stress the effective pressure decreases and as a result the resistance and the shear strength of sand decreases, allowing larger shear strains to develop. If this process continues under sustained shear stress, the sand will approach a condition of "near failure". This condition here is considered as initial liquefaction. Following initial liquefaction sand is in a state of post-failure and the behavior is quite different than the behavior of sand prior to initial liquefaction. A post-initial liquefaction model is developed for this range up to the final liquefaction.

This method of seismic analysis is applied in some case studies. The results appear to be reasonable and in agreement with field observations.

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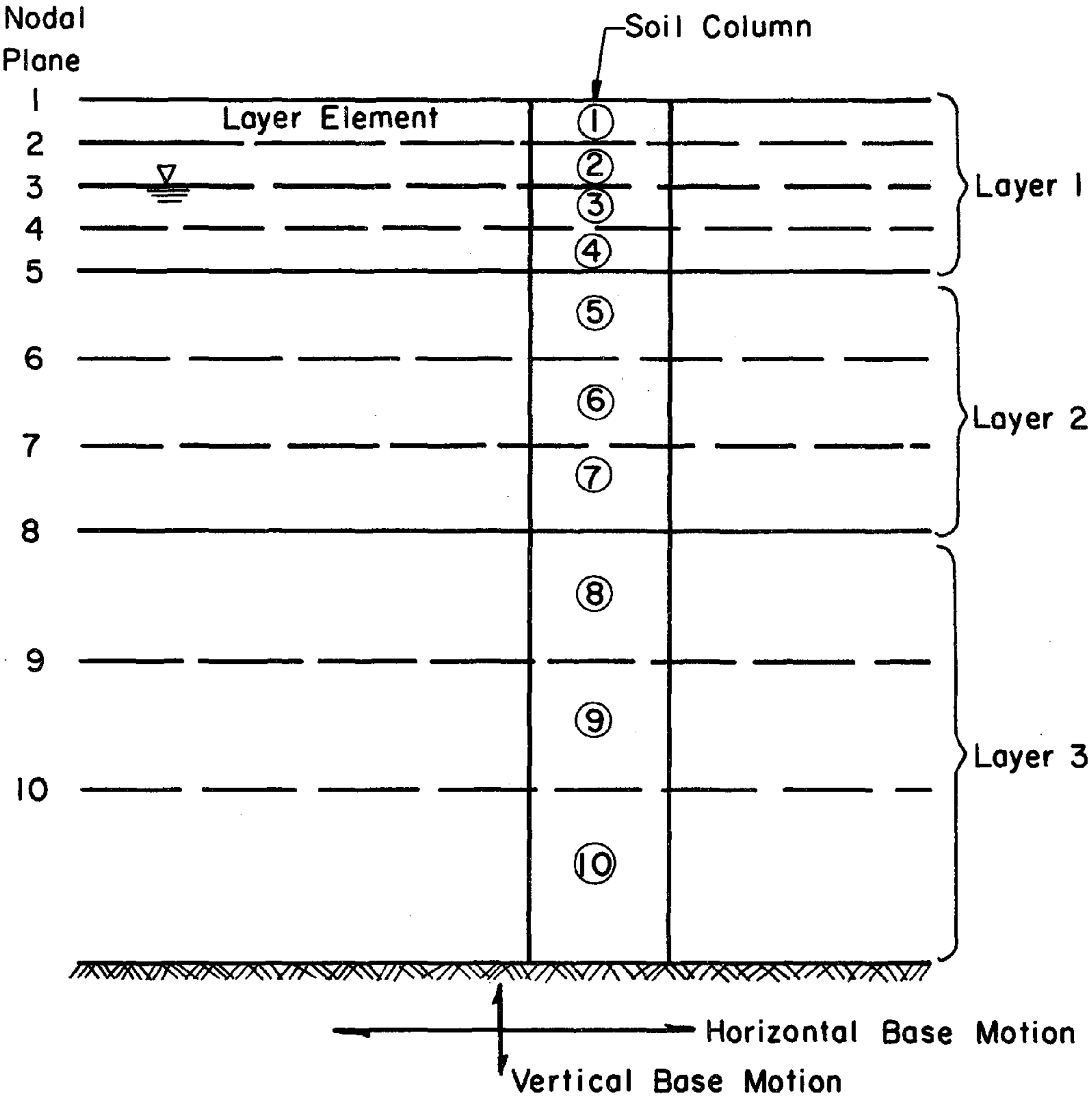

FIG. 1.—Schematic Representation of Layered System

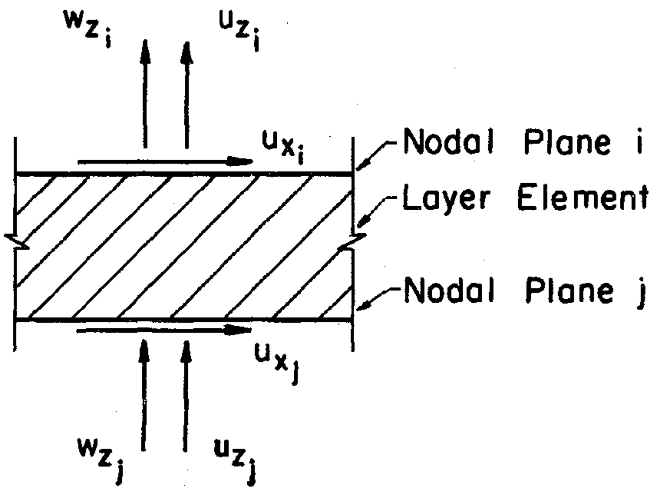

FIG. 2.—Layer Element

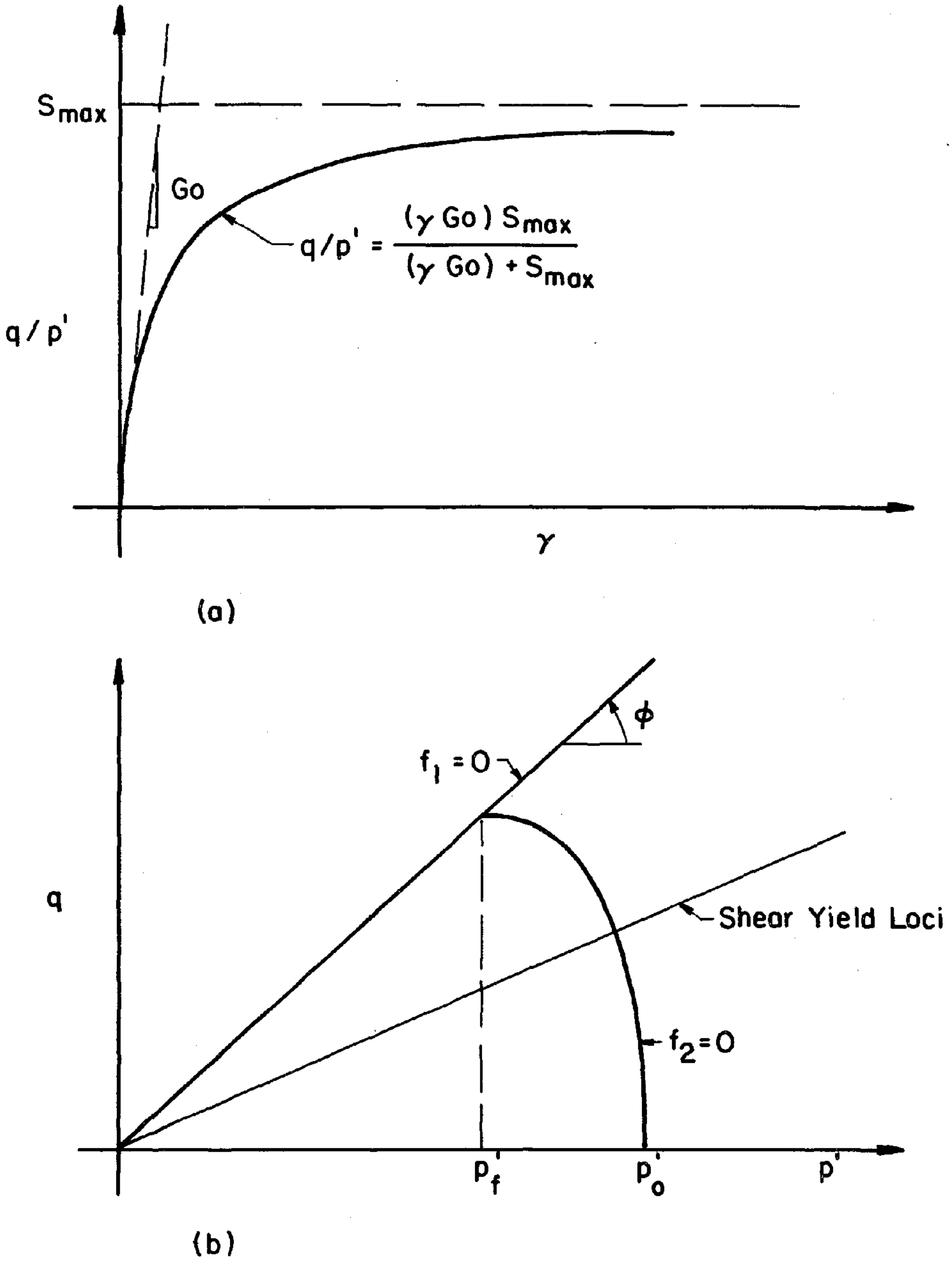

FIG. 3.—Material Model

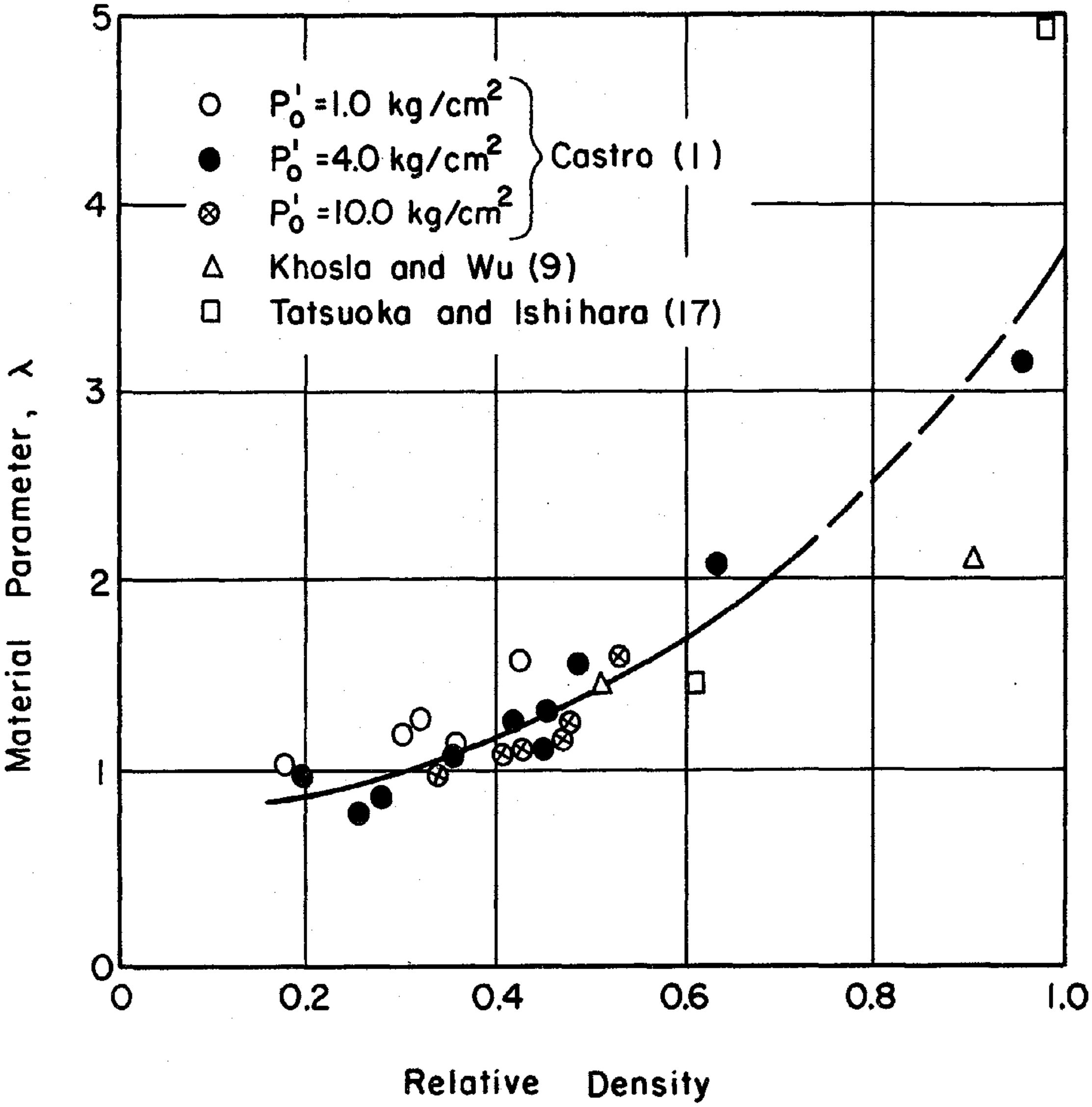

FIG. 4.—Relationship Between Material Parameter λ and Relative Density

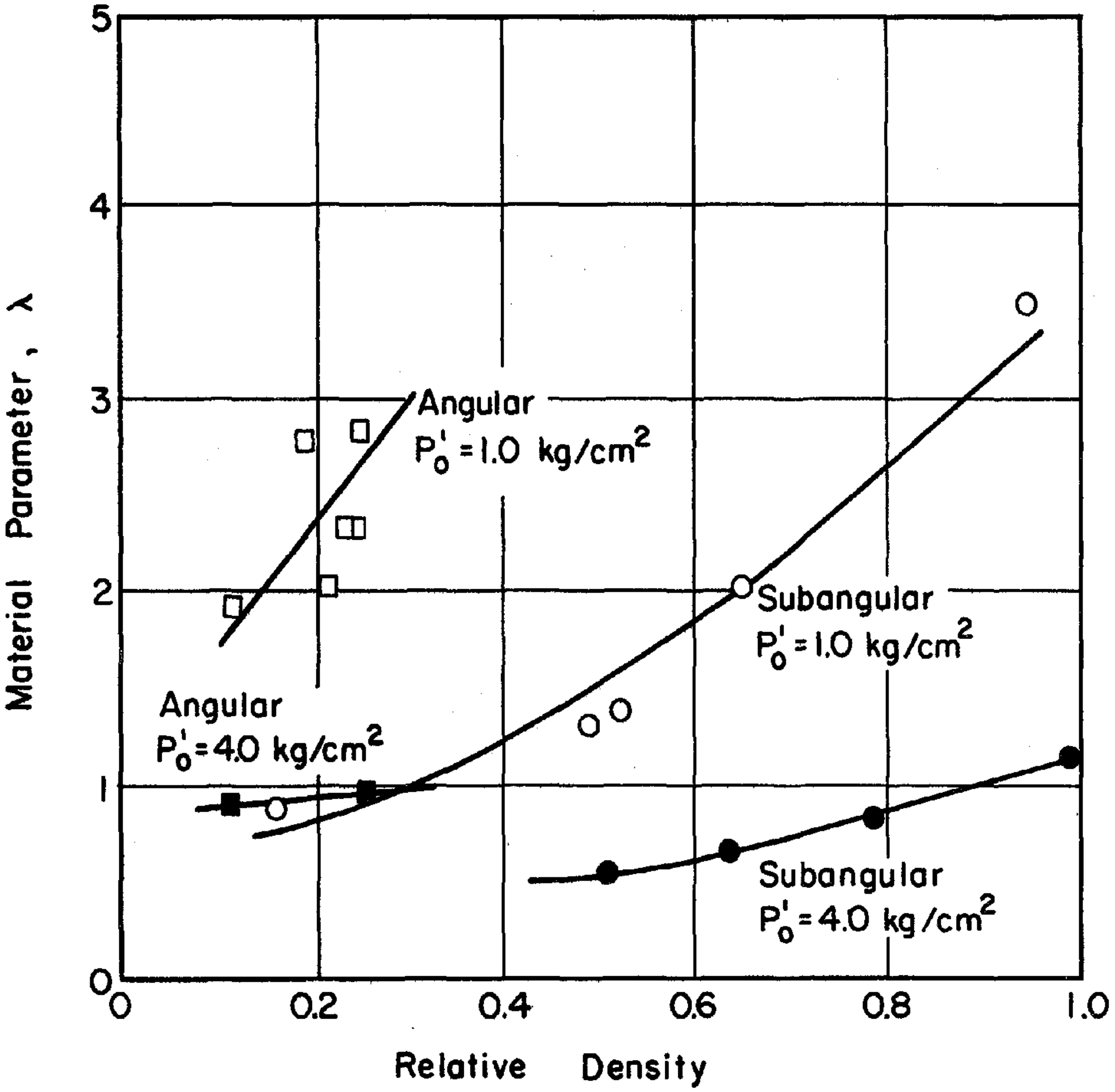

FIG. 5.—Influence of Grain Shape on Material Parameter λ

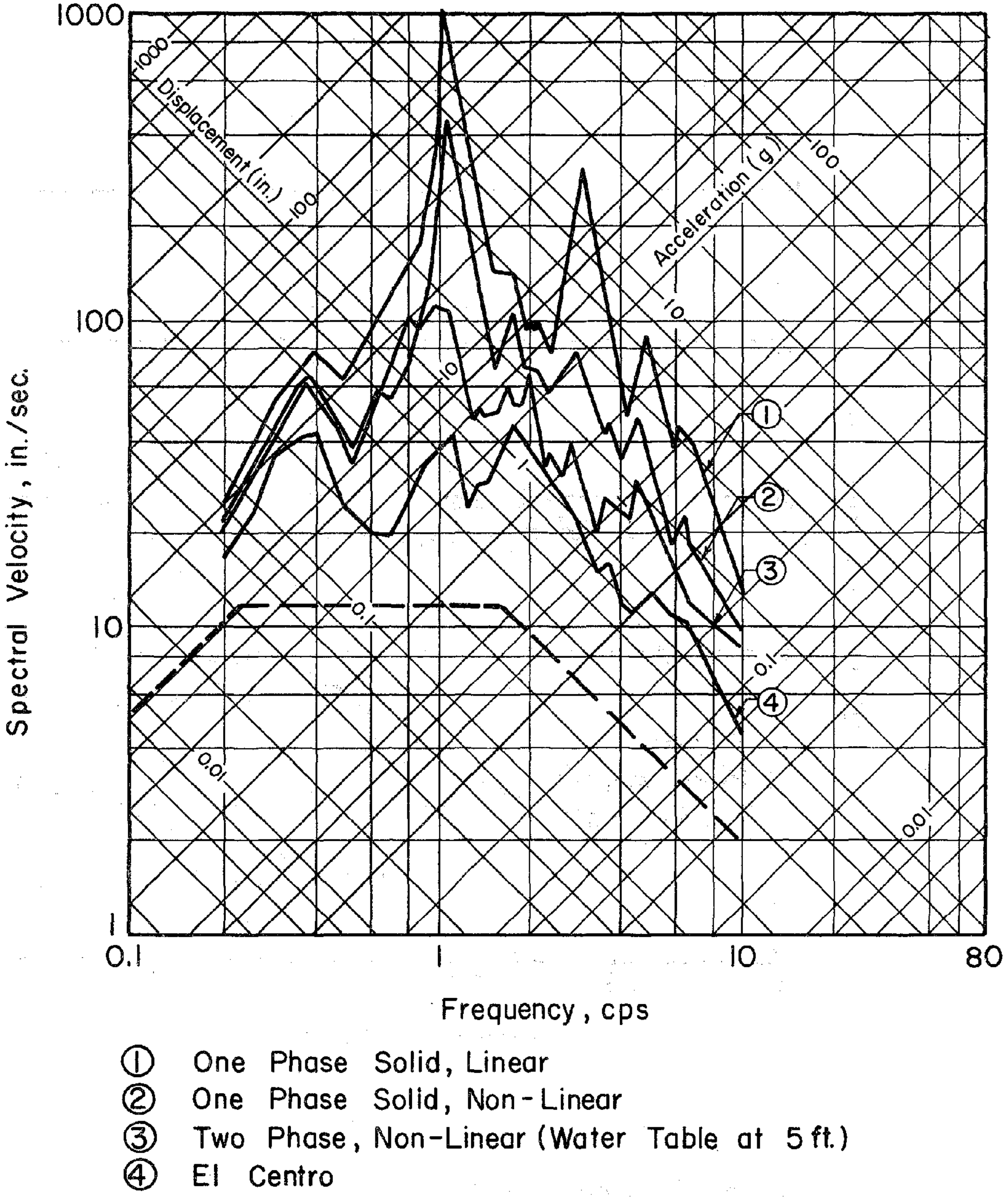

Fig. 6.—Ground Surface Response Spectra for Different Models

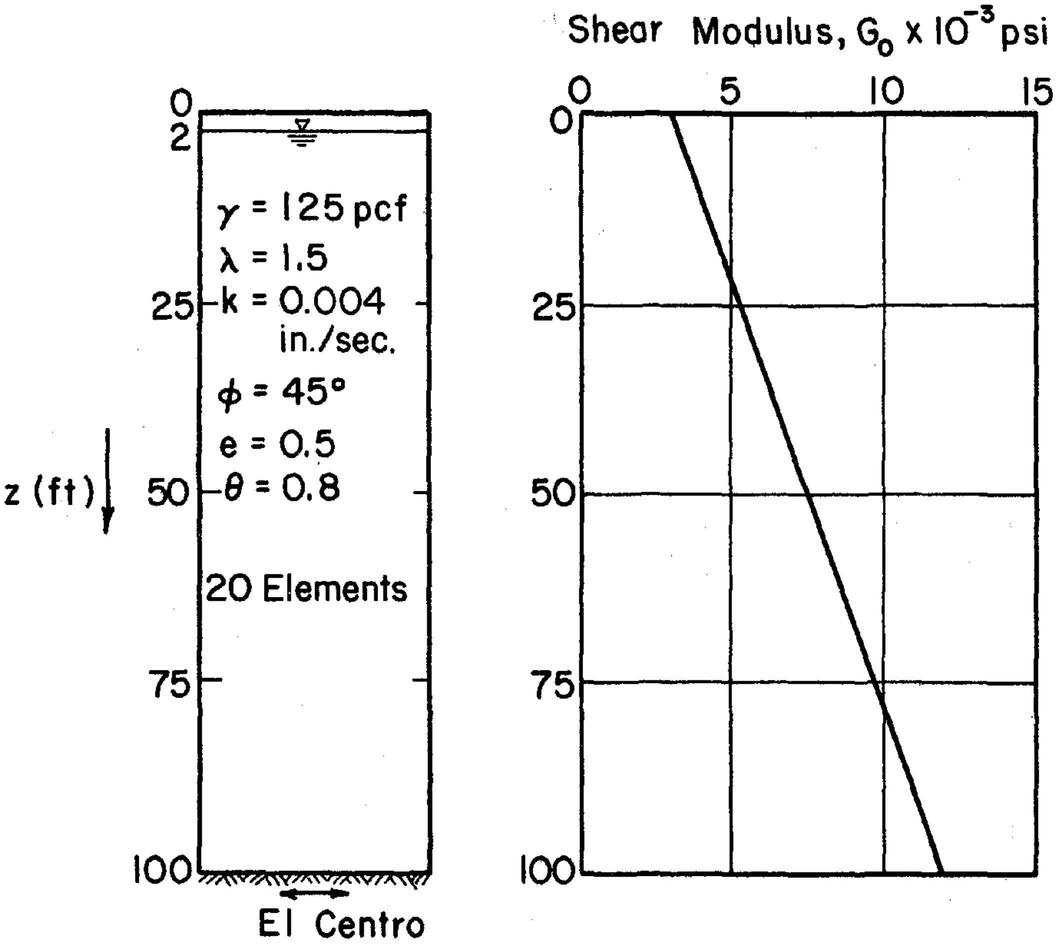

FIG. 7.—Properties Used in Example No. 1

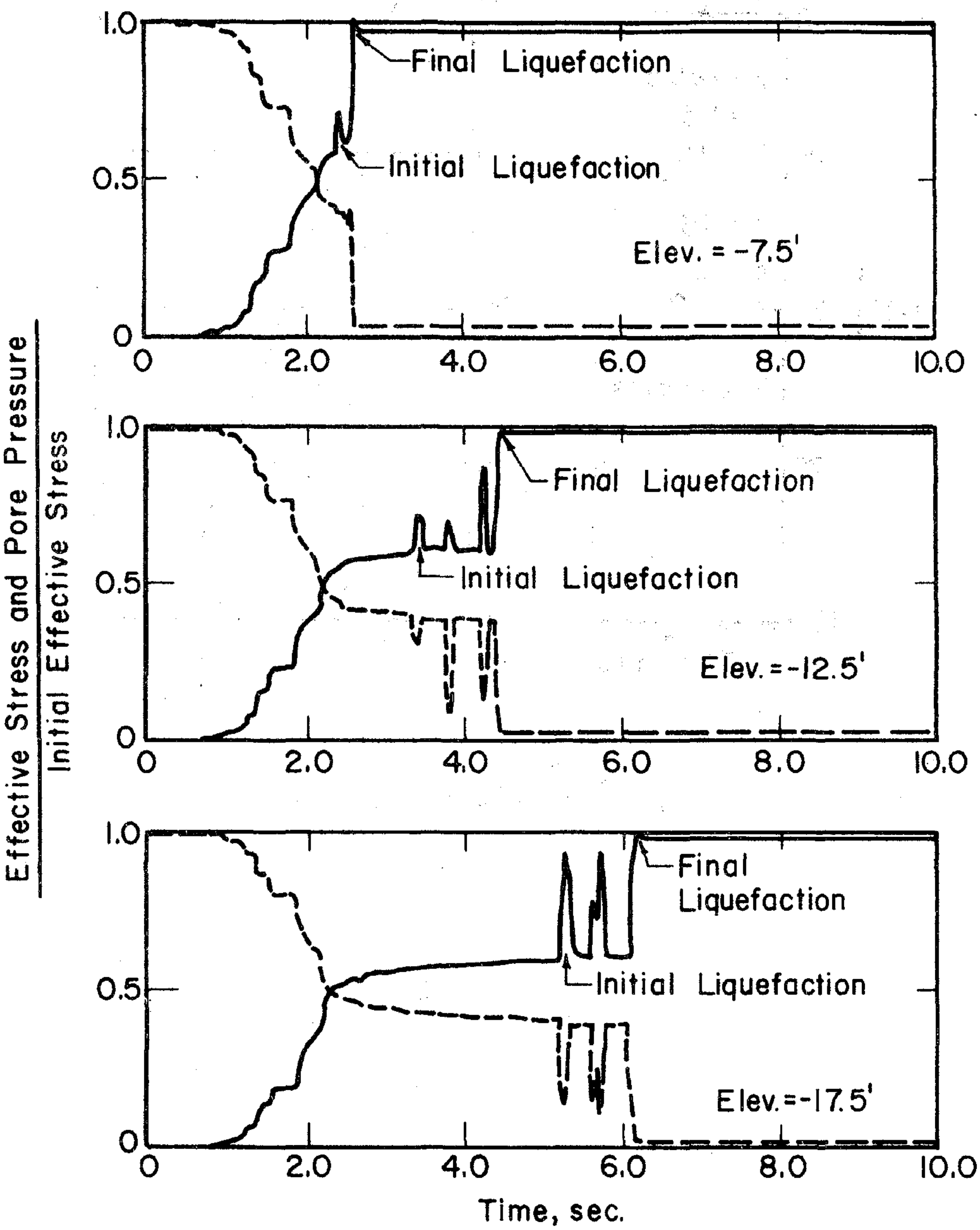

FIG. 8.—Excess Pore Pressure Time Histories, Example No. 1

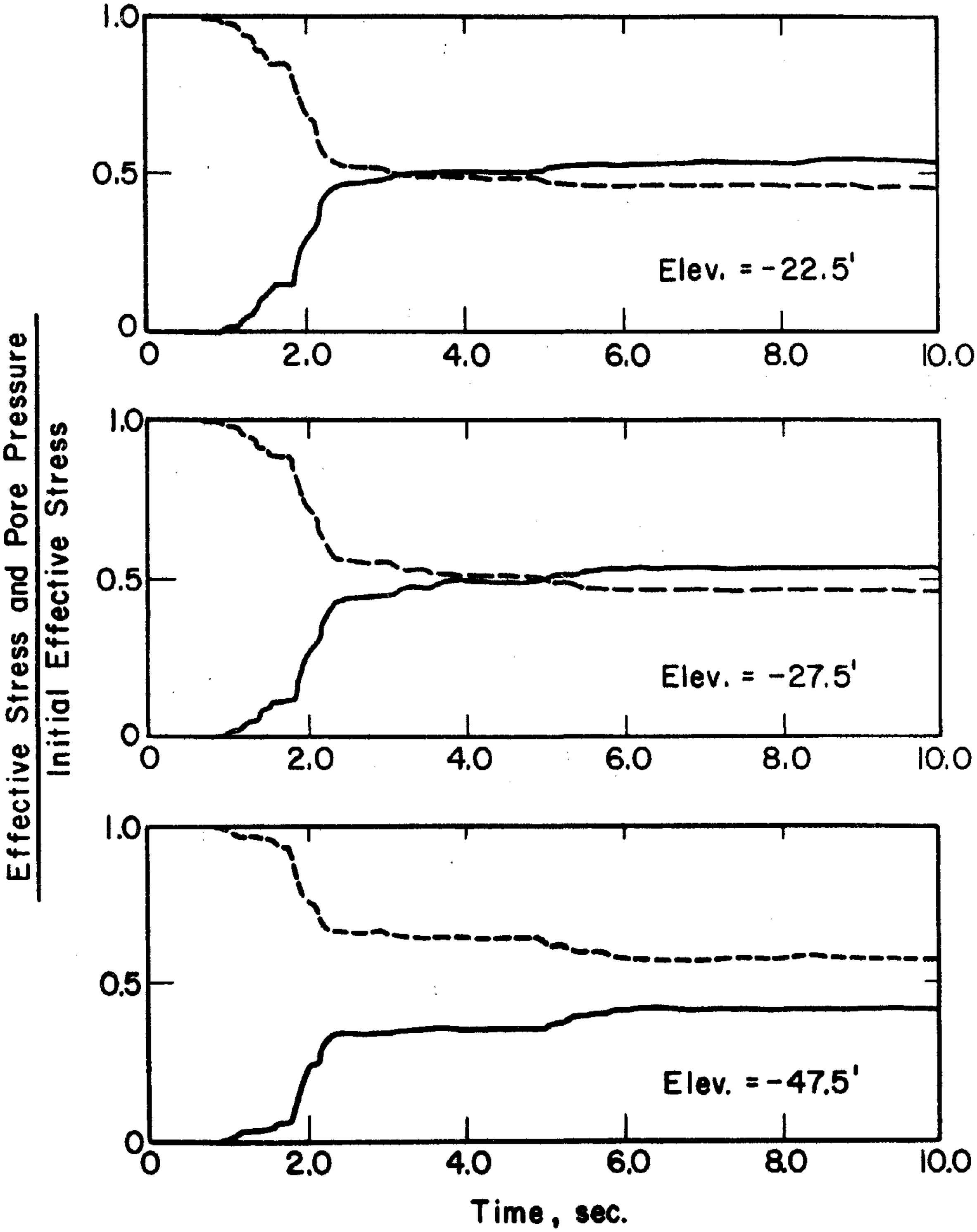

FIG. 8.—(Continued)

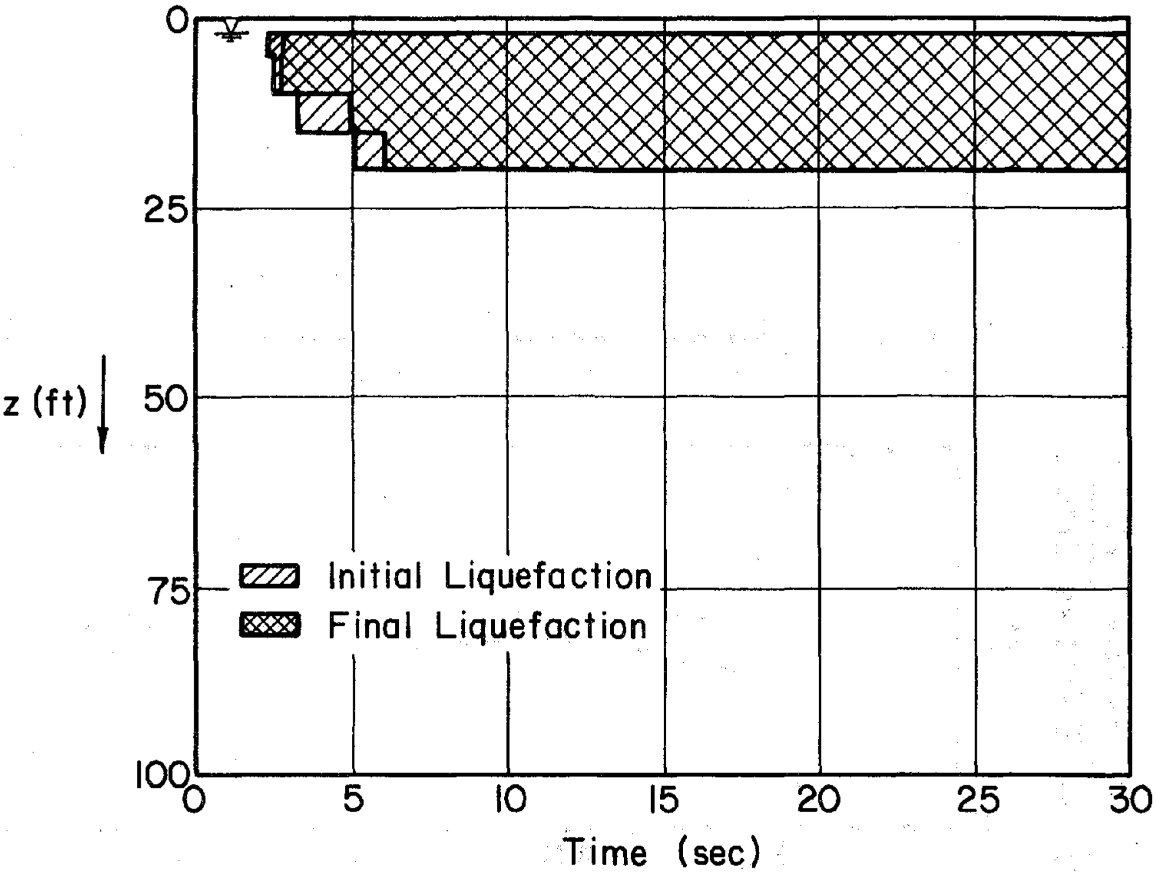

FIG. 9.—Development of Liquefaction with Time, Example No. 1

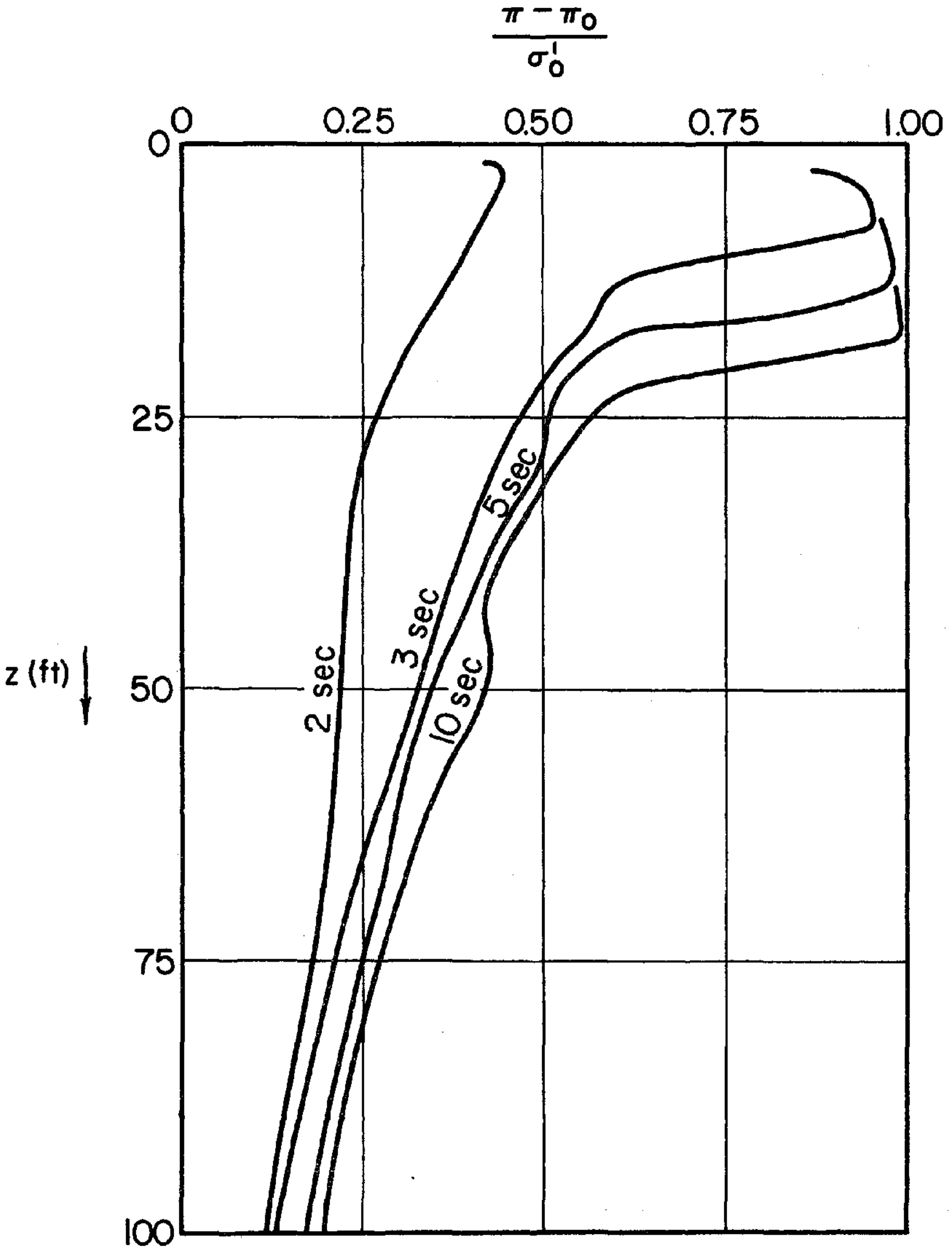

FIG. 10.—Pore Pressure Distribution at Various Times, Example No. 1

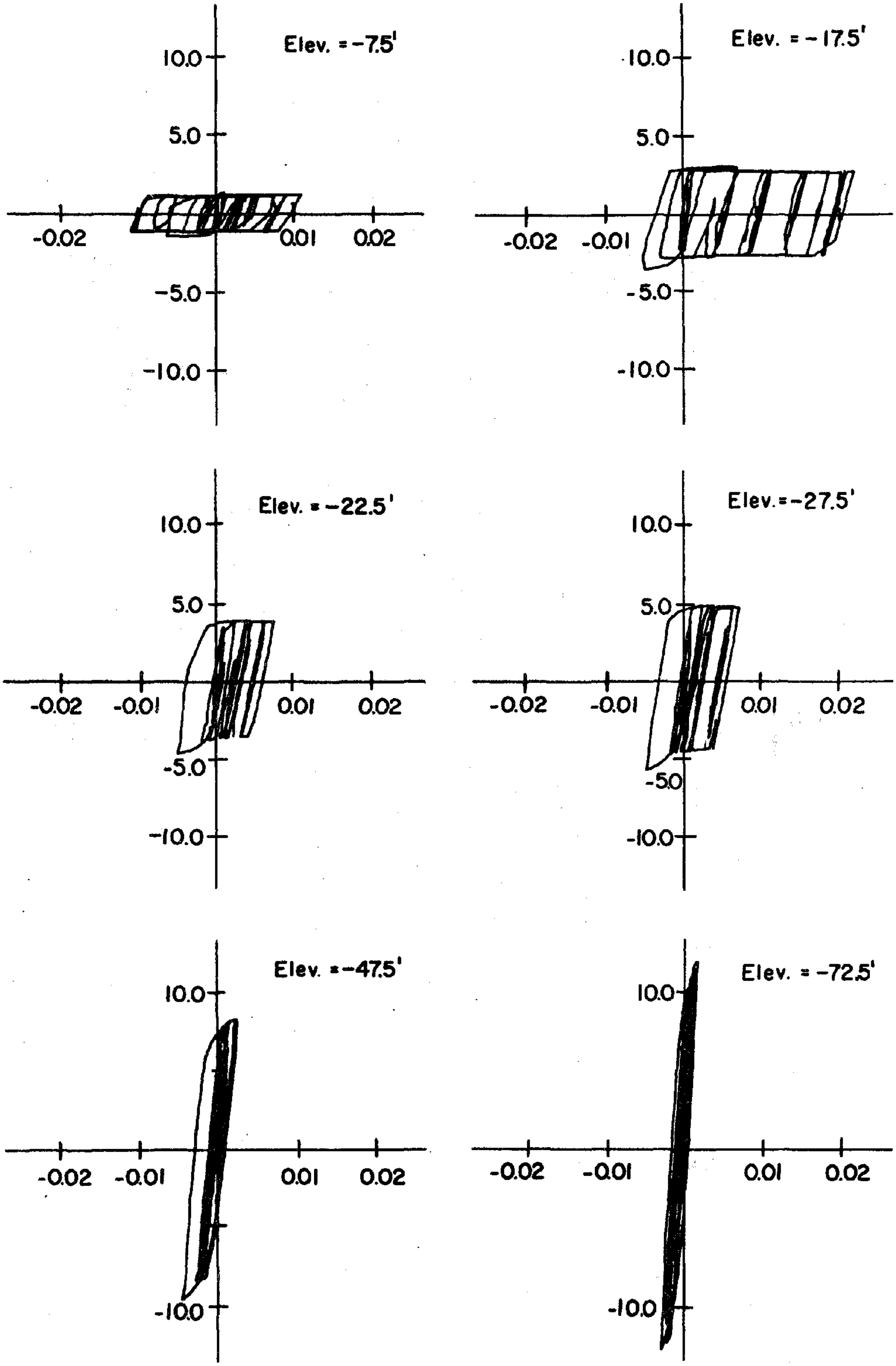

FIG. 11.—Shear Stress-Strain Plots, Example No. 1

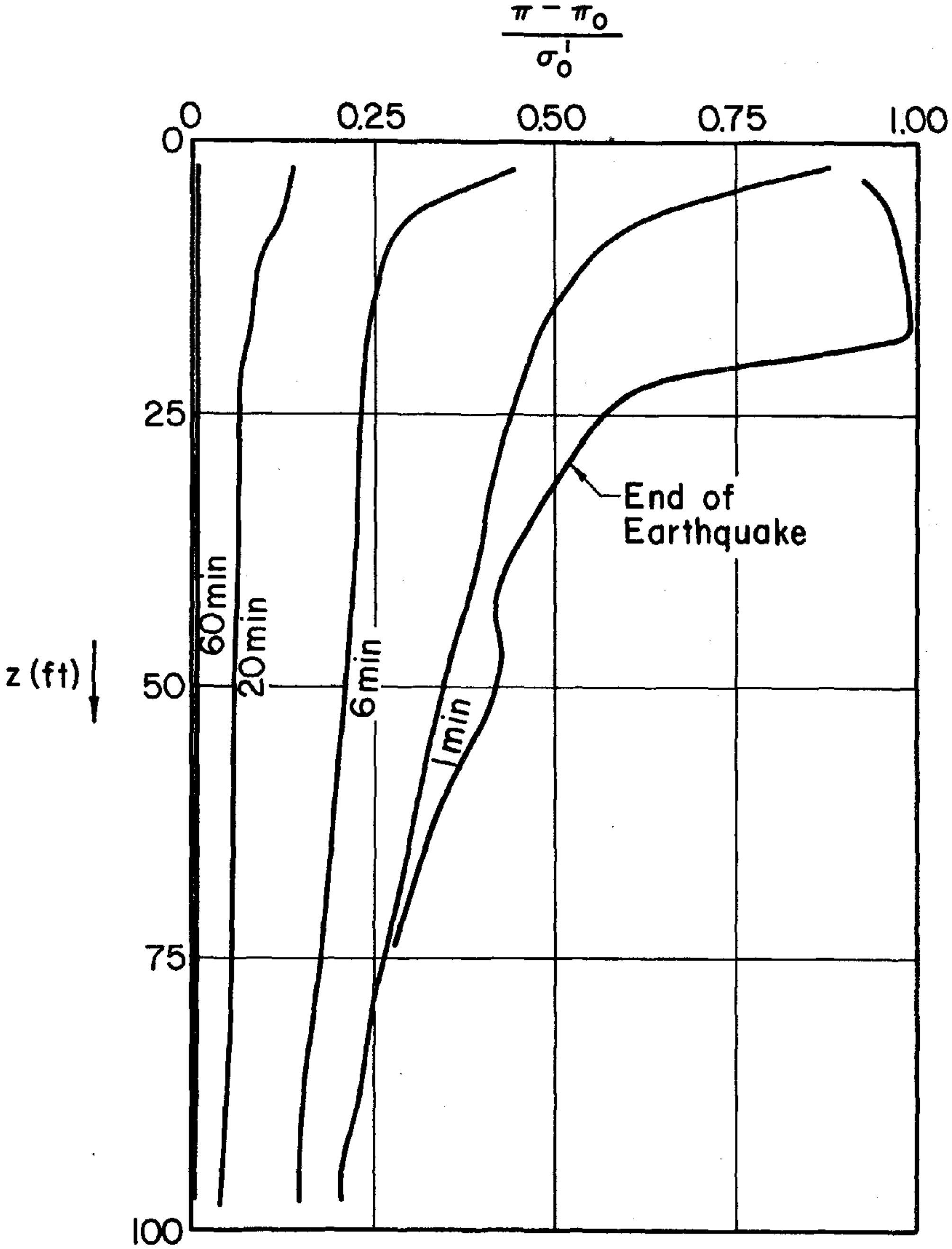

FIG. 12.—Post-Earthquake Dissipation of Excess Pore Pressures, Example No. 1

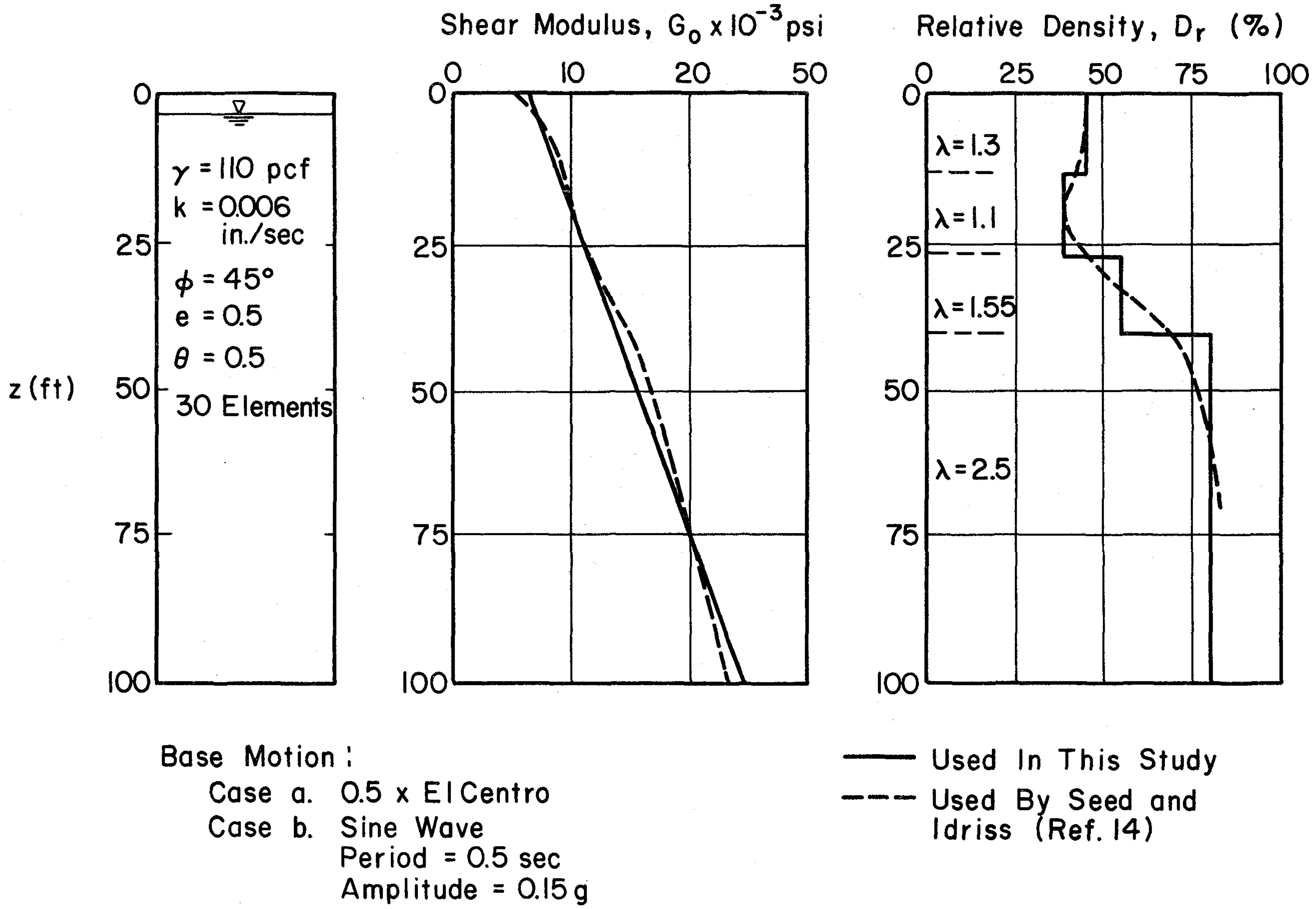

FIG. 13.—Properties Used in Example No. 2; Niigata Like Soil Profile

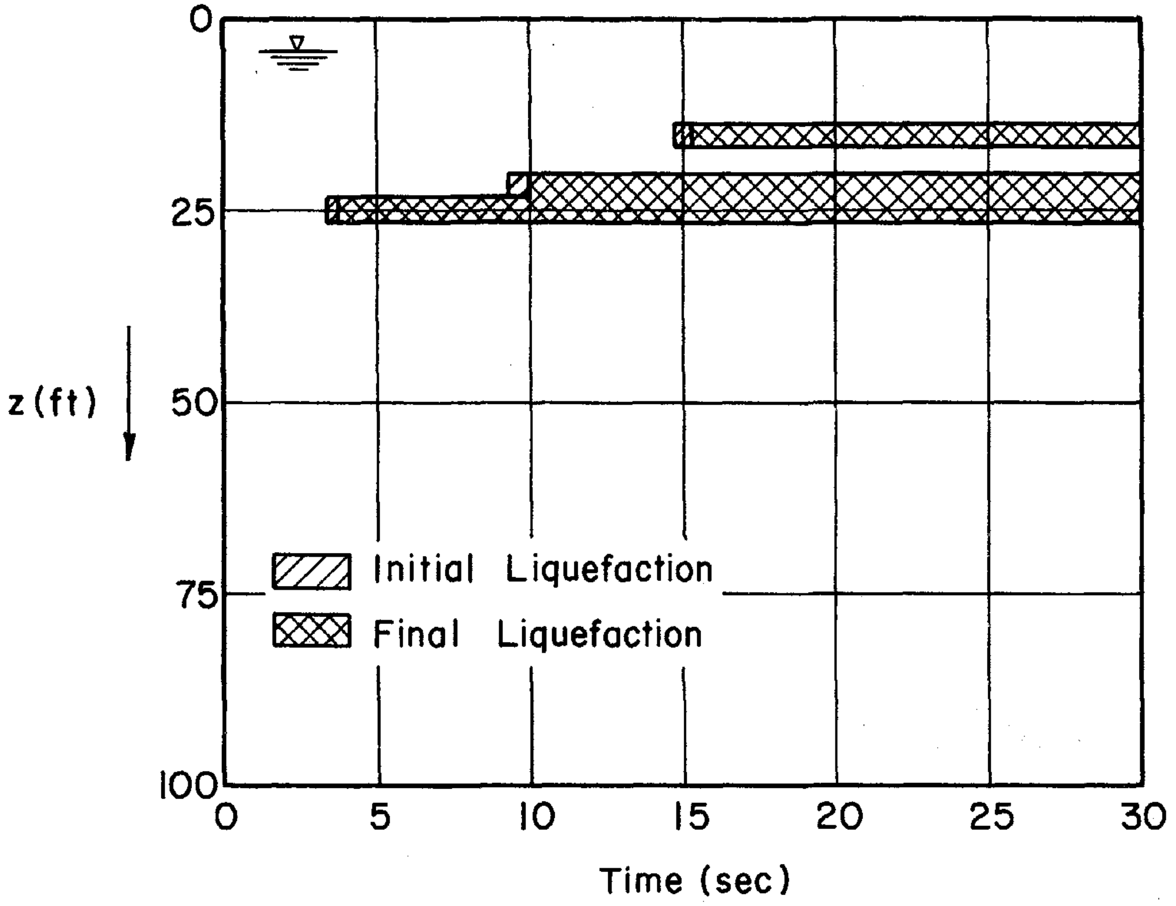

FIG. 14.—Development of Liquefaction with Time for Base Motion of 0.5 x El Centro Earthquake Record, Example No. 2

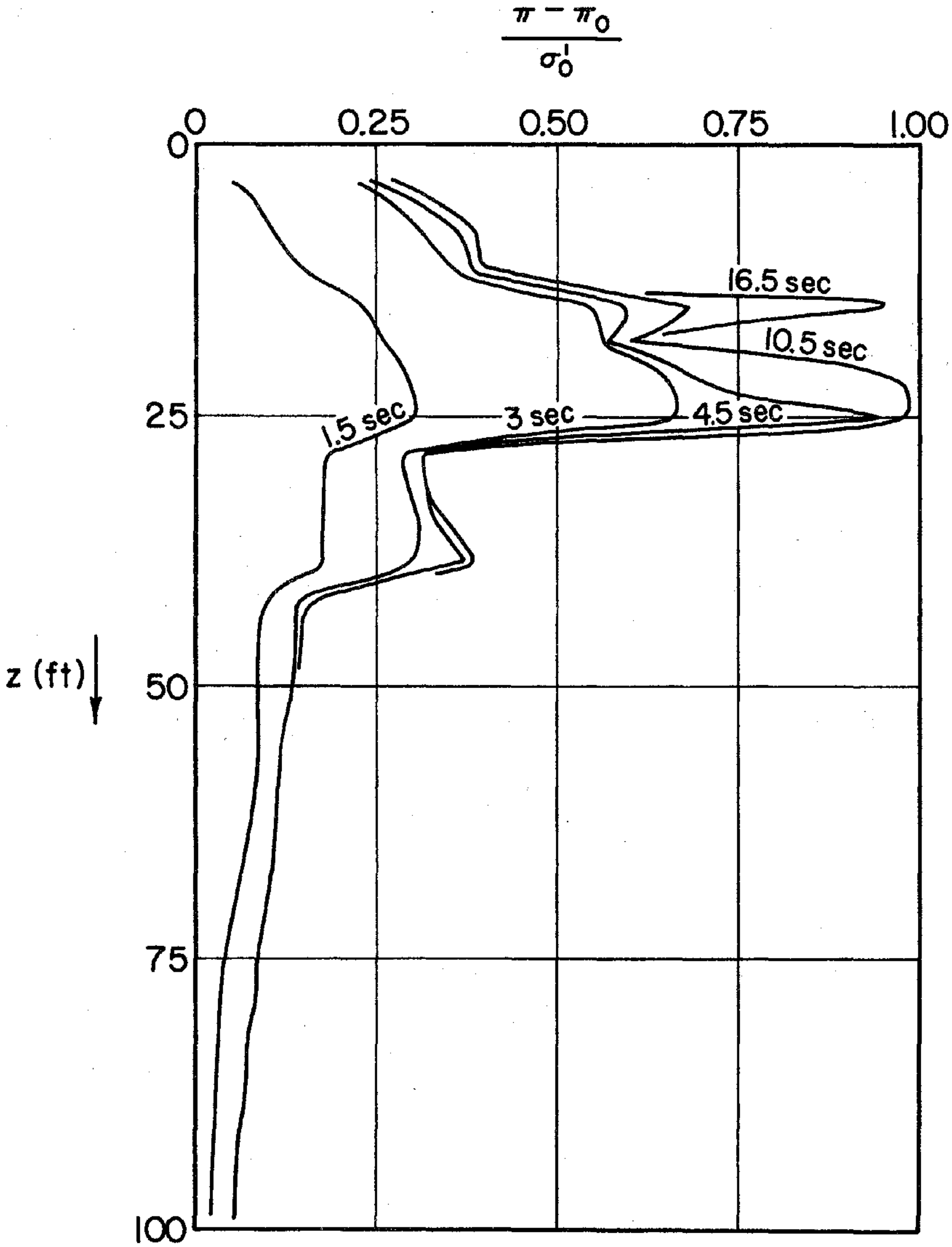

FIG. 15.—Variation of Pore Pressure with Depth for Base Motion of 0.5 x El Centro Earthquake Record, Example No. 2

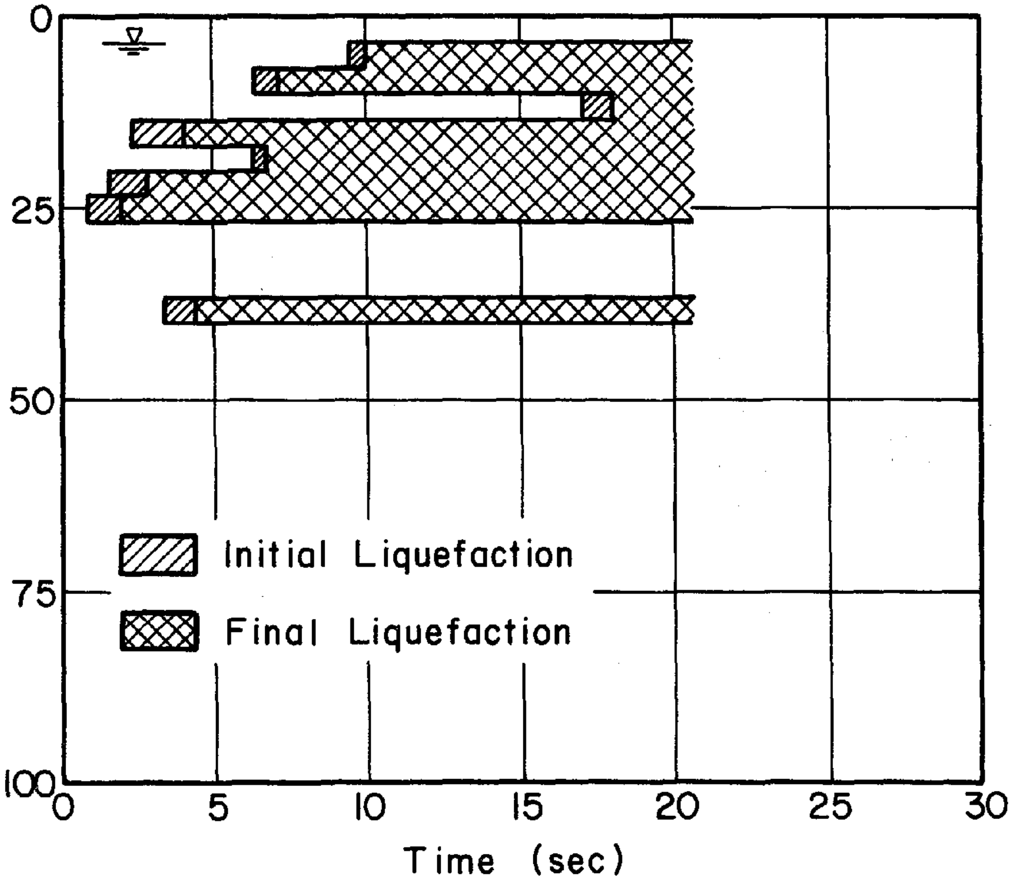

FIG. 16.—Development of Liquefaction with Time for Base Motion of Sine Wave, Example No. 2

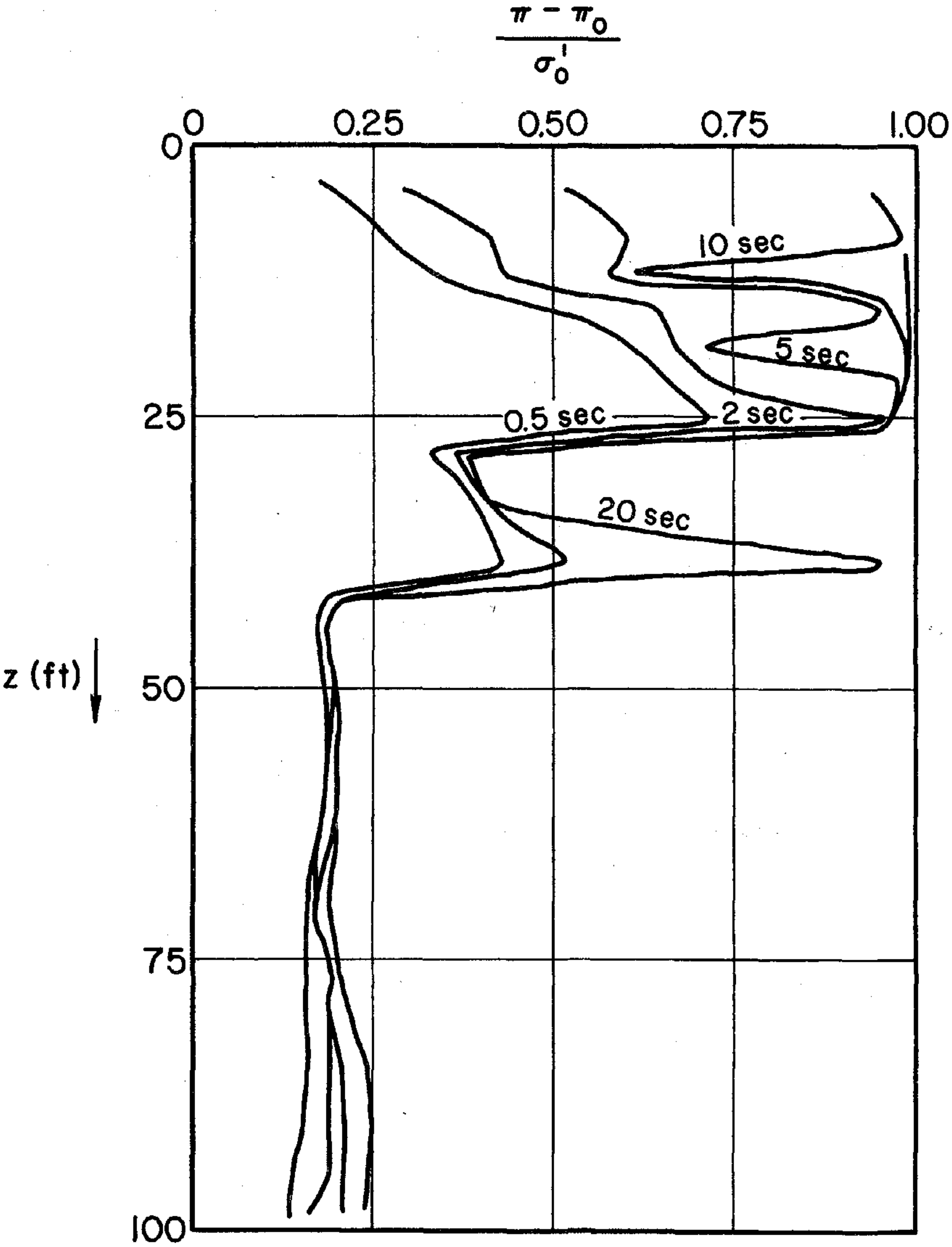

FIG. 17.—Variation of Pore Pressure with Depth for Base Motion of Sine Wave, Example No. 2

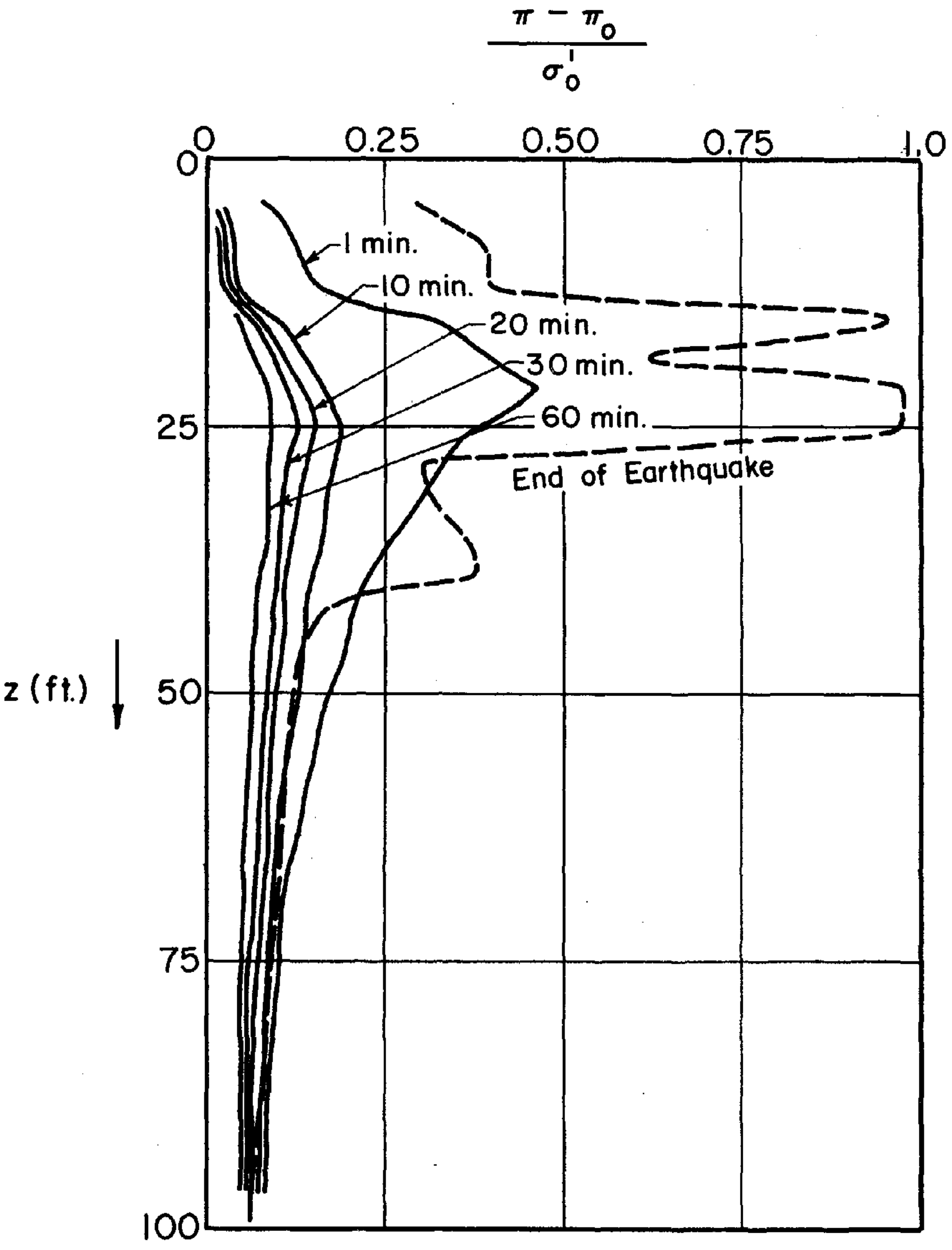

FIG. 18.—Post Earthquake Dissipation of Excess Pore Pressures for Base Motion of 0.5x El Centro Earthquake Record, Example No. 2

APPENDIX - I

INPUT DATA FOR COMPUTER PROGRAM LASS-II

APPENDIX I

INPUT DATA FOR COMPUTER PROGRAM LASS-II

The computer program LASS-II is for Liquefaction Analysis of Saturated Soil deposits. This first version is capable of dynamic analysis of horizontally layered saturated cohesionless soil deposits.

I. CONTROL CARDS

Card 1 (18A4)

Columns	1-72	Problem title (To be printed in output)

Card 2 (3I5, F10.0)

Columns	1-5	Number of layers
	6-10	Number of different material properties
	11-15	Number of dynamic time steps
	16-20	Dynamic time step (Δt)

Card 3 (4I5)

Columns	1-5	Interval of steps for printing of response (displacements, velocities, accelerations, strains and stresses).
	6-10	Interval of steps for saving of response at selected points to be specified later for the purpose of plotting.

Columns	11-15	Step number for starting printing of response at intervals indicated in columns 1-5 of this card.
	16-20	Interval of steps for updating of stiffness matrix.

Card 4 (3I5, 6F10.0)

Columns	1-5	Number of nodes for which the time histories of acceleration, velocity and displacement are to be plotted.
	6-10	Number of elements for which the time histories of shear stress and shear strain, and the shear stress vs. the shear strain are to be plotted.
	11-15	Number of elements at which the time histories of effective stress and pore water pressure are to be plotted.
	16-25	Height of the plotter paper in inches, (Default value is 10).
	26-35	Height of the stress and strain time history diagrams in inches, (Default value is 2).
	36-45	Length of the time axis in inches, (Default value is 10).
	46-55	Size (height = length) of the stress vs strain diagrams in inches, (Default value is 8).
	56-65	Height of the pore pressure and effective stress history diagrams in inches, (Default value is 4).
	66-75	Maximum time value to be plotted in seconds, (Default value is 10).

Card 5 (4I5)

Columns 1-5	A non-zero value indicates a request for the computation of response spectras (Acceleration, velocity and displacement).
6-10	A non-zero value indicates a request for the plot of response spectras.
11-15	Number of damping values to be used in the computation of response spectra, (Default value is 3). Maximum value that can be specified is 10.
16-20	Number of nodes for which the response spectras to be computed. Maximum value that can be specified is 10.

Card Group 6 (8F10.0)

This card is required if a non-zero value is specified in columns 11-15 of Card 5. In the above format give the damping values as percent of critical damping. If a zero is specified in columns 11-15 of Card 5, program computes spectras for .02, .05, .1 damping.

Card 7 (10I5)

This card is required if the computation of response spectra is requested. In the above format give the node numbers.

Card 8 (2I5)

Columns 1-5	A non-zero value indicates a request for the post-earthquake analysis.

Columns 6-10	If a non-zero value is specified in the column 1-5 of this card, give the number of different time steps which will be used in post-earthquake analysis. Maximum value that can be specified is 10.

Card Group 9 (F10.0, 2I5)

One card must be provided for each time step indicated in columns 6-10 of card 8.

Columns 1-10	Time step.
11-15	Number of times that this time step is to be repeated.
16-20	Print interval of the time step.

Card 10 (2F10.0)

Columns 1-10	Depth of water table.
11-20	Gravity, g, (Default value is 386.2 in/sec^2).

II. SOIL DEPOSIT DATA

Card Group 11 (F10.0, 2I5)

One card required for each layer of soil.

Columns 1-10	Depth of the base of the layer.
11-15	Number of elements the layer is to be subdivided.
16-20	Material number of layer. This number is to identify the type of material properties in the sequence given in the next card group to be assigned to this layer.

This data is provided for the layers in the sequence of increasing depth starting at the layer at the ground surface.

Card Group 12 (8F10.0)

The following cards must be provided for each material type as indicated in columns 6-10 of Card 2.

Card 12.1

Columns 1-10	Bulk modulus for effective stresses.
11-20	Shear modulus at the top of the layer.
21-30	Change in shear modulus per unit of depth.
31-40	Bulk modulus of fluid.
41-50	Permeability.
51-60	Mass density of solid.
61-70	Mass density of fluid.
71-80	S_{max}

Card 12.2

Columns 1-10	$1/\lambda$
11-20	ϕ
21-30	α
31-40	Constant for the direction of stress vector in p'-q stress plane for post-initial liquefaction calculation.
41-50	Effective stress at final liquefaction.
51-60	Void ratio

III. PLOT DATA

Card Group 13 (16I5)

This card group is required if a non-zero value is specified in columns 1-5 of Card 4. In the above format give the node numbers of the nodes where the motion plots are required.

Card Group 14 (16I5)

This card group is required if a non-zero value is specified in columns 6-10 of Card 4. In the above format give the element numbers of the elements for which the time histories of shear stresses and shear strains, and the stress-strain diagrams are to be plotted.

Card Group 15 (16I5)

This card group is required if a non-zero value is specified in columns 11-14 of Card 4. In the above format give the element numbers of the elements for which the time histories of effective stresses and pore water pressures are to be plotted.

IV. EARTHQUAKE DATA

Card 16 (12A6)

Columns 1-72	Earthquake identification title (to be printed in output).

Card 17 (2F10.0, 2I5)

Columns 1-10	Time scale factor. Earthquake time points are multiplied by this time scale factor. (If zero or blank, a value of one is used). This is not required if a non-zero value is specified in columns 26-30 of this card.

Columns 11-20	Amplitude scale factor. Earthquake amplitudes are multiplied by this scale factor (If zero or blank, a value of one is used).
21-25	Number of time points to define the time history of base acceleration.
26-30	Base acceleration data type: zero or blank when the base acceleration data are given at irregular time intervals; any non-zero value when the base acceleration is given at equal intervals with the same time step as specified in columns 21-30 of Card 2.

If the value in columns 26-30 of Card 14 is zero provide Card group 15, otherwise provide Card group 16.

Card Group 18 (8F10.0)

In the above format for each base acceleration time point give sequentially the values of time and corresponding base acceleration. The program interpolates to determine the value of base acceleration at intervals of time step Δt.

Card Group 19 (8F9.0)

In the above format for each base acceleration time point give sequentially the values of base acceleration at intervals of time step Δt.

APPENDIX - II

LISTING OF COMPUTER
PROGRAM LASS-II

```
C        PROGRAM IASS2
C
C
C        PROGRAM FOR EARTHQUAKE ANALYSIS OF HORIZONTALLY LAYERED
C        SATURATED SOILS WITH EVALUATION OF LIQUEFACTION POTENTIAL
C
C        DEVELOPED BY  JAMSHID GHABOUSSI
C                      CIVIL ENGINEERING DEPARTMENT
C                      UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
C                      OCTOBER 1975
C
C        MODIFIED BY  JAMSHID GHABOUSSI AND UMIT DIKMEN
C                     CIVIL ENGINEERING DEPARTMENT
C                     UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
C                     MARCH 1977
C
C
C
         COMMON A (40000)
         COMMON/CONTL/HED(15),NCYCL,DT,NDI,NPRNT,NSAVE,LOUT,NC,NUPDAT,NPIT
        *   ,NSTAT,NINCR,NSTPRT
         COMMON/WIVL/ WTABLE,GRAV
         COMMON/PLTING/ NPLOTM,NPLTSS,NSETS,HPAP,HPLOT,BPLOT,DPLOT,EPLOT,
        *   TEND
         COMMON/SPEC/DV(10),NODE(10),NNODE,IRS,IRSP
         COMMON/POSEQ/NTREP(10),TS(10),ILIMIT,NTS,NPLQPT(10)
C
         MTOT=40000
         READ (5,1000) HED
         READ (5,1001)NLAYER,NMAT,NCYCL,NDI,DT,NSTAT,NINCR
         WRITE (6,2000) HED,NLAYER,NMAT,NCYCL,NDI,DT
         READ (5,1003) NPRNT,NSAVE,NSTPRT,NUPDAT,NWRITE
         WRITE (6,2001) NPRNT,NSAVE,NSTPRT,NUPDAT,NWRITE
         READ(5,1004) NPLOTM,NPLTSS,NSETS,HPAP,HPLOT,BPLOT,DPLOT,EPLOT,TEN
         IF(NPLOTM.LE.0.AND.NPLTSS.LE.0.AND.NSETS.LE.0) GO TO 200
         IF(HPAP.LT.1..OR.HPLOT.LT.1..OR.BPLOT.LT.1..OR.DPLOT.LT.1..OR.TEN
        *  .LT.1..OR.EPLOT.LT.1.) WRITE(6,2004)
         IF(HPAP.LT.1.) HPAP=10.
         IF(HPLOT.LT.1.) HPLOT=2.
         IF(BPLOT.LT.1.) BPLOT=10.
         IF(DPLOT.LT.1.) DPLOT=6.
         IF(EPLOT.LT.1.) EPLOT=4.
         IF(TEND.LT.1.) TEND=10.
         WRITE(6,2003) NPLOTM,NPLTSS,NSETS,HPAP,HPLOT,BPLOT,DPLOT,EPLOT,
        *  TEND
     200 READ(5,1005) IRS,IRSP,NDV,NNODE
         IF(IRS.EQ.0) GO TO 215
         WRITE(6,2005)
         IF(NDV.LE.0) GO TO 230
         READ(5,1006) (DV(L),L=1,NDV)
         GO TO 240
     230 NDV=3
         WRITE(6,2006)
         DV(1)=0.02
         DV(2)=0.05
         DV(3)=0.1
     240 WRITE(6,2007) (DV(L),L=1,NDV)
         READ(5,1007) (NODE(L),L=1,NNODE)
         WRITE(6,2008) (NODE(I),L=1,NNODE)
     215 READ(5,1007) IPOSEQ,NTS
         IF(IPOSEQ.EQ.0) GO TO 210
```

```
      WRITE(6,2009)
      READ(5,1008)  (TS(I),NTREP(I),NPEQPR(I),I=1,NTS)
      WRITE(6,2010)  (TS(I),NTREP(I),NPEQPR(I),I=1,NTS)
210   IF(NDI.EQ.0) NDI=1
      NC=NDI+1
      IF (NDI.EQ.1) NC=NC+1
      READ (5,1002) WTABLE,GRAV
      IF (GRAV.LE.0.0) GRAV=386.2
      WRITE (6,2002) WTABLE,GRAV
      N1=1
      N2=N1+NLAYER
      N3=N2+NLAYER
      N4=N3+NLAYER
      N5=N4+35*NMAT
      IF(NDI.EQ.0) NDI=1
      N6=N5+NDI*NCYCL
      KK1=N6
      KK2=KK1+NPLOTM
      KK3=KK2+NPLTSS
      KK4=KK3+NSETS
      K1=KK4
      CALL REED (A(N1),A(N2),A(N3),A(N4),A(N5),A(KK1),A(KK2),A(KK3),
     *  NLAYER,NMAT,NUMNP,NCYCL,NDI,A(K1))
      K2=K1+NUMNP
      K3=K2+NUMNP
      K4=K3+NUMNP
      CALL MESH (A(N1),A(N2),A(N3),A(K1),A(K2),A(K3),WTABLE,NUMNP,
     *  NLAYER)
      NEQ=NC*NUMNP
      MBAND=2*NC
      K5=K4+NEQ*MBAND
      K6=K5+NEQ*MBAND
      K7=K6+NEQ
      K8=K7+NEQ
      K9=K8+NEQ
      K10=K9+NEQ
      K11=K10+NEQ
      K12=K11+NEQ
      K13=K12+NEQ
      K14=K13+11*NUMNP
      K15=K14+11*NUMNP
      KK15=K15+NEQ
      KK16=KK15+2*NUMNP
      K16=KK16+NNODE*NCYCL
      NTLL=K16-K4+1
      NCCY=NCYCL
      CALL SZERO (A(K4),NTLL)
      NTSAVE=(NCYCL+1)/NSAVE
      KN1=K16
      KN2=KN1+NTSAVE+2
      K16=KN2+NTSAVE+2
      NBLK=NTSAVE
      NPTOT=3*NPLOTM+2*NPLTSS+2*NSETS+3
      IF(NDI.GT.1) NPTOT=NPTOT+3*NPLOTM
      IF (NPTOT.LE.0) GO TO 100
      NLEFT=MTOT-K16-1
      NEED=NPTOT*NTSAVE
      IF (NEED.LE.NLEFT) GO TO 100
      NUM=(NEED-1)/NLEFT+1
      NBLK=NLEFT/NPTOT
      REWIND LOUT
```

```
 130 CONTINUE
     NTIL=NPTOT*NBLK
     K17=K16+NTLL
     K18=K17+NDV*130
     K19=K18+NDV*130
     K20=K19+NDV*130
     K21=K20+130
     K22=K21+NUMNP*2
     K23=K22+NUMNP*2
     K24=K23+NUMNP*2
     K25=K24+NUMNP*2
     K26=K25+NUMNP
     K27=K26+NUMNP
     K28=K27+NUMNP
     K29=K28+NUMNP
     K30=K29+NUMNP
     WRITE(6,2012)  MTOT,K30
     IF(K30.LT.MTOT)  GO TO 140
     WRITE(6,2011)
     STOP
 140 CONTINUE
     CALL SZERO (A(K16),NTLL)
     CALL MASSMT (A(K10),A(K1),A(K2),A(K3),A(N4),NUMNP,NC)
     CALL SELFLD (A(K1),A(K2),A(K3),A(N4),A(K13),A(K15),NUMNP,NC)
     CALL SOLVE (A(K1),A(K2),A(K3),A(N4),A(N5),A(K4),A(K5),A(K6),A(K7)
    *  A(K8),A(K9),A(K10),A(K11),A(K12),A(K13),A(K14),A(K15),A(KK1),
    *  A(KK2),A(KK3),A(K16),A(KK15),A(KK16),NBLK,NPTOT,NUMNP,
    *  NMAT,NEQ,MBAND,NCCY)
     IF (NSAVE.LE.0) GO TO 150
     CALL OUTP (A(KK1),A(KK2),A(KK3),A(KN1),A(KN2),A(K16),A(KK15),
    *  NUMNP,LUN,NBLK,NPTOT,NTSAVE,NDI)
 150 CONTINUE
     IF(NNODE.LE.0) GO TO 160
     CALL RESPEC(A(KK16),NCYCL,A(K17),A(K18),A(K19),A(K20),NDV,DT)
 160 IF(IPOSEQ.EQ.0) GO TO 170
     IF(IPOSEQ.GE.1) CALL SOLPEQ (A(N4),A(K1),A(K2),A(K3),A(K13),
    *  A(K21),A(K22),A(K23),A(K24),A(K25),A(K26),A(K27),A(K28),A(K29),
    *  NUMNP)
 170 CONTINUE
     STOP
1000 FORMAT(18A4)
1001 FORMAT (4I5,F10.0,2I5)
1002 FORMAT (8F10.0)
1003 FORMAT (16I5)
1004 FORMAT(3I5,6F10.0)
1005 FORMAT(4I5)
1006 FORMAT(8F10.0)
1007 FORMAT(16I5)
1008 FORMAT(F10.0,2I5)
2000 FORMAT (1H1/18A4////
    * 35H NUMBER OF LAYERS .............    = ,I5//
    * 35H NUMBER OF MATERIALS ..........    = ,I5//
    * 35H NUMBER OF CYCLES .............    = ,I5//
    * 35H NUMBER OF INPUT DIRECTIONS ..    = ,I5//
    * 35H TIME STEP (DT) ...............    = ,E10.4 )
2001 FORMAT (// 35H PRINT INTERVAL  .............    = ,I5//
    * 35H INTERVAL FOR SAVING RESPONSE     = ,I5//
    * 35H STEP FOR STARTING PRINT ....     = ,I5//
    * 35H STIFFNESS UPDAT CYCLE ......     = ,I5//
    * 35H OUTPUT TAPE FLAG ...........     = ,I5//)
2002 FORMAT (//
```

```
     * 35H DEPTH OF WATER TABLE ........    = ,F10.3//
     * 35H GRAVITY  ...................     = ,F10.3//)
2003 FORMAT (//25H ..... PLOT DATA .....,       //
     * 55H NUMBER OF MOTION PLOTS  ........................  =  ,I5,/
     * 55H NUMBER OF STRESS, STRAIN, TIME PLOTS  ..........  =  ,I5,/
     * 55H NUMBER OF PORE PRESS., EFF. STRESS VS. TIME PLOTS =  ,I5,/
     * 55H HEIGHT OF THE PLOT PAPER (INCHES)  .............  =  ,F5.1,
     * 55H HEIGHT OF THE STRESS AND STRAIN HISTORY PLOTS (IN) =  ,F5.1,
     * 55H LENGTH OF THE TIME AXIS (INCHES)  ..............  =  ,F5.1,
     * 55H SIZE OF THE STRESS VS. STRAIN PLOTS (INCHES)  ...  =  ,F5.1,
     * 55H HEIGHT OF THE PORE PRESSURE AND EFFECTIVE STRESS      ,/,
     * 55H HISTORY PLOTS (INCHES)  ........................  =  ,F5.1,
     * 55H MAX. TIME VALUE TO BE PLOTTED (SECONDS)  ........  =  ,F5.1,
     *  //)
2004 FORMAT(//,50H DEFAULT VALUE(S) ASSUMED FOR PLOT PARAMETER(S)
2005 FORMAT(30H  ....RESPONSE SPECTRA DATA...    /)
2006 FORMAT(54H DEFAULT VALUES WILL BE ASSUMED FOR DAMPING VALUES
2007 FORMAT(16H DAMPING VALUES=    ,10F10.5)
2008 FORMAT(45H RESPONSE SPECTRA WILL CALCULATED FOR NODES   ,10I5//)
2009 FORMAT(//40H ...DATA FOR POST EARTHQUAKE ANALYSIS...     //
     *  11H TIME STEPS ,3X,10H NO. REP. ,3X,11H PRINT INT.      )
2010 FORMAT(F10.5,9X,I5,9X,I5)
2011 FORMAT(45H PROBLEM DEFINED IS TOO LARGE TO BE COMPUTED  )
2012 FORMAT(//22H STORAGE INFORMATION    //
     *  23H CORE SPACE AVAILABLE=    ,I6,
     *  23H CORE SPACE REQUESTED=      ,I6)
     END
```

```
      SUBROUTINE REED (DEPTH,NEL,MATYP,EMATL,BACC,JPLTM,JPLTSS,
     *  JSETS,NLAYER,NMAT,NUMNP,NCYCL,NDI,ACC)
C
      DIMENSION DEPTH(NLAYER),NEL(NLAYER),MATYP(NLAYER),EMATL(35,NMAT),
     *  BACC(NCYCL,NDI),ACC(2,1),TITLE(18),JPLTM(1),JPLTSS(1),JSETS(1)
C
      COMMON/CONTL/ HED(18),DUMMM,DT
      COMMON/PLTING/ NPLOTM,NPLTSS,NSETS,HPAP,HPLOT,BPLOT,DPLOT,EPLOT,
     *  TEND
      COMMON/WLVL/ WTABLE,GRAV
C
      READ (5,1000) (DEPTH(I),NEL(I),MATYP(I),I=1,NLAYER)
      WRITE (6,2000)
      WRITE (6,2001)  (I,DEPTH(I),NEL(I),MATYP(I),I=1,NLAYER)
      WRITE (6,2002)
      DO 100 L=1,NMAT
      READ (5,1001) (EMATL(I,L),I=1,3),(EMATL(I,L),I=12,24)
  100 CONTINUE
      WRITE(6,2016)
      DO 101 L=1,NMAT
      WRITE(6,2003) L,(EMATL(I,L),I=1,3),(EMATL(I,L),I=12,16)
  101 CONTINUE
      WRITE(6,2017)
      DO 102 L=1,NMAT
      WRITE(6,2006) L,(EMATL(I,L),I=17,22)
  102 CONTINUE
      NUMNP=0
      DO 110 I=1,NLAYER
  110 NUMNP=NUMNP+NEL(I)
      IF (NPLOTM.LE.0) GO TO 130
      READ  (5,1005) (JPLTM(I),I=1,NPLOTM)
      WRITE (6,2008)
      WRITE (6,2013) (JPLTM(I),I=1,NPLOTM)
  130 IF (NPLTSS.LE.0) GO TO 140
      READ  (5,1005) (JPLTSS(I),I=1,NPLTSS)
      WRITE (6,2010)
      WRITE (6,2013) (JPLTSS(I),I=1,NPLTSS)
  140 IF (NSETS.LE.0) GO TO 150
      READ  (5,1005) (JSETS(I),I=1,NSETS)
      WRITE (6,2011)
      WRITE (6,2013) (JSETS(I),I=1,NSETS)
  150 CONTINUE
C
C     READ AND INTERPOLATE BASE ACCEL.
C
      DO 400 LL=1,NDI
      READ (5,1002) TITLE,TSCAL,ASCAL,NPOINT,NTYPE
      WRITE (6,2004) TITLE,TSCAL,ASCAL
      IF (NTYPE.NE.0) GO TO 162
      WRITE(6,2014)
      READ (5,1003) (ACC(1,I),ACC(2,I),I=1,NPOINT)
      WRITE (6,2005) (ACC(1,I),ACC(2,I),I=1,NPOINT)
      IF (TSCAL.LE.0.0) GO TO 170
      DO 160 I=1,NPOINT
  160 ACC(1,I)=ACC(1,I)*TSCAL
      GO TO 170
  162 READ (5,1004) (ACC(2,I),I=1,NPOINT)
      WRITE(6,2015)
      WRITE (6,2005) (ACC(2,I),I=1,NPOINT)
  170 IF (ASCAL.LE.0.0) GO TO 190
```

```
      DO 180 I=1,NPOINT
  180 ACC(2,I)=ACC(2,I)*ASCAL
  190 CONTINUE
      IF (NTYPE.NE.0) GO TO 300
      GA1=0
      I=1
      T=DT
      K=0
  200 IF(ACC(1,I).GE.T) GO TO 250
  220 I=I+1
      IF (I.LE.NPOINT) GO TO 200
      WRITE (6,2007)
      STOP
  250 SLOPE=(ACC(2,I)-ACC(2,I-1))/(ACC(1,I)-ACC(1,I-1))
  280 K=K+1
      IF (K.GT.NCYCL) GO TO 400
      BACC(K,LL)=ACC(2,I-1)+SLOPE*(T-ACC(1,I-1))
      T=T+DT
      IF (ACC(1,I).GE.T) GO TO 280
      GO TO 220
  300 GRAVTY=GRAV
      DO 320 I=1,NCYCL
  320 BACC(I,LL)=ACC(2,I)*GRAVTY
  400 CONTINUE
  500 RETURN
 1000 FORMAT (F10.0,2I5)
 1001 FORMAT (8F10.0)
 1002 FORMAT (18A4/2F10.0,2I5)
 1003 FORMAT (8F10.0)
 1004 FORMAT (8F9.0)
 1005 FORMAT (16I5)
 2000 FORMAT (1H1/45H ---------- PROPERTIES OF LAYERS -----------  ,//
     *  5X,5HLAYER,15X,5HDEPTH,11X,9HNUMBER OF,12X,8HMATERIAL /4X,
     *  6HNUMBER,32X,8HELEMENTS,14X6HNUMBER//)
 2001 FORMAT (I10,F20.3,2I20)
 2002 FORMAT (1H1/45H ---------- MATERIAL PROPERTIES ------------  ,//
 2003 FORMAT(I5,8E15.6)
 2004 FORMAT (1H1//18A4//
     * 29H TIME SCALE -------------    =,F10.4 //
     * 29H AMPLITUDE SCALE --------    =,F10.4 //)
 2005 FORMAT (8E15.6)
 2006 FORMAT(I5,6E15.6)
 2007 FORMAT (///////
     * 60H ------   INPUT BASE ACCEL. IS LESS THAN REQUESTED RESPONSE /
     * 21H EXECUTION TERMINATED /)
 2008 FORMAT (/30H MOTION PLOT REQUEST FOR NODES  /)
 2010 FORMAT (/40H STRESS-STRAIN PLOT REQUEST FOR ELEMENTS /)
 2011 FORMAT(/,60H PORE PRESSURE AND EFFECTIVE STRESS PLOTS FOR ELEMENT
     * :        )
 2013 FORMAT (10I5)
 2014 FORMAT(4(11X,4HTIME,10X,5HACCEL)//)
 2015 FORMAT(15H ACCELERATION :,//)
 2016 FORMAT(10H MAT. NO.   ,
     *  10H BULK MOD.   2X,
     *  11H SHEAR MOD.   ,2X,
     *  15H SH. MOD. CHGE.     ,
     *  15H BULK MOD.(FL.)    ,
     *  13H PERMEABILITY   ,2X,
     *  17H MASS DEN.(TOTAL)    ,
     *  15H MASS DEN.(FL.)    ,
     *  8H S(MAX)      )
```

```
2017 FORMAT(10H MAT. NO.     ,
     *  10H 1./LAMBDA    ,
     *  4H PHI,10X,
     *  6H ALPHA  ,9X,
     *  6H THETA  ,9X,
     *  16H RES. EFF. STRS.      ,
     *  10H VOID RAT.        )
      END
```

```
      SUBROUTINE MESH (DEPTH,NEL,MATYP,XLENT,MATNUM,IWTBL,WTABLE,NUMNP
     *  NLAYER)
C
      DIMENSION DEPTH(1),NEL(1),MATYP(1),XLENT(1),MATNUM(1),IWTBL(1)
C
      ZCOORD=0.0
      NUM=0
      DO 200 I=1,NLAYER
      NTL=NEL(I)
      IF (I.EQ.1) XL=DEPTH(I)/NTL
      IF (I.GT.1) XL=(DEPTH(I)-DEPTH(I-1))/NTL
      DO 150 J=1,NTL
      NUM=NUM+1
      ZCOORD=ZCOORD+XL
      XLENT(NUM)=XL
      MATNUM(NUM)=MATYP(I)
      IF (ZCOORD.LE.WTABLE) IWTBL(NUM)=0
      IF (ZCOORD.GT.WTABLE) IWTBL(NUM)=1
  150 CONTINUE
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SELFLD (XLENT,MATNUM,IWTBL,EMATL,STRS,SLVCT,NUMNP,NC)
C
      DIMENSION XLENT(1),MATNUM(1),IWTBL(1),EMATL(35,1),STRS(11,1),
     *   SLVCT(1)
C
      COMMON/WLVL/WTABLE,GRAV
C
      DEPT=0.
      SYN=-1.0
      DO 500 LL=1,NUMNP
      ZLENT=XLENT(LL)
      NUM=MATNUM(LL)
      IW=IWTBL(LL)
      GMA=GRAV*EMATL(14,NUM)
      GMAW=GRAV*EMATL(15,NUM)
      DEPT=DEPT+0.5*ZLENT
      STRS2=0.5*SYN*GMA*ZLENT
      IF(IW.EQ.0)  GO  TO  100
      STRS(6,LL)=(DEPT-WTABLE)*GMAW*SYN
      STRS2=STRS2+0.5*GMAW*ZLENT
  100 CONTINUE
      IL2=LL*NC+1
      IL1=IL2-NC
      SLVCT(IL1+1)=SLVCT(IL1+1)+STRS2
      IF  (LL.EQ.NUMNP) GO  TO  150
      SLVCT(IL2+1)=SLVCT(IL2+1)+STRS2
  150 CONTINUE
      DEPT=DEPT+0.5*ZLENT
  500 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MASSMT (EM,XLENT,MATNUM,IWTBL,EMATL,NUMNP,NC)
C
      DIMENSION EM(1),XLENT(1),MATNUM(1),IWTBL(1),EMATL(35,1)
C
      NCC=NC-1
      K=0
      L=NC
      DO 300 LL=1,NUMNP
      NUM=MATNUM(LL)
      RHO=EMATL(14,NUM)
      RHOF=EMATL(15,NUM)
      ZLENT=XLENT(LL)
      EMAS=0.5*RHO*ZLENT
      DO 100 I=1,NC
      EM(K+I)=EMAS+EM(K+I)
      IF (LL.GE.NUMNP) GO TO 100
      EM(L+I)=EMAS
  100 CONTINUE
      IF (IWTBL(LL).EQ.0) GO TO 200
      EMAS=0.5*RHOF*ZLENT
      EM(K+NC)=EMAS+EM(K+NC)
      IF (LL.GE.NUMNP) GO TO 200
      EM(L+NC)=EMAS
  200 CONTINUE
      K=L
      L=L+NC
  300 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GSTIF (A,C,NC,NEQ,LFLAG)
C
      DIMENSION A(1),C(6,6)
C
      NCC=NC+NC
      DO 400 N=1,NC
      L=N
      DO 100 K=N,NC
      A(L)=A(L)+C(N,K)
  100 L=L+NEQ
      IF (LFLAG.EQ.0) GO TO 400
      DO 200 K=1,NC
      A(L)=-C(N,K)
  200 L=L+NEQ
      L=NC+N
      DO 300 K=N,NC
      A(L)=C(N,K)
  300 L=L+NEQ
  400 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SOLVE (XLENT,MATNUM,IWTBL  ,EMATL,BACC,ST,DD,DI,VE,AC,
     *  DU,EM,ELD,NBW,STRS,STRN,SLVCT,JPLTM,JPLTSS,JSETS,
     *  PL,TLIO,AHIST,NBLK,NPTOT,NUMNP,NMAT,NEQ,MBAND,NCCY)
C
      COMMON/CONTL/HED(18),NCYCL,DT,NDI,NPRNT,NSAVE,LUN,NC,NUPDAT,NWRITE
     *  ,NSTAT,NINCR,NSTPRT
      COMMON/PLTING/ NPLOTM,NPLTSS,NSETS,HPAR,HPLOT,BPLOT,DPLOT,EPLOT,
     *  TEND
      COMMON/SPEC/DV(10),NODE(10),NNODE,IRS,IRSP
C
      DIMENSION XLENT(1),MATNUM(1),IWTBL(1),EMATL(35,1),BACC(NCCY,1),
     *  ST(NEQ,1),DD(NEQ,1),DI(1),VE(1),AC(1),DU(1),EM(1),ELD(1),NBW(1)
     *  STRN(11,1),STRS(11,1),C(4,4),DEPSL(6),SK(6,6),SLVCT(1),
     *  JPLTM(1),JPLTSS(1),JSETS(1),PL(NBLK,1),TLIO(NUMNP,1),
     *  AHIST(NCCY,1)
C
C     INTEGRATION CONSTANT
C
      TETA=2.0
      TAU=2.0*DT
      A0=6.0/(TAU*TAU)
      A1=6.0/TAU
      A2=2.0
      A3=A0/TETA
      A4=-6.0/(TETA*TAU)
      A5=1.0-3.0/TETA
      A6=DT/2.0
      A7=DT*DT/6.0
      B0=3.0/TAU
      B1=2.0
      B2=TAU/2.0
C
      TIME=0.0
      NDYNST=NSTAT+1
      NTPRNT=NCCY*NDI
      NOB=NEQ*MBAND
      KPRNT=0
      KSAVE=0
      KUPDAT=0
      NCYST=NCYCL+NSTAT+1
      XINCRT=0.0
      NFIRST=0
      CALL SZERO (SK(1,1),36)
      AST=0.0
      NM=0
      DO 40 I=1,NUMNP
      J=NC*(I-1)+2
      AST=AST+SLVCT(J)
      SLVCT(J+1)=SLVCT(J+1)+STRS(6,I)
      SLVCT(J)=SLVCT(J)+SLVCT(J+1)
      IF (I.NE.NUMNP) SLVCT(J+NC+1)=-STRS(6,I)
      STRS(2,I)=AST
      IF (MATNUM(I).EQ.NM) GO TO 20
      NM=MATNUM(I)
      DPT=0.0
      GZRO=EMATL(2,NM)
      DG=EMATL(3,NM)
   20 CONTINUE
      DPT=DPT+0.5*XLENT(I)
      G=GZRO+DG*DPT
```

```
      STRS (10,I)=-G/STRS(2,I)
      DPT=DPT+0.5*XLENT(I)
   40 CONTINUE
      DO 45 I=1,NUMNP
      TLIQ(I,1)=-1.0
   45 TLIQ(I,2)=-1.0
      DO 800 NCNT=1,NCYST
      LFLAG=1
      KUPDAT=KUPDAT+1
      IF (NCNT.EQ.NDYNST) KUPDAT=NUPDAT
      IF(KUPDAT.EQ.NUPDAT) CALLSZERO (ST(1,1),NQB)
      IF (NCNT.LE.NINCR) XINCRT=XINCRT+1.0
      NUMYLD=0
      DO 200 LL=1,NUMNP
      ZLENT=XLENT(LL)
      IL2=LL*NC+1
      IL1=IL2-NC
      IF(LL.EQ.NUMNP) LFLAG=0
      IF(LFLAG.EQ.0) GO TO 50
      DEPSL(1)=0.0
      DEPSL(2)=(DU(IL1+1)-DU(IL2+1))/ZLENT
      DEPSL(3)=0.0
      DEPSL(4)=(DU(IL1)-DU(IL2))/ZLENT
      DEPSL(5)=(DU(IL1+2)-DU(IL2+2))/ZLENT
      GO TO 60
   50 CONTINUE
      DEPSL(1)=0.0
      DEPSL(2)=DU(IL1+1)/ZLENT
      DEPSL(3)=0.0
      DEPSL(4)=DU(IL1)/ZLENT
      DEPSL(5)=DU(IL1+2)/ZLENT
   60 CONTINUE
      NM=MATNUM(LL)
      DO 100 I=1,4
  100 STRN(I,LL)=STRN(I,LL)+DEPSL(I)
      STRN(11,LL)=STRN(11,LL)+DEPSL(5)
      IW=IWTBL(LL)
      CALL MATPAC (STRN(1,LL),STRS(1,LL),DEPSL,C,SK,EMATL(1,NM),
     *  EMATL(16,NM),TLIQ,TIME,LL,NC,NFIRST,IW,NUMNP)
      IF (NCNT.LE.NDYNST) GO TO 110
      IF (IW.EQ.0) GO TO 110
      BULKF=EMATL(12,NM)
      STRS(6,LL)=STRS(6,LL)+BULKF*(DEPSL(5)+DEPSL(2))
  110 CONTINUE
      ELD(IL1)=ELD(IL1)-STRS(4,LL)
      ELD(IL1+1)=ELD(IL1+1)-STRS(2,LL)
      ELD(IL1+1)=ELD(IL1+1)-STRS(6,LL)
      ELD(IL1+2)=ELD(IL1+2)-STRS(6,LL)
      IF(LFLAG.EQ.0) GO TO 120
      ELD(IL2)=ELD(IL2)+STRS(4,LL)
      ELD(IL2+1)=ELD(IL2+1)+STRS(2,LL)
      ELD(IL2+1)=ELD(IL2+1)+STRS(6,LL)
      ELD(IL2+2)=ELD(IL2+2)+STRS(6,LL)
  120 CONTINUE
      IF(NCNT.EQ.1) GO TO 145
      IF(KUPDAT.NE.NUPDAT) GO TO 180
  145 CONTINUE
      DO 150 I=1,6
      DO 150 J=1,6
  150 SK(I,J)=SK(I,J)/ZLENT
      NPOS=NC*(LL-1)+1
```

```
      CALL GSTIF (ST(NPOS,1),SK,NC,NEQ,LFLAG)
      IF (IW.EQ.0) ST(NPOS+2,1)=1.0
      IF (NCNT.LE.NSTAT) GO TO 160
      PERM=EMATL(13,NM)
      FAC=ZLENT/(6.0*PERM)
      NPOS=NPOS+NC-1
      ST(NPOS,1)=ST(NPOS,1)+2.0*FAC*B0
      IF(LFLAG.EQ.0) GO TO 160
      ST(NPOS,NC+1)=ST(NPOS,NC+1)+FAC*B0
      ST(NPOS+NC,1)=ST(NPOS+NC,1)+2.0*FAC*B0
  160 CONTINUE
      IF(NCNT.NE.NDYNST) GO TO 180
      IF (IW.EQ.0) GO TO 180
      DD(LL,1)=DD(LL,1)+2.0*FAC
      DD(LL,2)=FAC
      DD(LL+1,1)=2.0*FAC
  180 CONTINUE
  200 CONTINUE
      IF (NCNT.LE.NDYNST) GO TO 201
      IF (NFIRST.EQ.0) GO TO 201
      IF (NSAVE.LE.0) GO TO 201
      KSAVE=KSAVE+1
      IF (KSAVE.LT.NSAVE) GO TO 201
      CALL SAVE (JPLTM,JPLTSS,JSETS,PL,AC,VE,DI,STRN,STRS,
     *  NUMNP,NBLK,TIME,NPTOT,LUN,BACFLX,BACFLY,NDI)
      KSAVE=0
  201 CONTINUE
      IF (KPRNT.NE.0) GO TO 205
      IF(NFIRST.NE.0) GO TO 202
      WRITE (6,2004)
      WRITE (6,2005) (I,STRS(2,I),STRS(6,I),I=1,NUMNP)
      DO 203 I=1,NUMNP
      PL(I,NPTOT-1)=STRS(6,I)
  203 PL(I,NPTOT)=STRS(2,I)
      GO TO 205
  202 CONTINUE
      IF (NCNT.LT.NSTPRT) GO TO 205
      WRITE (6,2006) TIME
      WRITE (6,2007) (I,STRN(2,I),STRN(4,I),STRN(11,I),STRS(2,I),STRS(4
     *I),STRS(6,I),I=1,NUMNP)
  205 CONTINUE
      NFIRST=1
      NDL=0
      IF (NCNT.EQ.NCYST) GO TO 800

      IF(KUPDAT.NE.NUPDAT) GO TO 230
  210 DO 220 I=1,NEQ
  220 ST(I,1)=ST(I,1)+A0*EM(I)
  230 CONTINUE
      DO 250 I=1,NEQ
      AA=A1*VE(I)+A2*AC(I)
  250 ELD(I)=ELD(I)+EM(I)*AA+SLVCT(I)
      DO 280 I=NC,NEQ,NC
      L=0
      AA=B1*VE(I)+B2*AC(I)
      IF(L)260,260,255
  255 ELD(I-NC)=ELD(I-NC)+DD(L,2)*AA
  260 L=L+1
      ELD(I)=ELD(I)+DD(L,1)*AA
      IF (I.EQ.NEQ) GO TO 280
      ELD(I+NC)=ELD(I+NC)+DD(L,2)*AA
```

```
  280 CONTINUE
      NND=0
      DO 310 I=1,NEQ,NC
      NND=NND+1
      IF (NND.LE.NDL) GO TO 310
      J=I+NC-2
      IF (NDI.EQ.1) J=I
      L=0
      BACELX=BACC(NCNT-NSTAT,1)
      IF(NDI.GT.1) BACELY=BACC(NCNT-NSTAT,2)
      DO 300 N=I,J
      L=L+1
      ELD(N)=ELD(N)-FM(N)*BACC(NCNT-NSTAT,L)
  300 CONTINUE
  310 CONTINUE
C
C     SOLVE
C
      IF (NCNT.EQ.1) GO TO 351
      IF (KUPDAT.NE.NUPDAT) GO TO 352
  351 CALL TRIA (ST,NBW,NEQ,MBAND)
  352 CONTINUE
      CALL BACKS (ST,ELD,NBW,NEQ,MBAND)
C
C     DISPL.,VELOCITY,ACCEL.
C
      DO 400 I=1,NEQ
      ACCEL=A3*ELD(I)+A4*VF(I)+A5*AC(I)
      VELOC=VF(I)+A6*(AC(I)+ACCEL)
      DISPL=DI(I)+DT*VF(I)+A7*(2.*AC(I)+ACCEL)
      AC(I)=ACCEL
      VF(I)=VELOC
      DU(I)=DISPL-DI(I)
      DI(I)=DISPL
      ELD(I)=0.0
  400 CONTINUE
      IF(NNODE.LE.0) GO TO 409
      DO 408 I=1,NNODE
      J=(NODE(I)-1)*NC+1
      AHIST(NCNT,I)=AC(J)+BACELX
  408 CONTINUE
  409 CONTINUE
      TIME=TIME+DT
      KPRNT=KPRNT+1
      IF (KPRNT.LT.NPRNT) GO TO 420
      KPRNT=0
      IF (NCNT.LT.NSTPRT) GO TO 420
      WRITE (6,2000) TIME
      J=0
      DO 410 I=1,NEQ,3
      J=J+1
      II=I+2
      WRITE (6,2001) J,(DI(K),K=I,II),(VF(K),K=I,II),(AC(K),K=I,II)
  410 CONTINUE
  420 CONTINUE
      IF (KUPDAT.EQ.NUPDAT) KUPDAT=0
  800 CONTINUE
      RETURN
 2000 FORMAT (1H1/ 40H  ---------- RESPONSE AT TIME -----   =   ,F10.5//
     * 2X,1HN,3X,2HDX,11X,2HDY,11X,2HDW,11X,2HVX,11X,2HVY,11X,2HVW,11X,
     * 2HAX,11X,2HAY,11X,2HAW  / )
```

```
2001 FORMAT (I3,9E13.4)
2003 FORMAT (I10,E20.5)
2004 FORMAT (//40H  ----- INSITU STRESS CONDITION -----    /
    *  3X,7HELEMENT,5X,9HEFFECTIVE,6X,4HPORE/3X,6HNUMBER,6X,8HPRESSURE
    *  7X,8HPRESSURE//)
2005 FORMAT (5X,I5,5X,2E15.4)
2006 FORMAT (//45H  ----- STRAINS AND STRESSES AT TIME ----- = ,F10.5/
    *  3X,7HELEMENT,5X,6HVOLUME,9X,5HSHEAR,10X,3HFLUID VOL,6X,
    *  9HEFFECTIVE,6X,5HSHEAR,10X,4HPORE/3X,6HNUMBER,6X,6HSTRAIN,9X,
    *  6HSTRAIN,9X,6HCHANGE,9X,8HPRESSURE,7X,6HSTRESS,9X,8HPRESSURE//)
2007 FORMAT (5X,I5,5X,6E15.4)
     END
```

```
      SUBROUTINE MATPAC (STRN,STRS,DEPSL,C,SK,EMATLA,EMATLB,TLIQ,TIME,
     * LL,NC,NFIRST,IW,NUMNP)
C
      DIMENSION STRN(11),STRS(11),DEPSL(6),C(4,4),SK(6,6),EMATLA(1),
     * EMATLB(1),TLIQ(NUMNP,1)
C
      BLKF=EMATLA(12)
      BLK=EMATLA(1)
      GZRO=STRS(10)
      IF (NFIRST.NE.0) GO TO 100
      GG=GZRO
      PE=-STRS(2)
      TAU=0.0
      ISP=0
      TAUP=0.0
      PMTPP=0.0
      PMTPN=0.0
      PMGP=0.0
      PMGN=0.0
      GSHFTP=0.0
      GSHFTN=0.0
      EXP=PE
      EXN=PE
      GO TO 800
  100 CONTINUE
      SMAX=EMATLB(1)
      ELAMDA=EMATLB(2)
      PHI=EMATLB(3)
      FAIL=EMATLB(4)*TAN(PHI)
      DGAMA=DEPSL(4)
      PE=-STRS(2)
      IF(TLIQ(LL,1).GT.0.0) PE=-STRS(1)
      ISP=STRS(5)
      PMTPP=STRS(7)
      PMTPN=STRS(8)
      TAUP=STRS(9)
      GAMA=STRN(4)
      GSHFTP=STRN(5)
      GSHFTN=STRN(6)
      PMGP=STRN(7)
      PMGN=STRN(8)
      EXP=STRN(9)
      EXN=STRN(10)
      TAUP=TAUP+DGAMA*GZRO
C
      IF (ISP) 240,180,220
  180 IF (TAUP.LT.PMTPP) GO TO 200
  190 CONTINUE
      GEL=GAMA-(TAUP-PMTPP)/GZRO
      GSHFTP=PMGP-GEL+GSHFTP
      CALL FINDX (PE,PMTPP,ELAMDA,PHI,EXP)
      GO TO 400
  200 IF (TAUP.GT.PMTPN) GO TO 300
  210 CONTINUE
      GEL=GAMA-(TAUP-PMTPN)/GZRO
      GSHFTN=PMGN-GEL+GSHFTN
      CALL FINDX (PE,PMTPN,ELAMDA,PHI,EXN)
      GO TO 500
  220 IF (GAMA.GT.PMGP) GO TO 400
      TAUP=PMTPP+DGAMA*GZRO
```

```
      IF (TAUP.LT.PMTPN) GO TO 210
      GO TO 300
  240 IF (GAMA.LT.PMGN) GO TO 500
      TAUP=PMTPN+DGAMA*GZRO
      IF (TAUP.GT.PMTPP) GO TO 190
      GO TO 300
  300 CONTINUE
      ISP=0
      GG=GZRO
      GO TO 700
  400 CONTINUE
      GA=GAMA+GSHFTP
      TAUP=GA*GZRO
      TAUP=(TAUP*SMAX)/(TAUP+SMAX)
      PMTPP=TAUP
      PMGP=GAMA
      ISP=2
      GG=SMAX+GA*GZRO
      GG=GZRO*SMAX*SMAX/(GG*GG)
      EX=EXP
      GO TO 600
  500 CONTINUE
      GA=GAMA+GSHFTN
      TAUP=GA*GZRO
      TAUP=(TAUP*SMAX)/(SMAX-TAUP)
      PMTPN=TAUP
      PMGN=GAMA
      ISP=-2
      GG=SMAX-GA*GZRO
      GG=GZRO*SMAX*SMAX/(GG*GG)
      EX=EXN
  600 CONTINUE
      ETA=FLAMDA*TAN(PHI)
      ELLAA=FLAMDA*TAUP
      ELLAA=ELLAA*ELLAA
      AA=1.0+ELLAA
      BB=ETA*ETA
      BB=BB*AA-ELLAA
      BB=SQRT(BB)
      BB=1.0+BB
      AA=1.0/AA
      IF(IW.EQ.0) GO TO 700
      PE=EX*AA*BB/(1.0+ETA)
  700 TAU=PE*TAUP
      IF (ABS(TAUP).LT.FAIL) GO TO 800
      IF(TLIQ(LL,1).GT.0.0) GO TO 800
      TLIQ(LL,1)=TIME
      STRS(1)=-PE
      X=TAU/ABS(TAU)
      STRS(3)=X*FAIL*PE
      STRS(11)=TAU
  800 CONTINUE
      GG=GG*PE
      IF(TLIQ(LL,1).LE.0.0) GO TO 1000
      IF(TLIQ(LL,2).LE.0.0) GO TO 890
      PENEW=-STRS(2)
      GO TO 970
  890 EK=EMATLB(5)
      QT=STRS(3)
      QR=STRS(11)
      IF(QR.LT.0.0) GO TO 910
```

```
      IF(TAU.GT.QR) GO TO 900
      PR=EK*QT*QT/(FAIL*QR)
      PENEW=TAU/FAIL+PR*(1.0-TAU/QR)
      AB=TAU/PENEW
      IF(ABS(AB).LE.FAIL) GO TO 950
      BETA=QT/QR
      BETA=FAIL/(1.0-EK*BETA*BETA)
      QF=FAIL*BETA*PR/(BETA+FAIL)
      PENEW=ABS(TAU)/FAIL
      QT=-QF
      QR=TAU
      GO TO 950
  910 IF(TAU.LT.QR) GO TO 900
      PR=-EK*QT*QT/(FAIL*QR)
      PENEW=-TAU/FAIL+PR*(1.0-TAU/QR)
      AB=TAU/PENEW
      IF(ABS(AB).LE.FAIL) GO TO 950
      BETA=QT/QR
      BETA=FAIL/(1.0-EK*BETA*BETA)
      QF=FAIL*BETA*PR/(BETA+FAIL)
      PENEW=ABS(TAU/FAIL)
      QT=QF
      QR=TAU
      GO TO 950
  900 CONTINUE
      PENEW=ABS(TAU/FAIL)
      QR=TAU
  950 CONTINUE
      CL=FMATLB(6)
      IF(PENEW.GT.CL) GO TO 960
      IF((QT/FAIL).GT.CL) GO TO 960
      IF(TLIQ(LL,2).GT.0.0) GO TO 960
      TLIQ(LL,2)=TIME
      PENEW=CL
  960 CONTINUE
      STRS(3)=QT
      STRS(11) =QR
  970 CONTINUE
      STRS(2)=-PENEW
      STRS(1)=-PE
      GO TO 1100
 1000 CONTINUE
      STRS(2)=-PE
 1100 CONTINUE
      STRS(4)=TAU
      STRS(5)=ISP
      STRS(7)=PMTPP
      STRS(8)=PMTPN
      STRS(9)=TAUP
      STRN(5)=GSHFTP
      STRN(6)=GSHFTN
      STRN(7)=PMGP
      STRN(8)=PMGN
      STRN(9)=EXP
      STRN(10)=EXN
C
      IF (TW.EQ.0) BLKF=0.0
      SK(1,1)=GG
      SK(1,2)=0.0
      SK(1,3)=0.0
      SK(2,1)=0.0
```

```
      SK(2,2)=BLK+BLKF
      SK(2,3)=BLKF
      SK(3,1)=0.0
      SK(3,2)=BLKF
      SK(3,3)=BLKF
C
      RETURN
      END
```

```
      SUBROUTINE SAVE (JPLTM,JPLTSS,JSETS,PL,AC,VE,DI,STRN,
     * STRS,NUMNP,NBLK,TIME,NPTOT,LUN,BACELX,BACELY,NDI)
C
      DIMENSION JPLTM(1),JPLTSS(1),JSETS(1),PL(NBLK,
     * NPTOT),AC(1),VE(1),DI(1),STRN(11,1),STRS(11,1)
C
      COMMON/PLTING/ NPLOTM,NPLTSS,NSETS,HPAP,HPLOT,BPLOT,DPLOT,TEND
C
      DATA IR/0/
C
      IF (IR.LE.NBLK) GO TO 600
      IR=0
      WRITE (LUN) PL
      N=NPTOT*NBLK
      CALL SZERO (PL,N)
  600 CONTINUE
      IC=1
      IR=IR+1
      PL(IR,IC)=TIME
      IF (NPLOTM.LE.0) GO TO 120
      DO 100 N=1,NPLOTM
      JL=JPLTM(N)
      JL=3*JL-2
      IC=IC+1
      PL(IR,IC)=AC(JL)+BACELX
      IC=IC+1
      PL(IR,IC)=VE(JL)
      IC=IC+1
      PL(IR,IC)=DI(JL)
      IF(NDI.LE.1) GO TO 100
      IC=IC+1
      PL(IR,IC)=AC(JL+1)+BACELY
      IC=IC+1
      PL(IR,IC)=VE(JL+1)
      IC=IC+1
      PL(IR,IC)=DI(JL+1)
  100 CONTINUE
  120 CONTINUE
      IF (NPLTSS.LE.0) GO TO 320
      DO 300 N=1,NPLTSS
      JL=JPLTSS(N)
      IC=IC+1
      PL(IR,IC)=STRS(4,JL)
      IC=IC+1
      PL(IR,IC)=STRN(4,JL)
  300 CONTINUE
  320 CONTINUE
      IF (NSETS.LE.0) GO TO 420
      DO 400 N=1,NSETS
      JL=JSETS(N)
      PIO=PL(JL,NPTOT-1)
      SIG=PL(JL,NPTOT)
      IC=IC+1
      PL(IR,IC)=+STRS(2,JL)/SIG
      IC=IC+1
      PL(IR,IC)=+(STRS(6,JL)-PIO)/SIG
  400 CONTINUE
  420 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PLTLAS(PL,JPLTM,JPLTSS,JSETS,X,Y,NBLK,NCYCL,LUN,NDI)
C
      COMMON/PLTING/ NPLOTM,NPLTSS,NSETS,HPAP,HPLOT,BPLOT,DPLOT,EPLOT,
     *  TEND
C
      DIMENSION PL(NBLK,1),JPLTM(1),JPLTSS(1),JSETS(1)
      DIMENSION X(1),Y(1),DMAX(3),SCA(6,2)
C
C     SCALE DETERMINATION FOR THE MOTION DIAGRAMS
C
      CALL LOADXY(X,Y,1,0,PL,NBLK,NCYCL,LUN)
      DO 100 I=1,NCYCL
      IF(X(I).GT.TEND) GO TO 24
      N=I
  100 CONTINUE
      GO TO 25
   24 NCYCL=N
   25 CONTINUE
      SCT=TEND/BPLOT
      TIN=0
      IF(NPLOTM.NE.0) GO TO 23
      CALL PLOT(0.0,HPAP,-3)
      GO TO 200
   23 CONTINUE
      DO 1 I=1,3
    1 DMAX(I)=-9999.
      N=1
      DO 2 I=1,NPLOTM
      DO 2 J=1,3
      N=N+1
      CALL LOADXY(X,Y,N,0,PL,NBLK,NCYCL,LUN)
      XMAX=-9999.
      XMIN=+9999.
      DO 3 K=1,NCYCL
      IF(X(K).GT.XMAX) XMAX=X(K)
    3 IF(X(K).LT.XMIN) XMIN=X(K)
      DX=XMAX
      IF(ABS(XMIN).GT.DX) DX=ABS(XMIN)
      IF(DX.LE.DMAX(J)) GO TO 2
      DMAX(J)=DX
    2 CONTINUE
      DO 4 I=1,3
    4 CALL SCAL(DMAX(I),HPLOT,SCA(I,1),SCA(I,2))
C
C     PLOTTING OF THE MOTION DIAGRAMS
C
      HGAP=(HPAP-HPLOT*3)/4.
      CALL PLOT(0.0,HPAP,-3)
      HTIT=HGAP/3.
      N=1
C
      DO 5 I=1,NPLOTM
      DO 50 III=1,NDI
      CALL PLOT(1.0,0.0,-3)
      YY=-(2./3.)*HGAP
      CALL SYMBOL(0.0,YY,HTIT,'NODE N. ',0.0,8)
      CALL NUMBER(0.0,0.0,-HTIT,FLOAT(JPLTM(I)) ,0.0,-1)
      IF(III.EQ.2) GO TO 110
      CALL SYMBOL(0.0,0.0,-HTIT,' X-DIR.',0.0,7)
      GO TO 120
```

```
  110 CALL SYMBOL(0.0,0.0,-HTIT,' Y-DIR.',0.0,7)
  120 CONTINUE
      ILN=ILN+1
C
      DO 10 J=1,3
      YY=-(HGAP+HPLOT)
      CALL PLOT(0.0,YY,-3)
      N=N+1
      CALL LOADXY(X,Y,1,N,PL,NBLK,NCYCL,LUN)
      X(NCYCL+1)=0.0
      X(NCYCL+2)=SCC
      Y(NCYCL+1)=SCA(J,1)
      Y(NCYCL+2)=SCA(J,2)
      CALL AXIS(0.0,0.0,'TIME (SEC)',-10,BPLOT,0.0,0.0,SCC)
      GO TO (6,7,8),J
    6 CALL AXIS(0.0,0.0,'ACC.',4,HPLOT,90.,SCA(J,1),SCA(J,2))
      GO TO 9
    7 CALL AXIS(0.0,0.0,'VEL.',4,HPLOT,90.,SCA(J,1),SCA(J,2))
      GO TO 9
    8 CALL AXIS(0.0,0.0,'DISPL.',6,HPLOT,90.,SCA(J,1),SCA(J,2))
    9 CALL PLOT(0.0,HPLOT,3)
      CALL PLOT(BPLOT,HPLOT,2)
      CALL PLOT(BPLOT,0.0,2)
      YY=HPLOT/2.
      CALL PLOT(BPLOT,YY,3)
      CALL PLOT(0.0,YY,2)
   10 CALL LINE(X,Y,NCYCL,1,0,0)
C
      YY=HPAP-HGAP
      CALL PLOT(BPLOT,YY,-3)
   50 CONTINUE
      WRITE(6,2000) JPLTM(I)
    5 CONTINUE
  200 CONTINUE
C
C     SCALE DETERMINATION FOR THE STRESS AND STRAIN DIAGRAMS
C
      IF(NPLTSS.EQ.0) GO TO 400
      NF=NPLTSS
      N=1+NPLOTM*NDI*3
   13 DMAX(1)=-9999.
      DMAX(2)=-9999.
      DO 12 I=1,NF
      N=N+2
      CALL LOADXY(X,Y,N-1,N,PL,NBLK,NCYCL,LUN)
      XMAX=-9999.
      XMIN=9999.
      YMAX=-9999.
      YMIN=9999.
      DO 11 J=1,NCYCL
      IF(X(J).GT.XMAX)  XMAX=X(J)
      IF(Y(J).GT.YMAX)  YMAX=Y(J)
      IF(X(J).LT.XMIN)  XMIN=X(J)
   11 IF(Y(J).LT.YMIN)  YMIN=Y(J)
      DX=XMAX
      IF(ABS(XMIN).GT.DX)  DX=ABS(XMIN)
      IF(DX.GT.DMAX(1))  DMAX(1)=DX
      DX=YMAX
      IF(ABS(YMIN).GT.DX)  DX=ABS(YMIN)
      IF(DX.GT.DMAX(2))  DMAX(2)=DX
   12 CONTINUE
```

```
C
      CALL SCAL(DMAX(1),HPLOT,SCA(6,1),SCA(6,2))
      CALL SCAL(DMAX(2),HPLOT,SCA(5,1),SCA(5,2))
      CALL SCAL(DMAX(1),DPLOT,SCA(4,1),SCA(4,2))
      CALL SCAL(DMAX(2),DPLOT,SCA(3,1),SCA(3,2))
C
  400 CONTINUE
C
C     PLOTTING OF THE STRESS AND STRAIN DIAGRAMS
C
      MAXS=0
      MAXP=0
      IF(NPLTSS.EQ.0) GO TO 500
      DO 16 I=1,NPLTSS
   16 IF(JPLTSS(I).GT.MAXP) MAXP=JPLTSS(I)
  500 IF(NSETS.EQ.0) GO TO 600
      DO 17 I=1,NSETS
   17 IF(JSETS(I).GT.MAXS) MAXS=JSETS(I)
  600 IF(MAXS.EQ.0.AND.MAXP.EQ.0) GO TO 102
      I=0
C
   18 I=I+1
      IF(I.GT.MAXS.AND.I.GT.MAXP) GO TO 102
      KP=0
      JS=0
      IF(NSETS.EQ.0) GO TO 800
      DO 19 J=1,NSETS
      IF(JSETS(J).NE.I) GO TO 19
      JS=JSETS(J)
      GO TO 800
   19 CONTINUE
  800 IF(NPLTSS.EQ.0) GO TO 900
      DO 20 K=1,NPLTSS
      IF(JPLTSS(K).NE.I) GO TO 20
      KP=JPLTSS(K)
      GO TO 900
   20 CONTINUE
  900 IF(KP.EQ.0.AND.JS.EQ.0) GO TO 18
C
      ILN=ILN+1
      IF(KP.EQ.0) GO TO 101
      CALL PLOT(1.0,0.0,-3)
      HGAP=(HPAP-HPLOT*2.)/3.
      HTIT=HGAP/3.
      YY=-2.*HTIT
      CALL SYMBOL(0.0,YY,HTIT,'ELEM. N. ',0.0,9)
      DX=FLOAT(KP)
      CALL NUMBER(0.0,0.0,-HTIT,DX,0.0,-1)
C
      N=NPLOTM*NDI*3+K*2
      DO 21 L=1,2
      YY=-(HGAP+HPLOT)
      CALL PLOT(0.0,YY,-3)
      N=N+L-1
      CALL LOADXY(X,Y,1,N,PL,NBLK,NCYCL,LUN)
      Y(NCYCL+1)=SCA(6-L+1,1)
      Y(NCYCL+2)=SCA(6-L+1,2)
      X(NCYCL+1)=0.0
      X(NCYCL+2)=SCC
      CALL AXIS(0.0,0.0,'TIME (SEC)',-10,BPLOT,0.0,0.0,SCC)
      IF(L.EQ.1) CALL AXIS(0.0,0.0,'SH. STRESS',10,HPLOT,90.,SCA(6,1),
```

```
     *  SCA(6,2))
      IF(L.EQ.2) CALL AXIS(0.0,0.0,'SH. STRAIN',10,HPLOT,90.,SCA(5,1),
     *  SCA(5,2))
      CALL PLOT(0.0,HPLOT,3)
      CALL PLOT(BPLOT,HPLOT,2)
      CALL PLOT(BPLOT,0.0,2)
      YY=HPLOT/2.
      CALL PLOT(BPLOT,YY,3)
      CALL PLOT(0.0,YY,2)
   21 CALL LINE(X,Y,NCYCL,1,0,0)
C
      YY=HGAP
      HGAP=(HPAP-DPLOT)/2.
      YY=HGAP-YY
      CALL PLOT(BPLOT+1,YY,-3)
      N=NPLOTM*NDI*3+K*2
      CALL LOADXY(X,Y,N+1,N,PL,NBLK,NCYCL,LUN)
      X(NCYCL+1)=SCA(3,1)
      X(NCYCL+2)=SCA(3,2)
      Y(NCYCL+1)=SCA(4,1)
      Y(NCYCL+2)=SCA(4,2)
      CALL AXIS(0.0,0.0,'SH. STRAIN',-10,DPLOT,0.0,SCA(3,1),SCA(3,2))
      CALL AXIS(0.0,0.0,'SH. STRESS',10,DPLOT,90.,SCA(4,1),SCA(4,2))
      CALL PLOT(0.0,DPLOT,3)
      CALL PLOT(DPLOT,DPLOT,2)
      CALL PLOT(DPLOT,0.0,2)
      YY=DPLOT/2.
      CALL PLOT(DPLOT,YY,3)
      CALL PLOT(0.0,YY,2)
      CALL PLOT(YY,DPLOT,3)
      CALL PLOT(YY,0.0,2)
      CALL LINE(X,Y,NCYCL,1,0,0)
      YY=HPAP-HGAP
      CALL PLOT(DPLOT,YY,-3)
      IF(JS.EQ.0) WRITE(6,3000) KP
  101 IF(JS.EQ.0) GO TO 18
      CALL PLOT(1.0,0.0,-3)
      HGAP=(HPAP-EPLOT)/2.
      IF(KP.NE.0) GO TO 300
      HTIT=HGAP/3.
      YY=-2.*HTIT
      CALL SYMBOL(0.0,YY,HTIT,'ELEM. N. ',0.0,9)
      DX=FLOAT(JS)
      CALL NUMBER(0.0,0.0,-HTIT,DX,0.0,-1)
  300 YY=-(HGAP+EPLOT)
      CALL PLOT(0.0,YY,-3)
      DX=1./EPLOT
      CALL AXIS(0.0,0.0,'TIME (SEC)',-10,BPLOT,0.0,0.0,SCC)
      CALL AXIS(0.0,0.0,'EFF. STRESS AND PORE PRESS.',27,EPLOT,90.,0.0,
     *  DX)
      CALL PLOT(0.0,EPLOT,3)
      CALL PLOT(BPLOT,EPLOT,2)
      CALL PLOT(BPLOT,0.0,2)
      N=NPLOTM*NDI*3+NPLTSS*2+J*2
      DO 22 L=1,2
      N=N+L-1
      CALL LOADXY(X,Y,1,N,PL,NBLK,NCYCL,LUN)
      Y(NCYCL+1)=0.0
      Y(NCYCL+2)=DX
      X(NCYCL+1)=0.0
      X(NCYCL+2)=SCC
```

```
   22 CALL LINE(X,Y,NCYCL,1,0,0)
      YY=HPAP-HGAP
      CALL PLOT(BPLOT,YY,-3)
      WRITE(6,3000) JS
      GO TO 18
C
  102 WRITE(6,1000) ILN
      YY=-HPAP
      CALL PLOT(0.0,YY,-3)
      RETURN
C
 1000 FORMAT(//,I5,' SETS OF PLOTS COMPLETED')
 2000 FORMAT(/,' PLOTS FOR NODE  NO.',I4,' COMPLETED')
 3000 FORMAT(/,' PLOTS FOR ELEM. NO.',I4,' COMPLETED')
      END
```

```
      SUBROUTINE OUTP (JPLTM,JPLTSS,JSETS,X,Y,PL,TLIQ,NUMNP,LUN,
     *  NBLK,NPTOT,NCYCL,NDI)
C
      DIMENSION JPLTM(1),JPLTSS(1),JSETS(1),X(1),Y(1),PL(NBLK,NPTOT),
     *  TLIQ(NUMNP,1)
C
      COMMON/PLTING/ NPLOTM,NPLTSS,NSETS,HPAP,HPLOT,BPLOT,DPLOT,EPLOT,
     *  TEND
C
      WRITE (6,2002)
      DO 100 I=1,NUMNP
      TT=TLIQ(I,1)
      IF(TT.GT.0.0) GO TO 40
      WRITE(6,2003)  I
      GO TO 100
   40 TTT=TLIQ(I,2)
      IF(TTT.GT.0.0) GO TO 50
      WRITE(6,2018) I,TT
      GO TO 100
   50 CONTINUE
      WRITE(6,2004) I,TT,TTT
  100 CONTINUE
      NT=NBLK
      N=1
      NN=NPLOTM+NPLTSS+NSETS
      IF(NN.LE.0) GO TO 600
      IF (NPLOTM.EQ.0) GO TO 200
      DO 150 I=1,NPLOTM
      DO 140 K=1,NDI
      N=N+1
      IF(K.EQ.2) GO TO 141
      WRITE(6,2005) JPLTM(I)
      GO TO 142
  141 WRITE(6,2015) JPLTM(I)
  142 WRITE (6,2001) (PL(J,N),J=1,NT)
  140 CONTINUE
      DO 147 K=1,NDI
      N=N+1
      IF(K.EQ.2) GO TO 143
      WRITE (6,2006) JPLTM(I)
      GO TO 144
  143 WRITE(6,2016) JPLTM(I)
  144 WRITE (6,2001) (PL(J,N),J=1,NT)
  147 CONTINUE
      DO 148 K=1,NDI
      N=N+1
      IF(K.EQ.2) GO TO 145
      WRITE (6,2007) JPLTM(I)
      GO TO 146
  145 WRITE(6,2017) JPLTM(I)
  146 WRITE (6,2001) (PL(J,N),J=1,NT)
  148 CONTINUE
  150 CONTINUE
  200 CONTINUE
      IF (NPLTSS.EQ.0) GO TO 400
      DO 350 I=1,NPLTSS
      N=N+1
      WRITE (6,2010) JPLTSS(I)
      WRITE (6,2001) (PL(J,N),J=1,NT)
      N=N+1
```

```
      WRITE (6,2009) JPLTSS(I)
      WRITE (6,2001) (PL(J,N),J=1,NT)
  350 CONTINUE
  400 CONTINUE
      IF (NSETS.EQ.0) GO TO 500
      DO 450 I=1,NSETS
      N=N+1
      WRITE (6,2011) JSETS(I)
      WRITE (6,2001) (PL(J,N),J=1,NT)
      N=N+1
      WRITE (6,2012) JSETS(I)
      WRITE (6,2001) (PL(J,N),J=1,NT)
  450 CONTINUE
  500 CONTINUE
      CALL PLTLAS(PL,JPLIM,JPLTSS,JSETS,X,Y,NBLK,NCYCL,LUN,NDI)
  600 RETURN
 2001 FORMAT (10F12.4)
 2002 FORMAT (//30H ELEMENT LIQUEFACTION DATA      //10H   EL. NO. /)
 2003 FORMAT (3X,I5,5X,20H NO LIQUEFACTION       )
 2004 FORMAT(3X,I5,5X,26H INITIAL LIQUEF. AT TIME =    ,F10.4,18H LIQUEF
     * AT TIME =  ,F10.4)
 2005 FORMAT (// 45H ----- ACCELERATION TIME HISTORY FOR NODE NO ,I4,
     * 12H X-DIRECTION  /)
 2006 FORMAT (// 45H --------- VELOCITY TIME HISTORY FOR NODE NO ,I4,
     * 12H X-DIRECTION  /)
 2007 FORMAT (// 45H ----- DISPLACEMENT TIME HISTORY FOR NODE NO ,I4,
     * 12H X-DIRECTION  /)
 2009 FORMAT (// 45H ----- SHEAR STRAIN TIME HISTORY FOR ELEM NO ,I4 /)
 2010 FORMAT (// 45H ----- SHEAR STRESS TIME HISTORY FOR ELEM NO ,I4 /)
 2011 FORMAT (// 50H ----- EFFECTIVE STRESS TIME HISTORY FOR ELEM NO. ,
     *  I4 /)
 2012 FORMAT (// 45H ----- PORE PRESSURE TIME HISTORY FOR ELEM NO,I4 /)
 2015 FORMAT (// 45H ----- ACCELERATION TIME HISTORY FOR NODE NO ,I4,
     * 12H Y-DIRECTION  /)
 2016 FORMAT (// 45H --------- VELOCITY TIME HISTORY FOR NODE NO ,I4,
     * 12H Y-DIRECTION  /)
 2017 FORMAT (// 45H ----- DISPLACEMENT TIME HISTORY FOR NODE NO ,I4,
     * 12H Y-DIRECTION  /)
 2018 FORMAT(3X,I5,5X,26H INITIAL LIQUEF. AT TIME =    ,F10.4,
     *  18H NO FINAL LIQUEF.       )
      END
```

```
      SUBROUTINE RESPEC (ACC,NP,R1,R2,R3,R4,NDV,DT)
C
      DIMENSION R1(130,NDV),R2(130,NDV),R3(130,NDV),R4(1),ACC(NP,1),
     *  DW(5),NM(5),SDISP(10),SVP(10),SACC(10),SI(10),SAMAX(10)
C
      COMMON/SPEC/DV(10),NODE(10),NNODE,IRS,IRSP
      COMMON/WLVL/ WTABLE,GRAV
C
      DATA DW(1)/.05/,DW(2)/.01/,DW(3)/.05/,DW(4)/.1/,DW(5)/.2/
      DATA NM(1)/2/,NM(2)/80/,NM(3)/21/,NM(4)/20/,NM(5)/5/
C
C     THIS SUBROUTINE COMPUTES RESPONSE SPECTRA BY
C     SIMPSON'S RULE FOR PERIODS .1 TO 5.0 SECONDS
C
C
C
C     SORT THE GIVEN DAMPING VALUES IN INCREASING ORDER
C
      INDV=NDV-1
      DO 100 IK=1,INDV
      IP=IK+1
      DO 100 IJ=IP,NDV
      IF(DV(IK).LE.DV(IJ)) GO TO 100
      TDV=DV(IK)
      DV(IK)=DV(IJ)
      DV(IJ)=TDV
  100 CONTINUE
C
C     COMPUTE SPECTRAL VALUES
C
  190 DO 160 K=1,NNODE
      NNOD=NODE(K)
  200 WRITE(6,2002) NODE(K)
      WRITE(6,2000)
      IND=0
      PERIO=0.05
      DO 150 L=1,5
      M=NM(L)
      DO 150 LOOP=1,M
      IND=IND+1
      PERIO=PERIO+DW(L)
      W=6.2831853/PERIO
      DO 140 J=1,NDV
      SVP(J)=0.0
      TIME=0.0
  110 AMULT=EXP(-2.0*DV(J)*W*DT)
      BMULT=4.0*EXP(-DV(J)*W*DT)
      W=SQRT(1-DV(J)*DV(J))*W
      WT=TIME*W
      A11=COS(WT)*ACC(1,K)
      B11=SIN(WT)*ACC(1,K)
      AA=0.0
      BB=0.0
      DO 130 N=2,NP,2
      A21=AA+A11
      A31=AMULT*A21
      B21=BB+B11
      B31=AMULT*B21
      SV=(AA*SIN(WT)-BB*COS(WT))*(DT/3.0)
      IF(ABS(SV).GT.SVP(J)) SVP(J)=ABS(SV)
```

```
      TIME=TIME+DT
      WT=W*TIME
      A12=COS(WT)*ACC(N,K)
      A32=A12*BMULT
      B12=SIN(WT)*ACC(N,K)
      B32=B12*BMULT
      TIME=TIME+DT
      WT=W*TIME
  120 I=1+N
      A11=COS(WT)*ACC(I,K)
      B11=SIN(WT)*ACC(I,K)
      AA=A31+A32+A11
      BB=B31+B32+B11
  130 CONTINUE
      SACC(J)=SVP(J)*W/GRAV
      SDISP(J)=SVP(J)/W
      R1(IND,J)=SDISP(J)
      R2(IND,J)=SVP(J)
      R3(IND,J)=SACC(J)
      R4(IND)=PERIO
  140 CONTINUE
      WRITE(6,2001) PERIO,(DV(J),SDISP(J),SVP(J),SACC(J),J=1,NDV)
  150 CONTINUE
C
C     COMPUTE SPECTRUM INTENSITIES
C
      DO 155 J=1,NDV
      SI(J)=0.0
      DO 155 INT=1,127
      IN=INT
      SI(J)=(R2(IN,J)+R2(IN+1,J))/2*(R4(IN+1)-R4(IN))+SI(J)
  155 CONTINUE
C
      AMAX=0.0
      DO 157 M=1,NP
  157 IF(ABS(ACC(M,K)).GT.ABS(AMAX)) AMAX=ACC(M,K)
      WRITE(6,2004) AMAX
C
C     FIND MAXIMUMS OF SPECTRAL VALUES
C
      DO 156 N=1,NDV
      SAMAX(N)=0.0
      DO 156 M=1,IND
  156 IF(R3(M,N).GT.SAMAX(N)) SAMAX(N)=R3(M,N)
      WRITE(6,2005) (DV(J),SAMAX(J),J=1,NDV)
      WRITE(6,2003) (DV(J),SI(J),J=1,NDV)
      IF(IPSP.LE.0) GO TO 160
C
C     PLOT RESPONSE SPECTRA IF REQUESTED
C
      CALL PLORES(NNOD,IND,R1,R2,R3,R4,NDV)
  160 CONTINUE
      RETURN
 2000 FORMAT(27X,11H DAMP. RAT.,7X,11H SPEC. DIS.,9X,11H SPEC. VEL.,10X
     *  20H SPEC. ACC.(/GRAV.)      )
 2001 FORMAT(8H PERIOD=,F8.5/(27X,F10.5,3X,3(E15.6,5X)))
 2002 FORMAT(37X,31H ***RESPONSE SPECTRA OF NODE N.,I5,4H ***//)
 2003 FORMAT(//,35H  * RESPONSE SPECTRUM INTENSITIES * ,/6X,11H DAMP. R
     *T.,5X,11H SPEC. INT./(4X,F10.5,3X,E15.6))
 2004 FORMAT(/20 H MAX. ACCELARATION= ,E15.6)
 2005 FORMAT(/11H DAMP. RAT.,5X,25H MAX. SPEC. ACCELARATION /(3X,F10.5,
```

```
      SUBROUTINE PLORES(NNOD,IND,R1,R2,R3,R4,NDV)
C
      DIMENSION  R1(130,1),R2(130,1),R3(130,1),R4(1)
C
      CALL SYMBOL (1.0,8.3,0.5,'RESPONSE SPECTRA',0.0,16)
      CALL SYMBOL(1.0,7.3,0.5,'NODE N.',0.0,7)
      CALL NUMBER(4.5,7.3,0.5,FLOAT(NNOD),0.0,-1)
      R1MAX=0.0
      R2MAX=0.0
      R3MAX=0.0
      DO 100 K=1,IND
      IF(R1(K,1).GT.R1MAX)  R1MAX=R1(K,1)
      IF(R2(K,1).GT.R2MAX)  R2MAX=R2(K,1)
      IF(R3(K,1).GT.R3MAX)  R3MAX=R3(K,1)
  100 CONTINUE
      IS1=R1MAX*1.05
      IS2=R2MAX*1.05
      IS3=R3MAX*1.40
      YINC1=IS1/4.0
      YINC2=IS2/4.0
      YINC3=IS3/4.0
      DO 350 J=1,NDV
      R1(IND+1,J)=0.0
      R1(IND+2,J)=YINC1
      R2(IND+1,J)=0.0
      R2(IND+2,J)=YINC2
      R3(IND+1,J)=0.0
      R3(IND+2,J)=YINC3
  350 CONTINUE
      R4(IND+1)=0.0
      R4(IND+2)=1.
      DO 400 LOOP=1,3
      CALL PLOT(1.0,2.3,-3)
      CALL AXIS(0.0,0.0,'PERIOD (SEC)',-12,5.0,0.0,0.0,1.0)
      IF(LOOP.EQ.1) CALL AXIS(0.0,0.0,'SPEC. DISP.',11,4.0,90.,0.0,YINC
     *  )
      IF(LOOP.EQ.2) CALL AXIS(0.0,0.0,'SPEC. VEL. ',11,4.0,90.0,0.0,
     *  YINC2)
      IF(LOOP.EQ.3) CALL AXIS(0.0,0.0,'SPEC. ACC. ',11,4.0,90.0,0.0,
     *  YINC3)
      CALL PLOT(0.0,4.0,3)
      CALL PLOT(5.0,4.0,2)
      CALL PLOT(5.0,0.0,2)
      DO 500 J=1,NDV
      IF(LOOP.EQ.1) CALL LINE(R4,R1(1,J),128,1,0,0)
      IF(LOOP.EQ.2) CALL LINE(R4,R2(1,J),128,1,0,0)
      IF(LOOP.EQ.3) CALL LINE(R4,R3(1,J),128,1,0,0)
  500 CONTINUE
      CALL PLOT(5.0,-2.3,-3)
  400 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SOLPEQ (EMATL,XLENT,MATNUM,IWTBL,STRS,A,B,C,D,E,PPO,
     *  PI,MB,PPE,NUM)
C
      COMMON/WLVL/ WTABLE,GRAV
      COMMON/POSEQ/NTREP(10),DT(10),TLIMIT,NTS,NPEQPR(10)
C
      DIMENSION EMATL(35,1)    ,MATNUM(1),IWTBL(1),XLENT(1),A(NUM,1),
     *  B(NUM,1),C(NUM,1),D(NUM,1),E(1),PPO(1),PI(1),MB(1)
     *  ,PPE(1),STRS(11,1)
C
      WRITE(6,2000)
      DO 850 I=1,NUM
      PPE(I)=-STRS(6,I)
  850 CONTINUE
      TLIMIT=0.0
      DO 800 I=1,NTS
      M=NTREP(I)
      DO 800 J=1,M
      TLIMIT=TLIMIT+DT(I)
  800 CONTINUE
      GMAW=EMATL(15,1)*GRAV
      TIME=0.0
      WTCH=0.0
      SETTL=0.0
      KONTR=0
      KOUNT=0
      DO 500 J=1,2
      DO 500 I=1,NUM
      A(I,J)=0.0
      B(I,J)=0.0
  500 CONTINUE
      DO 550 I=1,NUM
      C(I,1)=1.0
      C(I,2)=0.0
      D(I,1)=1.0
      D(I,2)=0.0
      E(I)=0.0
  550 CONTINUE
      CALL MATAB (A,B,NDRY,NSEL,EMATL,XLENT,MATNUM,IWTBL,NUM)
      MDRY=NDRY
C
C     CALCULATE HYDROSTATIC WATER PRESSURES
C
      DEPT=0.0
      DO 100 I=1,NUM
      PPO(I)=0.0
      MI=MATNUM(I)
      DEPT=DEPT+0.5*XLENT(I)
      IF(IWTBL(I).EQ.0) GO TO 95
       PPO(I)=(DEPT-WTABLE)*EMATL(15,MI)  *GRAV
   95 DEPT=DEPT+0.5*XLENT(I)
  100 CONTINUE
C
C     CALCULATE EXCESS PORE PRESSURE AFTER EQ
C
      DO 90 I=1,NSEL
      PI(I)=PPE(NDRY+I)-PPO(NDRY+I)
   90 CONTINUE
      WRITE(6,2010)
      IF(NDRY.EQ.0) GO TO 120
```

```
      DO 110 I=1,NDRY
      WRITE(6,2011) I,PPO(I),PPE(I)
  110 CONTINUE
  120 I1=NDRY+1
      DO 130 I=I1,NUM
      WRITE(6,2012) I,PPO(I),PPE(I),PI(I-NDRY)
  130 CONTINUE
C
C     CALCULATE EXCESS PORE PRESSURE DISSIPATION
C
      WRITE(6,2008) TLIMIT
      DO 400 I=1,NTS
      M=NTREP(I)
      DO 400 J=1,M
      NSEL=NUM-NDRY
      DO 200 K=1,2
      DO 200 L=1,NSEL
      C(L,K)=A(L,K)/2.+B(L,K)/DT(I)
      D(L,K)=B(L,K)/DT(I)-A(L,K)/2.0
  200 CONTINUE
      NSE=NSEL-1
      E(1)=D(1,1)*PI(1)+D(1,2)*PI(2)
      DO 210 K=2,NSE
      E(K)=D(K,1)*PI(K)+D(K,2)*PI(K+1)+D(K-1,2)*PI(K-1)
  210 CONTINUE
      E(NSEL)=D(NSEL,1)*PI(NSEL)+D(NSEL-1,2)*PI(NSEL-1)
      CALL TRIA(C,MB,NUM,2)
      CALL BACKS(C,E,MB,NUM,2)
      TIME=TIME+DT(I)
C
C     CALCULATE SETTLEMENT
C
      DO 230 K=1,NSEL
      M1=MATNUM(NDRY+K)
      SETTL=SETTL+XLENT(NDRY+K)/EMATL(1,M1)*(PI(K)-E(K))
  230 CONTINUE
C
C     CALCULATE WATER TABLE RISE
C
      M1=MATNUM(NDRY+1)
      DWTCH=DT(I)*EMATL(13,M1)*E(1)/XLENT(NDRY+1)/EMATL(22,M1)
      WTCH=WTCH+DWTCH
      WTABLE=WTABLE-DWTCH
      DO 220 K=1,NSEL
      PI(K)=E(K)
  220 CONTINUE
      KOUNT=KOUNT+1
      IF(KOUNT.LT.NPEOPR(I)) GO TO 261
      KOUNT=0
      WRITE(6,2001) TIME,SETTL,WTABLE
      WRITE(6,2002)
      IF(NDRY.EQ.0) GO TO 257
      Z=0.0
      DO 250 K=1,NDRY
  250 WRITE(6,2003) K,Z
  257 IF(NDRY.EQ.MDRY) GO TO 256
      DO 255 K=NDRY,MDRY
      IND=K+1
      WRITE(6,2003) IND,E(IND-NDRY)
  255 CONTINUE
  256 K1=NDRY+1
```

```
      TDSPR=0.0
      TYLENT=0.0
      DO 260 K=K1,NUM
      DSPR=1.0-E(K-NDRY)/(PPE(K)-PPO(K))
      TDSPR=XLENT(K)*DSPR+TDSPR
      TYLENT=TYLENT+XLENT(K)
      WRITE(6,2004) K, E(K-NDRY),DSPR
  260 CONTINUE
      ODSPR=TDSPR/TYLENT
      WRITE(6,2009) ODSPR
  261 CONTINUE
      IF(NDRY.EQ.0) GO TO 400
      IF(KONTR.NE.1) GO TO 900
      IF(WTCH.LT.XDUM) GO TO 950
      WTCH=WTCH-XDUM
      XLENT(NDRY)=XDUM
      KONTR=0
      CALL MATAB(A,B,NDRY,NSEL,EMATL,XLENT,MATNUM,IWTBL,NUM)
      GO TO 950
  900 WTCR=WTCH/XLENT(NDRY)
      IF(WTCR.LT.0.5) GO TO 950
      XDUM=XLENT(NDRY)
      XLENT(NDRY)=WTCH
      IWTBL(NDRY)=1
      CALL MATAB(A,B,NDRY,NSEL,EMATL,XLENT,MATNUM,IWTBL,NUM)
      KONTR=1
      NSF=NSEL-1
      DO 295 K=1,NSF
      PI(K+1)=E(K)
  295 CONTINUE
      PI(1)=WTCH*GMAW/2.
      GO TO 400
  950 IF(NDRY.EQ.0) GO TO 951
      M0=MATNUM(NDRY)
  951 M1=MATNUM(NDRY+1)
      M2=MATNUM(NDRY+2)
      AEMAT=(EMATL(1,M0)*WTCH+EMATL(1,M1)*XLENT(NDRY+1))/(WTCH+
     *XLENT(NDRY+1))
      A(1,1)=EMATL(1,M2)/XLENT(NDRY+2)+AEMAT/(WTCH+XLENT(NDRY+1))
      B(1,1)=B(1,1)+DWTCH/EMATL(13,M0)/3.
  400 CONTINUE
      RETURN
 2000 FORMAT(1H1,37X,35H *** POST-EARTHQUAKE ANALYSIS ***    //)
 2001 FORMAT(// 15H -----TIME---=   ,F10.5/
     * 12H SETTLEMENT=   ,F10.5/
     * 20H WATER TABLE DEPTH=   ,F10.5//)
 2002 FORMAT(3X,12H NODE N.      ,5X11H EXCESS PP. ,5X,14H DISSIP. RAT.
 2003 FORMAT(5X,I5,5X,E15.6,5X,10H UNDEFINED )
 2004 FORMAT(5X,I5,5X,E15.6,5X,F10.5)
 2008 FORMAT(5X,37H TOTAL TIME FOR DISSIPATION ANALYSIS=   ,F10.5)
 2009 FORMAT(3X,28H OVERALL DISSIPATION RATIO=      ,F10.5)
 2010 FORMAT(30X,15H PORE PRESSURES      /
     *   8H NODE N.    ,
     *    7X,8H IN SITU   ,
     *   9X,10H AFTER EQ.   ,
     *   7X,7H EXCESS  )
 2011 FORMAT(2X,I5,3X,E15.6,3X,E15.6,10H        0.0       )
 2012 FORMAT(2X,I5,3X,E15.6,3X,E15.6,3X,E15.6)
      END
```

```
      SUBROUTINE MATAB (AM,BM,NDRY,NSEL,EMATL,XLENT,MATNUM,IWTBL,NUM)
C
      DIMENSION AM(NUM,1),BM(NUM,1),EMATL(35,1),XLENT(1),MATNUM(1),
     * IWTBL(1)
      NSEL=0
      DO 100 I=1,NUM
      IF(IWTBL(I).LE.0) GO TO 100
      NSEL=NSEL+1
      MN=MATNUM(I)
      AM(NSEL,1)=EMATL( 1,MN)/XLENT(I)
      BM(NSEL,1)=XLENT(I)/EMATL(13,MN)/3.
  100 CONTINUE
      N=NSEL-1
      DO 200 K=1,N
      AM(K,1)=AM(K,1)+AM(K+1,1)
      AM(K,2)=-AM(K+1,1)
      BM(K,1)=BM(K,1)+BM(K+1,1)
      BM(K,2)=BM(K+1,1)/2.
  200 CONTINUE
      AM(NSEL,2)=0.0
      BM(NSEL,2)=0.0
      NDRY=NUM-NSEL
      RETURN
      END
```

```
      SUBROUTINE SZERO (A,NTLLL)
C
      DIMENSION  A(NTLLL)
C
      DO 100 I=1,NTLLL
  100 A(I)=0.0
      RETURN
      END
```

```
      SUBROUTINE TRIA (A,MB,NEQ,M)
C
      DIMENSION A(1),MB(1)
C
      NE=NEQ-1
      MN=M-1
      MM=MN*NEQ
      MK=NEQ-MN
      DO 300 N=1,NE
      NT=N-MK
      IF(NT.GT.0) MM=MM-NEQ
      MB(N)=0
      IF(A(N).EQ.0.0) GO TO 300
      L=N
      IL=N+NEQ
      IH=N+MM
      JB=0
      IB=0
      DO 200 I=IL,IH,NEQ
      L=L+1
      J=L
      IB=IB+1
      C=A(I)/A(N)
      IF(C.EQ.0.0) GO TO 200
      DO 100 K=I,IH,NEQ
      A(J)=A(J)-C*A(K)
  100 J=J+NEQ
      A(I)=C
      JB=IB
  200 CONTINUE
      MB(N)=JB
  300 CONTINUE
      MB(NEQ)=0
      RETURN
      END
```

```
      SUBROUTINE BACKS (A,B,MB,NN,MM)
C
      DIMENSION  A(1),B(1),MB(1)
C
      MMM=MM-1
      N=0
  270 N=N+1
      C=B(N)
      IF (A(N).NE.0.0) B(N)=B(N)/A(N)
      IF(N.EQ.NN) GO TO 300
      IL=N+1
      IH=N+MB(N)
      M=N
      DO 285 I=IL,IH
      M=M+NN
  285 B(I)=B(I)-A(M)*C
      GO TO 270
C
  300 IL=N
      N=N-1
      IF (N.EQ.0) RETURN
      IH=N+MB(N)
      M=N
      C=B(N)
      DO 400 I=IL,IH
      M=M+NN
  400 C=C-A(M)*B(I)
      B(N)=C
      GO TO 300
C
      END
```

```
      SUBROUTINE FINDX  (PE,A,ELAMDA,PHI,EX)
C
      ETA=ELAMDA*TAN(PHI)
      EX=ELAMDA*A
      EX=EX*EX
      EX=ETA*ETA*(1.0+EX)-EX
      EX=1.0-SQRT(EX)
      EX=PE*EX/(1.0-ETA)
      RETURN
      END
```

```
      SUBROUTINE SCAL(CX,DIST,SCA1,SCA2)
C
      DX=CX*2.
      A=10.E+11
      DO 1 I=1,20
      A=A/10.
      B=A/10.
      IF(DX.LT.A.AND.DX.GE.B) GO TO 2
    1 CONTINUE
      SCA1=-DX/2.
      SCA2=DX/DIST
      RETURN
    2 ID=INT((DX/B)+0.99)
      SCA1=-(FLOAT(ID)/2.)*B
      SCA2=-2.*SCA1/DIST
      RETURN
      END
```

```
      SUBROUTINE LOADXY(X,Y,IX,IY,PL,NBLK,NCYCL,LUN)
C
      DIMENSION X(1),Y(1),PL(NBLK,1)
C
      NB=NCYCL/NBLK
      IF(NB.LT.1) NB=1
      IF(NCYCL.LE.NBLK) GO TO 4
      REWIND LUN
    4 N=-NBLK
      DO 1 I=1,NB
      N=N+NBLK
      IF(NCYCL.GT.NBLK) READ(LUN) PL
      IF(IX.EQ.0) GO TO 3
      DO 2 J=1,NBLK
    2 X(J+N)=PL(J,IX)
    3 IF(IY.EQ.0) GO TO 1
      DO 6 J=1,NBLK
    6 Y(J+N)=PL(J,IY)
    1 CONTINUE
      IF(NCYCL.LE.NBLK) RETURN
      READ(LUN) PL
      N=NB*NBLK
      NB=NCYCL-N
      N=N+1
      IF(IX.EQ.0) GO TO 8
      DO  7 J=1,NB
    7 X(N+J)=PL(J,IX)
    8 IF(IY.EQ.0) RETURN
      DO 9 J=1,NB
    9 Y(N+J)=PL(J,IY)
      RETURN
      END
```

APPENDIX - III

EXAMPLE INPUT AND OUTPUT

EXAMPLE INPUT

```
100 FT LAYER,  EXAMPLE PROBLEM
  1    1 1000   1   0.01
400    5  100   1


  1    5
 0.1       5    5
0.5        5    5
 5.0      12   12
10.0      50   50
60.0      50   50
60.
1200.     20    1
8000.   2000.     5.0      10000000. 0.108  0.0001873 .0000974 1.0
0.9     .7854    0.95      0.05     0.1      0.5
HORIZONTAL BASE ACCELERATION, EL CENTRO
1.0      1.0     1008    1
(EARTHQUAKE DATA CODED BY 8F9.0 FORMAT, 126 CARDS)
```

EXAMPLE OUTPUT

```
 100 FT LAYER,  EXAMPLE PROBLEM

NUMBER OF LAYERS ............   =      1
NUMBER OF MATERIALS .........   =      1
NUMBER OF CYCLES ............   =   1000
NUMBER OF INPUT DIRECTIONS ..   =      1
TIME STEP (DT) ..............   = 0.1000E-01

PRINT INTERVAL  .............   =    400
INTERVAL FOR SAVING RESPONSE    =      5
STEP FOR STARTING PRINT ....    =    100
STIFFNESS UPDAT CYCLE ......    =      1
OUTPUT TAPE FLAG ...........    =      0


...DATA FOR POST EARTHQUAKE ANALYSIS...
TIME STEPS    NO. REP.      PRINT INT.
  0.10000            5               5
  0.50000            5               5
  5.00000           12              12
 10.00000           50              50
 60.00000           50              50

DEPTH OF WATER TABLE ........   =     60.000
GRAVITY  ....................   =    386.200
```

```
---------- PROPERTIES OF LAYERS -----------
   LAYER             DEPTH          NUMBER OF          MATERIAL
  NUMBER                             ELEMENTS            NUMBER

       1          1200.000                 20                 1
```

```
---------- MATERIAL PROPERTIES ------------

MAT. NO.  BULK MOD.    SHEAR MOD.    SH. MOD. CHGE. BULK MOD.(FL.) PERMEABILITY   MASS DEN.(TOTAL) MASS DEN.(FL.) S(MAX)
   1   0.800000E 04   0.200000E 04   0.500000E 01   0.100000E 08   0.108000E 00   0.187300E-03   0.974000E-04   0.100000E 01

MAT. NO.  1./LAMBDA    PHI           ALPHA          THETA          RES. EFF. STRS. VOID RAT.
   1   0.900000E 00   0.785400E 00   0.950000E 00   0.500000E-01   0.100000E 00   0.500000E 00
```

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 HORIZONTAL BASE ACCELERATION, EL CENTRO
TIME SCALE -------------     =     1.0000
AMPLITUDE SCALE --------     =     1.0000

ACCELERATION :

   0.108490E-01    0.849400E-02    0.613900E-02    0.378400E-02    0.140900E-02    0.335000E-02    0.600900E-02    0.870700E-02
   0.113840E-01    0.140620E-01    0.151290E-01    0.126140E-01    0.100980E-01    0.758300E-02    0.506800E-02    0.255200E-02
   0.370000E-04    0.283500E-02    0.597100E-02    0.910800E-02    0.122450E-01    0.153820E-01    0.185180E-01    0.151290E-01
   0.105880E-01    0.604700E-02    0.150600E-02    0.160900E-02    0.370200E-02    0.579500E-02    0.433300E-02    0.260200E-02
   0.872000E-03   -0.858000E-03    0.276100E-02    0.788900E-02    0.130170E-01    0.814400E-02    0.151740E-01    0.724000E-02
  -0.594000E-03   -0.862700E-02   -0.165610E-01   -0.231010E-01   -0.155430E-01   -0.798500E-02   -0.428000E-03    0.713000E-02
   0.105870E-01    0.137360E-01    0.168840E-01    0.200330E-01    0.231820E-01    0.263300E-01    0.294790E-01    0.326270E-01
   0.357760E-01    0.389250E-01    0.420730E-01    0.356550E-01    0.276790E-01    0.197030E-01    0.117270E-01    0.101790E-01
   0.112580E-01    0.123360E-01    0.134140E-01    0.116370E-01    0.752300E-02    0.340900E-02   -0.704000E-03   -0.481800E-02
  -0.257350E-01   -0.276170E-01   -0.294990E-01   -0.313810E-01   -0.332640E-01   -0.351460E-01   -0.370280E-01   -0.565210E-01
  -0.524730E-01   -0.484260E-01   -0.443780E-01   -0.403300E-01   -0.362830E-01   -0.322350E-01   -0.281880E-01   -0.241400E-01
  -0.349810E-01   -0.358360E-01   -0.366910E-01   -0.375460E-01   -0.384010E-01   -0.392560E-01   -0.401110E-01   -0.632310E-01
  -0.665880E-01   -0.699450E-01   -0.733020E-01   -0.766600E-01   -0.783260E-01   -0.765589E-01   -0.747910E-01   -0.730240E-01
  -0.712570E-01   -0.694900E-01   -0.677230E-01   -0.388830E-01   -0.406260E-01   -0.423690E-01   -0.316230E-01   -0.138520E-01
   0.391900E-02    0.216910E-01    0.394620E-01    0.572330E-01    0.750050E-01    0.867510E-01    0.690830E-01    0.514140E-01
   0.337460E-01    0.160780E-01   -0.159100E-02   -0.192590E-01   -0.369280E-01   -0.545960E-01   -0.722650E-01   -0.899330E-01
  -0.107602E 00   -0.125270E 00   -0.142939E 00   -0.160607E 00   -0.163475E 00   -0.150939E 00   -0.138403E 00   -0.125866E 00
  -0.113330E 00   -0.100794E 00   -0.882580E-01   -0.828739E-01   -0.828850E-01   -0.828969E-01   -0.862769E-01   -0.904990E-01
  -0.945510E-01   -0.930949E-01   -0.916390E-01   -0.901830E-01   -0.887270E-01   -0.947379E-01   -0.101768E 00   -0.108818E 00
  -0.116035E 00   -0.123252E 00   -0.118984E 00   -0.924230E-01   -0.658610E-01   -0.393000E-01   -0.127380E-01    0.138230E-01
   0.403850E-01    0.669460E-01    0.935070E-01    0.117891E 00    0.134079E 00    0.150268E 00    0.166457E 00    0.182646E 00
   0.198834E 00    0.215023E 00    0.231212E 00    0.228594E 00    0.219020E 00    0.209446E 00    0.199872E 00    0.190298E 00
   0.180723E 00    0.171149E 00    0.161575E 00    0.152001E 00    0.143062E 00    0.149367E 00    0.155672E 00    0.161977E 00
   0.168282E 00    0.174587E 00    0.146036E 00    0.826290E-01    0.192230E-01   -0.441840E-01   -0.107591E 00   -0.170997E 00
  -0.234404E 00   -0.265117E 00   -0.272154E 00   -0.279192E 00   -0.286230E 00   -0.293267E 00   -0.300305E 00   -0.307342E 00
  -0.314380E 00   -0.311160E 00   -0.281563E 00   -0.251966E 00   -0.222370E 00   -0.192773E 00   -0.163176E 00   -0.133580E 00
  -0.103983E 00   -0.743859E-01   -0.447890E-01   -0.151930E-01    0.144040E-01    0.440010E-01    0.735970E-01    0.103194E 00
   0.132791E 00    0.162388E 00    0.191984E 00    0.221581E 00    0.251178E 00    0.280774E 00    0.292348E 00    0.286606E 00
   0.280864E 00    0.275121E 00    0.269379E 00    0.263636E 00    0.154024E 00    0.411990E-01   -0.716259E-01   -0.184452E 00
  -0.297277E 00   -0.258138E 00   -0.217464E 00   -0.176791E 00   -0.136117E 00   -0.954440E-01   -0.547700E-01   -0.140960E-01
   0.318180E-01    0.825720E-01    0.133325E 00    0.184078E 00    0.234831E 00    0.285584E 00    0.239364E 00    0.191166E 00
   0.142967E 00    0.947680E-01    0.465700E-01   -0.162900E-02   -0.447850E-01   -0.893300E-02    0.269190E-01    0.627699E-01
   0.986220E-01    0.134474E 00    0.155443E 00    0.162673E 00    0.169903E 00    0.177134E 00    0.184364E 00    0.191594E 00
   0.198825E 00    0.206055E 00    0.193966E 00    0.176107E 00    0.158247E 00    0.140387E 00    0.122528E 00    0.103439E 00
   0.802320E-01    0.570250E-01    0.338190E-01    0.106120E-01   -0.125940E-01   -0.310240E-01   -0.201140E-01   -0.920200E-02
  -0.159870E-01    0.342000E-02   -0.365040E-01   -0.877290E-01   -0.138955E 00   -0.190180E 00   -0.185356E 00   -0.155350E 00
  -0.125883E 00   -0.151832E 00   -0.132426E 00   -0.113019E 00   -0.936130E-01   -0.742060E-01   -0.548000E-01   -0.353930E-01
   0.120620E-01    0.265430E-01    0.410240E-01    0.438810E-01    0.992900E-02   -0.240240E-01   -0.579770E-01   -0.919300E-01
  -0.444680E-01   -0.666040E-01   -0.748250E-01   -0.603440E-01   -0.458630E-01   -0.313820E-01   -0.169000E-01   -0.241900E-02
   0.889960E-01    0.999070E-01    0.883470E-01    0.662110E-01    0.440750E-01    0.219390E-01   -0.196000E-03   -0.223320E-01
   0.170800E-02    0.126190E-01    0.235300E-01    0.344410E-01    0.453520E-01    0.562630E-01    0.671740E-01    0.780849E-01
  -0.351360E-01   -0.246570E-01   -0.141790E-01   -0.370100E-02    0.677800E-02    0.172560E-01    0.277340E-01    0.339870E-01
   0.146930E 00    0.170805E 00    0.140924E 00    0.111042E 00    0.811610E-01    0.512800E-01    0.213980E-01   -0.848300E-02
  -0.440710E-01   -0.201960E-01    0.367900E-02    0.275540E-01    0.514300E-01    0.753050E-01    0.991800E-01    0.123055E 00
   0.114702E 00    0.144708E 00    0.174713E 00    0.158205E 00    0.719260E-01   -0.143540E-01   -0.918210E-01   -0.679460E-01
  -0.125345E 00   -0.953389E-01   -0.653329E-01   -0.353270E-01   -0.532100E-02    0.246840E-01    0.546900E-01    0.846960E-01
   0.180590E-01    0.213000E-02   -0.137980E-01   -0.297270E-01   -0.456560E-01   -0.615840E-01   -0.710919E-01   -0.602680E-01
  -0.494440E-01   -0.386200E-01   -0.277970E-01   -0.169730E-01   -0.614900E-02    0.467500E-02    0.154990E-01    0.263230E-01
   0.141410E-01   -0.168630E-01   -0.478680E-01   -0.788730E-01   -0.109878E 00   -0.140882E 00   -0.171887E 00   -0.171641E 00
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-0.153041E 00   -0.134440E 00   -0.115840E 00   -0.972400E-01   -0.786400E-01   -0.600390E-01   -0.414390E-01   -0.228390E-01
-0.423800E-02    0.143620E-01    0.139500E-01   -0.201700E-02   -0.179840E-01   -0.339520E-01   -0.383000E-01   -0.252190E-01
-0.121380E-01    0.943000E-03    0.140240E-01    0.137070E-01   -0.511300E-02   -0.239320E-01   -0.427510E-01   -0.615710E-01
-0.803900E-01   -0.992100E-01   -0.118029E 00   -0.136849E 00   -0.155668E 00   -0.174487E 00   -0.193307E 00   -0.195440E 00
-0.193138E 00   -0.190836E 00   -0.188534E 00   -0.186232E 00   -0.183929E 00   -0.181627E 00   -0.179325E 00   -0.177023E 00
-0.155763E 00   -0.124296E 00   -0.928290E-01   -0.613620E-01   -0.298950E-01    0.157200E-02    0.330400E-01    0.645069E-01
 0.959740E-01    0.127441E 00    0.134849E 00    0.107633E 00    0.804180E-01    0.532020E-01    0.259870E-01   -0.122900E-02
 0.107740E-01    0.286370E-01    0.465000E-01    0.643629E-01    0.822260E-01    0.100089E 00    0.117953E 00    0.135816E 00
 0.153679E 00    0.171542E 00    0.189405E 00    0.207268E 00    0.225131E 00    0.242994E 00    0.237676E 00    0.139628E 00
 0.415800E-01   -0.564670E-01   -0.154515E 00   -0.190295E 00   -0.161264E 00   -0.132233E 00   -0.103202E 00   -0.741720E-01
-0.451410E-01   -0.161100E-01    0.129210E-01    0.419520E-01    0.451650E-01    0.430000E-03   -0.443060E-01   -0.890410E-01
-0.133776E 00   -0.178511E 00   -0.223247E 00   -0.267982E 00   -0.244656E 00   -0.212049E 00   -0.179442E 00   -0.146835E 00
-0.114228E 00   -0.816210E-01   -0.490140E-01   -0.164070E-01    0.161990E-01    0.488060E-01    0.814130E-01    0.114020E 00
 0.146627E 00    0.177077E 00    0.155749E 00    0.134421E 00    0.113093E 00    0.917660E-01    0.704380E-01    0.491100E-01
 0.331200E-01    0.603240E-01    0.875280E-01    0.114732E 00    0.141936E 00    0.169140E 00    0.196344E 00    0.214392E 00
 0.193404E 00    0.172416E 00    0.151427E 00    0.130439E 00    0.109450E 00    0.884620E-01    0.674739E-01    0.464850E-01
 0.285300E-01    0.581010E-01    0.876710E-01    0.117242E 00    0.125630E 00    0.126184E 00    0.126737E 00    0.127291E 00
 0.127645E 00    0.128398E 00    0.128952E 00    0.123176E 00    0.115917E 00    0.105097E 00    0.882800E-02   -0.122030E-01
 0.552500E-02    0.232540E-01    0.409830E-01    0.587110E-01    0.764400E-01    0.941690E-01    0.111897E 00    0.129626E 00
 0.147355E 00    0.165083E 00    0.143114E 00    0.935590E-01    0.440040E-01   -0.555200E-02   -0.551070E-01   -0.101585E 00
-0.895820E-01   -0.775800E-01   -0.655770E-01   -0.535750E-01   -0.415720E-01   -0.295690E-01   -0.175670E-01   -0.556400E-02
 0.643800E-02    0.506100E-02   -0.201020E-01   -0.452660E-01   -0.704290E-01   -0.955930E-01   -0.120756E 00   -0.145920E 00
-0.171083E 00   -0.193960E 00   -0.173388E 00   -0.152816E 00   -0.132244E 00   -0.111672E 00   -0.911000E-01   -0.705280E-01
-0.499550E-01   -0.293830E-01   -0.190520E-01   -0.121350E-01   -0.521800E-02   -0.282420E-01   -0.331440E-01   -0.380470E-01
-0.429490E-01   -0.478510E-01   -0.527530E-01   -0.562990E-01   -0.385910E-01   -0.239650E-01   -0.108570E-01    0.225200E-02
 0.153610E-01    0.206390E-01    0.186900E-01    0.167410E-01    0.147920E-01    0.128430E-01    0.108940E-01    0.145970E-01
 0.184150E-01    0.222330E-01    0.152700E-01    0.275200E-02   -0.976500E-02   -0.222820E-01   -0.348000E-01   -0.473170E-01
-0.598350E-01   -0.599380E-01   -0.454690E-01   -0.309990E-01   -0.165300E-01   -0.206100E-02    0.101670E-01    0.216860E-01
 0.332060E-01    0.447250E-01    0.343970E-01   -0.209730E-01   -0.253420E-01   -0.297110E-01   -0.340790E-01   -0.374760E-01
-0.256420E-01   -0.138090E-01   -0.197500E-02    0.985900E-02    0.202940E-01    0.146460E-01    0.899800E-02    0.335000E-02
-0.229800E-02   -0.107110E-01   -0.238350E-01   -0.369580E-01   -0.500810E-01   -0.532940E-01   -0.213710E-01   -0.526500E-02
 0.782900E-02    0.194770E-01    0.119230E-01    0.436900E-02   -0.318500E-02   -0.107390E-01   -0.169520E-01   -0.961100E-02
-0.309200E-02   -0.122900E-02    0.633000E-03    0.249500E-02    0.435700E-02   -0.167400E-02   -0.534600E-02   -0.745900E-02
-0.957100E-02   -0.494500E-02   -0.429600E-02   -0.982400E-02   -0.153510E-01   -0.802000E-02    0.508900E-02    0.181990E-01
 0.313080E-01    0.384280E-01    0.404460E-01    0.424640E-01    0.444830E-01    0.447540E-01    0.421730E-01    0.395930E-01
 0.219700E-01   -0.659000E-03   -0.784900E-02   -0.150380E-01   -0.222270E-01    0.180100E-02    0.413100E-02    0.646100E-02
 0.879100E-02    0.111210E-01    0.929000E-02    0.709700E-02    0.490400E-02    0.271100E-02    0.319300E-02    0.447300E-02
 0.575200E-02    0.703200E-02    0.831200E-02    0.628000E-02   -0.684300E-02   -0.199650E-01   -0.330880E-01   -0.462110E-01
-0.593330E-01   -0.724559E-01   -0.855790E-01   -0.987009E-01   -0.844409E-01   -0.681180E-01   -0.517960E-01   -0.354740E-01
-0.191520E-01   -0.283000E-02    0.134920E-01    0.298140E-01    0.323030E-01    0.263130E-01    0.203230E-01    0.143330E-01
 0.834300E-02   -0.691100E-02   -0.229720E-01    0.432500E-02    0.154110E-01    0.264970E-01    0.323890E-01    0.378900E-01
 0.433910E-01    0.488920E-01    0.543920E-01    0.515190E-01    0.360840E-01    0.206500E-01    0.521500E-02   -0.102200E-01
-0.256550E-01   -0.410890E-01   -0.442990E-01   -0.337220E-01   -0.231450E-01   -0.125680E-01   -0.199200E-02    0.858500E-02
 0.191620E-01    0.297390E-01    0.245130E-01    0.192870E-01    0.140620E-01    0.125270E-01    0.165290E-01    0.130570E-01
 0.811000E-03   -0.114350E-01   -0.236810E-01   -0.266610E-01   -0.281320E-01   -0.296030E-01   -0.310740E-01   -0.325450E-01
-0.340160E-01   -0.307560E-01   -0.225720E-01   -0.143880E-01   -0.620500E-02    0.197900E-02   -0.152680E-01   -0.392760E-01
-0.626370E-01   -0.542730E-01   -0.459100E-01   -0.375470E-01   -0.291830E-01   -0.254560E-01   -0.224210E-01   -0.184930E-01
-0.653100E-02    0.543000E-02    0.508200E-02    0.305500E-02    0.102800E-02   -0.100000E-02   -0.302700E-02   -0.505400E-02
-0.159200E-01   -0.291360E-01   -0.423520E-01   -0.555680E-01   -0.565320E-01   -0.506050E-01   -0.446770E-01   -0.387490E-01
-0.399570E-01   -0.485920E-01   -0.572270E-01   -0.658620E-01   -0.693570E-01   -0.624140E-01   -0.554720E-01   -0.485290E-01
-0.415860E-01   -0.346440E-01   -0.277010E-01   -0.207580E-01   -0.139330E-01   -0.108970E-01   -0.786100E-02   -0.405000E-03
 0.196360E-01    0.253320E-01    0.288850E-01    0.324380E-01    0.359910E-01    0.395440E-01    0.430960E-01    0.466490E-01
 0.432600E-01    0.395040E-01    0.357490E-01    0.319940E-01    0.282390E-01   -0.323010E-01   -0.293140E-01   -0.263270E-01
-0.233400E-01   -0.203540E-01   -0.173670E-01   -0.143800E-01    0.117500E-02    0.298130E-01    0.584510E-01    0.614840E-01
 0.550450E-01    0.486070E-01    0.421680E-01    0.357290E-01    0.303130E-01    0.292550E-01    0.281970E-01    0.271390E-01
 0.260810E-01    0.250230E-01    0.255990E-01    0.270550E-01    0.285100E-01    0.299660E-01    0.314210E-01    0.328770E-01
 0.343320E-01    0.252780E-01    0.123360E-01   -0.606000E-03   -0.135470E-01   -0.264890E-01   -0.369070E-01   -0.365650E-01
-0.362230E-01   -0.358810E-01   -0.355390E-01   -0.351980E-01   -0.348560E-01   -0.345140E-01   -0.317120E-01   -0.279530E-01
-0.241940E-01   -0.204350E-01   -0.166760E-01   -0.129170E-01   -0.117870E-01   -0.155400E-01   -0.192920E-01   -0.230450E-01
-0.223430E-01   -0.382500E-02    0.146940E-01    0.332130E-01    0.517320E-01    0.702500E-01    0.887690E-01    0.107288E 00
 0.125807E 00    0.144326E 00    0.143813E 00    0.125016E 00    0.106219E 00    0.874209E-01    0.686240E-01    0.498260E-01
```

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  0.310290E-01   0.122310E-01  -0.154600E-02   0.475700E-02   0.110600E-01   0.173640E-01   0.222370E-01  -0.690000E-04
 -0.223740E-01  -0.201760E-01  -0.129590E-01  -0.574200E-02  -0.246650E-01  -0.687020E-01  -0.112740E 00  -0.156777E 00
 -0.173408E 00  -0.141314E 00  -0.109219E 00  -0.771250E-01  -0.450300E-01  -0.129360E-01   0.191580E-01   0.512530E-01
  0.833470E-01   0.115442E 00   0.110897E 00   0.883060E-01   0.657150E-01   0.431240E-01   0.437860E-01   0.667910E-01
  0.397950E-01   0.103438E 00   0.113960E 00   0.124483E 00   0.109634E 00   0.942670E-01   0.789000E-01   0.635329E-01
  0.481660E-01   0.328000E-01   0.174330E-01   0.206600E-02  -0.133010E-01  -0.286680E-01  -0.353170E-01  -0.387410E-01
 -0.421650E-01  -0.434980E-01  -0.308320E-01  -0.181670E-01  -0.550200E-02   0.716400E-02   0.198290E-01   0.324940E-01
  0.451600E-01   0.578250E-01   0.704899E-01   0.831560E-01   0.958210E-01   0.108486E 00   0.121151E 00   0.679680E-01
 -0.146438E 00  -0.138423E 00  -0.108406E 00  -0.783880E-01  -0.483710E-01  -0.183540E-01   0.116640E-01   0.416810E-01
  0.312060E-01   0.203220E-01   0.943800E-02  -0.144600E-02  -0.123290E-01  -0.232130E-01  -0.340970E-01  -0.449810E-01
 -0.558650E-01  -0.667490E-01  -0.776330E-01  -0.885170E-01  -0.802040E-01  -0.548690E-01  -0.295340E-01  -0.419800E-02
  0.211370E-01   0.464720E-01   0.718080E-01   0.723400E-01   0.570130E-01   0.416870E-01   0.263600E-01   0.110330E-01
 -0.429400E-02  -0.196200E-01  -0.349470E-01  -0.502740E-01  -0.656010E-01  -0.809270E-01  -0.820920E-01  -0.706969E-01
 -0.593030E-01  -0.479080E-01  -0.365140E-01  -0.251190E-01  -0.137240E-01  -0.233000E-02   0.604900E-02   0.433200E-02
  0.261400E-02   0.897000E-03   0.510000E-04   0.107810E-01   0.215110E-01   0.322410E-01   0.429710E-01   0.537010E-01
  0.332940E-01  -0.136370E-01  -0.605680E-01  -0.639300E-01  -0.543920E-01  -0.448050E-01  -0.164440E-01  -0.107630E-01

STORAGE INFORMATION

CORE SPACE AVAILABLE=  40000 CORE SPACE REQUESTED=   4173


 ----- INSITU  STRESS CONDITION -----
  ELEMENT       EFFECTIVE       PORE
  NUMBER        PRESSURE        PRESSURE


        1          -0.2170E 01     0.0
        2          -0.5382E 01    -0.1128E 01
        3          -0.7465E 01    -0.3385E 01
        4          -0.9548E 01    -0.5642E 01
        5          -0.1163E 02    -0.7899E 01
        6          -0.1371E 02    -0.1016E 02
        7          -0.1580E 02    -0.1241E 02
        8          -0.1788E 02    -0.1467E 02
        9          -0.1996E 02    -0.1693E 02
       10          -0.2205E 02    -0.1918E 02
       11          -0.2413E 02    -0.2144E 02
       12          -0.2621E 02    -0.2370E 02
       13          -0.2830E 02    -0.2595E 02
       14          -0.3038E 02    -0.2821E 02
       15          -0.3246E 02    -0.3047E 02
       16          -0.3455E 02    -0.3273E 02
       17          -0.3663E 02    -0.3498E 02
       18          -0.3871E 02    -0.3724E 02
       19          -0.4080E 02    -0.3950E 02
       20          -0.4288E 02    -0.4175E 02
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---------- RESPONSE AT TIME -----   =    3.99978

 N   DX            DY            DW            VX            VY            VW            AX            AY            AW

 1  -0.6894E 00   -0.5981E-02   -0.2601E-02    0.1720E 02   -0.2986E-02   -0.1493E-02   -0.5133E 01    0.1804E-04   -0.1251E-06
 2  -0.6903E 00   -0.5987E-02    0.5203E-02    0.1689E 02   -0.2985E-02    0.2985E-02    0.5871E 01    0.2953E-04    0.1793E-06
 3  -0.7746E 00   -0.1856E-02    0.1090E-02    0.1568E 02   -0.6434E-03    0.6434E-03    0.6789E 02    0.1505E-05   -0.3843E-08
 4  -0.1394E 01   -0.2070E-02    0.1332E-02    0.1636E 02   -0.1875E-03    0.1875E-03    0.9039E 02    0.1513E-05   -0.9562E-07
 5  -0.1556E 01   -0.2454E-02    0.1749E-02    0.1589E 02   -0.1879E-02    0.1879E-02    0.1424E 02    0.3238E-05    0.6191E-06
 6  -0.1265E 01   -0.1306E-02    0.6473E-03    0.1406E 02    0.2575E-03   -0.2576E-03    0.2359E 02    0.6578E-05   -0.1063E-05
 7  -0.1088E 01   -0.1116E-02    0.5046E-03    0.1277E 02   -0.1344E-03    0.1343E-03    0.3118E 01    0.4973E-05    0.3108E-06
 8  -0.8942E 00   -0.6138E-03    0.5047E-04    0.1239E 02    0.2008E-03   -0.2008E-03    0.1232E 01    0.2405E-05   -0.9834E-07
 9  -0.7495E 00   -0.4363E-03   -0.8054E-04    0.1166E 02    0.1088E-03   -0.1088E-03    0.1669E 02    0.3493E-05    0.3674E-07
10  -0.6328E 00   -0.3272E-03   -0.1446E-03    0.1036E 02    0.1521E-03   -0.1522E-03    0.1528E 02    0.1549E-05   -0.7154E-08
11  -0.5257E 00   -0.2784E-03   -0.1498E-03    0.8891E 01    0.1790E-03   -0.1791E-03   -0.1249E 02    0.3073E-05    0.1201E-07
12  -0.4261E 00   -0.4449E-03    0.5916E-04    0.7585E 01   -0.1535E-03    0.1535E-03   -0.4974E 02    0.3764E-05    0.7010E-08
13  -0.3321E 00   -0.2492E-03   -0.9349E-04    0.6440E 01    0.5196E-04   -0.5200E-04   -0.7807E 02    0.2549E-05    0.3778E-09
14  -0.2481E 00   -0.2591E-03   -0.4059E-04    0.5379E 01   -0.4049E-04    0.4044E-04   -0.9143E 02    0.2823E-05    0.3876E-08
15  -0.1748E 00   -0.2690E-03    0.1265E-04    0.4365E 01   -0.3148E-04    0.3144E-04   -0.9145E 02    0.2903E-05    0.1711E-07
16  -0.1151E 00   -0.9630E-04   -0.1166E-03    0.3411E 01    0.2276E-04   -0.2278E-04   -0.8126E 02    0.1281E-05   -0.8277E-08
17  -0.7168E-01   -0.1575E-03   -0.1198E-04    0.2541E 01   -0.2819E-05    0.2810E-05   -0.6494E 02    0.1003E-05    0.2251E-07
18  -0.4238E-01    0.7738E-04   -0.2036E-03    0.1769E 01    0.9760E-04   -0.9761E-04   -0.4680E 02    0.8742E-06   -0.7244E-07
19  -0.2311E-01    0.7557E-05   -0.9123E-04    0.1095E 01   -0.1607E-07    0.1157E-07   -0.2987E 02    0.3009E-06    0.1752E-06
20  -0.9381E-02    0.2529E-03   -0.2944E-03    0.5061E 00    0.1171E-03   -0.1171E-03   -0.1468E 02    0.2304E-06   -0.4312E-07

----- STRAINS AND STRESSES AT TIME ----- =    3.99978

ELEMENT     VOLUME        SHFAR         FLUID VOL     EFFECTIVE     SHEAR         PORE
NUMBER      STRAIN        STRAIN        CHANGE        PRESSURE      STRESS        PRESSURE

    1        0.9480E-07    0.1609E-04   -0.1301E-03   -0.2170E 01    0.1339E 00    0.0
    2       -0.6885E-04    0.1405E-02    0.6855E-04   -0.2294E 01    0.2885E 00   -0.4210E 01
    3        0.3569E-05    0.1033E-01   -0.4037E-05   -0.2786E 01   -0.2826E 00   -0.8063E 01
    4        0.6394E-05    0.2687E-02   -0.6952E-05   -0.3966E 01   -0.1303E 01   -0.1123E 02
    5       -0.1913E-04   -0.4838E-02    0.1836E-04   -0.3971E 01   -0.1194E 01   -0.1555E 02
    6       -0.3171E-05   -0.2959E-02    0.2378E-05   -0.5788E 01   -0.1312E 01   -0.1808E 02
    7       -0.8363E-05   -0.3227E-02    0.7568E-05   -0.7847E 01   -0.1071E 01   -0.2036E 02
    8       -0.2957E-05   -0.2412E-02    0.2183E-05   -0.1015E 02   -0.8853E 00   -0.2240E 02
    9       -0.1819E-05   -0.1945E-02    0.1067E-05   -0.1245E 02   -0.1000E 01   -0.2444E 02
   10       -0.8138E-06   -0.1785E-02    0.8701E-07   -0.1478E 02   -0.1117E 01   -0.2645E 02
   11        0.2775E-05   -0.1660E-02   -0.3482E-05   -0.1706E 02   -0.8333E 00   -0.2851E 02
   12       -0.3262E-05   -0.1566E-02    0.2544E-05   -0.1904E 02   -0.4787E-01   -0.3087E 02
   13        0.1645E-06   -0.1400E-02   -0.8817E-06   -0.2113E 02    0.1082E 01   -0.3312E 02
   14        0.1663E-06   -0.1221E-02   -0.8873E-06   -0.2317E 02    0.2363E 01   -0.3542E 02
   15       -0.2879E-05   -0.9955E-03    0.2154E-05   -0.2521E 02    0.3639E 01   -0.3772E 02
   16        0.1020E-05   -0.7233E-03   -0.1744E-05   -0.2731E 02    0.4785E 01   -0.3996E 02
   17       -0.3915E-05   -0.4884E-03    0.3194E-05   -0.2943E 02    0.5725E 01   -0.4218E 02
   18        0.1164E-05   -0.3211E-03   -0.1873E-05   -0.3162E 02    0.6438E 01   -0.4433E 02
   19       -0.4089E-05   -0.2288E-03    0.3385E-05   -0.3376E 02    0.6949E 01   -0.4653E 02
   20        0.4215E-05   -0.1563E-03   -0.4906E-05   -0.3597E 02    0.7292E 01   -0.4866E 02
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---------- RESPONSE AT TIME -----   =    7.99949

 N   DX           DY           DW           VX           VY           VW           AX           AY           AW

 1   0.2528E 01  -0.1833E-01  -0.8662E-02   0.6572E 01  -0.3041E-02  -0.1520E-02   0.1412E 02  -0.1769E-04  -0.9571E-07
 2   0.2532E 01  -0.1833E-01   0.1733E-01   0.6719E 01  -0.3041E-02   0.3040E-02   0.1274E 02  -0.9708E-05   0.1741E-06
 3   0.2382E 01  -0.6014E-02   0.5024E-02   0.7587E 01  -0.1156E-02   0.1156E-02   0.5628E 01   0.2441E-04   0.1132E-06
 4   0.1831E 01   0.6485E-03  -0.1608E-02   0.8381E 01   0.1337E-02  -0.1337E-02   0.1031E 02  -0.1159E-06  -0.1493E-06
 5   0.1617E 01  -0.2138E-01   0.2046E-01   0.8609E 01  -0.6757E-02   0.6757E-02   0.1521E 02  -0.3392E-04  -0.9806E-06
 6   0.4234E 00   0.1016E-01  -0.1101E-01   0.8323E 01   0.4974E-02  -0.4974E-02   0.1590E 02  -0.8901E-05  -0.5043E-07
 7   0.4985E 00  -0.7467E-02   0.6662E-02   0.7685E 01  -0.2400E-02   0.2400E-02   0.8910E 01   0.2556E-04  -0.4761E-07
 8   0.3365E 00   0.1191E-02  -0.1938E-02   0.6675E 01   0.8073E-03  -0.8073E-03  -0.3965E 01   0.1752E-05  -0.8762E-07
 9   0.3765E 00  -0.2903E-03  -0.4010E-03   0.5512E 01  -0.4667E-04   0.4659E-04  -0.1873E 02  -0.3199E-07   0.3045E-07
10   0.3703E 00   0.3756E-03  -0.1012E-02   0.4320E 01   0.4201E-03  -0.4201E-03  -0.3353E 02  -0.4744E-06  -0.2083E-06
11   0.3863E 00  -0.1154E-03  -0.4698E-03   0.3240E 01   0.7922E-04  -0.7926E-04  -0.4709E 02   0.1242E-05  -0.1116E-06
12   0.3807E 00  -0.1487E-02   0.9529E-03   0.2295E 01  -0.2352E-03   0.2351E-03  -0.5853E 02  -0.1490E-05   0.1559E-07
13   0.3720E 00  -0.5575E-03   0.7540E-04   0.1471E 01  -0.4083E-04   0.4079E-04  -0.6578E 02  -0.3307E-06  -0.2271E-07
14   0.3624E 00  -0.1657E-02   0.1229E-02   0.7746E 00  -0.3397E-03   0.3396E-03  -0.6628E 02   0.1035E-05   0.2634E-07
15   0.3392E 00  -0.1373E-02   0.1000E-02   0.2155E 00  -0.2638E-03   0.2637E-03  -0.5908E 02  -0.7234E-06  -0.1911E-07
16   0.3015E 00  -0.8779E-03   0.5644E-03  -0.1722E 00  -0.1857E-03   0.1857E-03  -0.4614E 02  -0.6932E-06   0.2270E-07
17   0.2503E 00  -0.6526E-03   0.3999E-03  -0.3745E 00  -0.1076E-03   0.1075E-03  -0.3183E 02   0.6850E-07  -0.1031E-07
18   0.1920E 00  -0.2190E-03   0.2817E-04  -0.4169E 00  -0.6360E-04   0.6359E-04  -0.1978E 02  -0.1273E-06   0.1337E-07
19   0.1289E 00  -0.6194E-03   0.4913E-03  -0.3431E 00  -0.1502E-03   0.1502E-03  -0.1093E 02  -0.1980E-06  -0.5381E-07
20   0.6404E-01   0.1866E-03  -0.2508E-03  -0.1919E 00  -0.9526E-05   0.9523E-05  -0.4677E 01  -0.5169E-07   0.1672E-07

----- STRAINS AND STRESSES AT TIME ----- =    7.99949

 ELEMENT    VOLUME       SHEAR        FLUID VOL    EFFECTIVE    SHEAR        PORE
 NUMBER     STRAIN       STRAIN       CHANGE       PRESSURE     STRESS       PRESSURE

      1     0.8629E-07  -0.7670E-04  -0.4331E-03  -0.2170E 01  -0.6556E-01   0.0
      2    -0.2053E-03   0.2501E-02   0.2050E-03  -0.2100E 01  -0.1806E 00  -0.4404E 01
      3    -0.1110E-03   0.9182E-02   0.1105E-03  -0.2424E 01  -0.2069E 00  -0.8419E 01
      4     0.3672E-03   0.3576E-02  -0.3678E-03  -0.3824E 01  -0.2968E 00  -0.1139E 02
      5    -0.5257E-03   0.1989E-01   0.5245E-03  -0.1000E 00  -0.4518E 00  -0.1940E 02
      6     0.2937E-03  -0.1252E-02  -0.2946E-03  -0.5217E 01  -0.6200E 00  -0.1867E 02
      7    -0.1443E-03   0.2701E-02   0.1433E-03  -0.6212E 01  -0.7114E 00  -0.2199E 02
      8     0.2468E-04  -0.6664E-03  -0.2562E-04  -0.8523E 01  -0.6637E 00  -0.2403E 02
      9    -0.1110E-04   0.1024E-03   0.1019E-04  -0.1089E 02  -0.4438E 00  -0.2600E 02
     10     0.8183E-05  -0.2662E-03  -0.9043E-05  -0.1345E 02  -0.4424E-01  -0.2778E 02
     11     0.2287E-04   0.9297E-04  -0.2371E-04  -0.1568E 02   0.5203E 00  -0.2990E 02
     12    -0.1550E-04   0.1456E-03   0.1463E-04  -0.1751E 02   0.1226E 01  -0.3240E 02
     13     0.1833E-04   0.1596E-03  -0.1922E-04  -0.1939E 02   0.2026E 01  -0.3487E 02
     14    -0.4741E-05   0.3875E-03   0.3804E-05  -0.2101E 02   0.2842E 01  -0.3758E 02
     15    -0.8246E-05   0.6285E-03   0.7264E-05  -0.2265E 02   0.3575E 01  -0.4028E 02
     16    -0.3754E-05   0.8531E-03   0.2741E-05  -0.2442E 02   0.4145E 01  -0.4285E 02
     17    -0.7227E-05   0.9716E-03   0.6196E-05  -0.2632E 02   0.4532E 01  -0.4529E 02
     18     0.6674E-05   0.1051E-02  -0.7719E-05  -0.2826E 02   0.4770E 01  -0.4769E 02
     19    -0.1343E-04   0.1082E-02   0.1237E-04  -0.3016E 02   0.4908E 01  -0.5014E 02
     20     0.3110E-05   0.1067E-02  -0.4180E-05  -0.3219E 02   0.4979E 01  -0.5245E 02

ELEMENT LIQUEFACTION DATA

 EL. NO.

     1       NO LIQUEFACTION
     2       NO LIQUEFACTION
```

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 3        NO LIQUEFACTION
 4        NO LIQUEFACTION
 5        INITIAL LIQUEF. AT TIME =     5.4697 LIQUEF. AT TIME =     5.8296
 6        NO LIQUEFACTION
 7        NO LIQUEFACTION
 8        NO LIQUEFACTION
 9        NO LIQUEFACTION
10        NO LIQUEFACTION
11        NO LIQUEFACTION
12        NO LIQUEFACTION
13        NO LIQUEFACTION
14        NO LIQUEFACTION
15        NO LIQUEFACTION
16        NO LIQUEFACTION
17        NO LIQUEFACTION
18        NO LIQUEFACTION
19        NO LIQUEFACTION
20        NO LIQUEFACTION
```

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                              *** POST-EARTHQUAKE ANALYSIS ***

                                   PORE PRESSURES
NODE N.        IN SITU               AFTER EQ.          EXCESS
     1      0.0                   0.0                0.0
     2      0.112848E 01          0.444664E 01       0.331817E 01
     3      0.338543E 01          0.845247E 01       0.506704E 01
     4      0.564238E 01          0.114208E 02       0.577841E 01
     5      0.789933E 01          0.193977E 02       0.114983E 02
     6      0.101563E 02          0.186880E 02       0.853176E 01
     7      0.124132E 02          0.219911E 02       0.957782E 01
     8      0.146702E 02          0.240302E 02       0.935999E 01
     9      0.169271E 02          0.259977E 02       0.907057E 01
    10      0.191841E 02          0.277790E 02       0.859491E 01
    11      0.214410E 02          0.298965E 02       0.845543E 01
    12      0.236980E 02          0.324040E 02       0.870601E 01
    13      0.259549E 02          0.348659E 02       0.891096E 01
    14      0.282119E 02          0.375849E 02       0.937297E 01
    15      0.304688E 02          0.402808E 02       0.981192E 01
    16      0.327258E 02          0.428472E 02       0.101214E 02
    17      0.349827E 02          0.452929E 02       0.103101E 02
    18      0.372397E 02          0.476920E 02       0.104523E 02
    19      0.394966E 02          0.501362E 02       0.106395E 02
    20      0.417536E 02          0.524455E 02       0.106919E 02
   TOTAL TIME FOR DISSIPATION ANALYSIS=3562.99976

-----TIME---=     0.50000
SETTLEMENT=    0.00321
WATER TABLE DEPTH=    59.99420

   NODE N.            EXCESS PP.       DISSIP. RAT.
        1          0.0                 UNDEFINED
        2          0.310173E 01          0.06523
        3          0.483654E 01          0.04549
        4          0.672692E 01         -0.16415
        5          0.999663E 01          0.13060
        6          0.933438E 01         -0.09407
        7          0.930345E 01          0.02865
        8          0.937745E 01         -0.00186
        9          0.903846E 01          0.00354
       10          0.864158E 01         -0.00543
       11          0.851060E 01         -0.00653
       12          0.868745E 01          0.00213
       13          0.895212E 01         -0.00462
       14          0.936694E 01          0.00064
       15          0.979484E 01          0.00174
       16          0.101061E 02          0.00151
       17          0.103040E 02          0.00059
       18          0.104622E 02         -0.00095
       19          0.106197E 02          0.00187
       20          0.106808E 02          0.00104
   OVERALL DISSIPATION RATIO=      0.00029

-----TIME---=     3.00000
SETTLEMENT=    0.01649
WATER TABLE DEPTH=    59.96999
```

```
    NODE N.          EXCESS PP.       DISSIP. RAT.
       1         0.0                UNDEFINED
       2         0.255266E 01          0.23070
       3         0.489265E 01          0.03442
       4         0.696863E 01         -0.20598
       5         0.852379E 01          0.25869
       6         0.925834E 01         -0.08516
       7         0.935760E 01          0.02299
       8         0.921726E 01          0.01525
       9         0.899910E 01          0.00788
      10         0.877495E 01         -0.02095
      11         0.867317E 01         -0.02575
      12         0.876617E 01         -0.00691
      13         0.902435E 01         -0.01272
      14         0.937487E 01         -0.00020
      15         0.973668E 01          0.00767
      16         0.100442E 02          0.00763
      17         0.102769E 02          0.00322
      18         0.104498E 02          0.00024
      19         0.105680E 02          0.00672
      20         0.106121E 02          0.00746
    OVERALL DISSIPATION RATIO=     0.01291

-----TIME---=    62.99998
SETTLEMENT=    0.20448
WATER TABLE DEPTH=    59.61452

    NODE N.          EXCESS PP.       DISSIP. RAT.
       1         0.0                UNDEFINED
       2         0.123169E 01          0.62880
       3         0.242978E 01          0.52047
       4         0.356366E 01          0.38328
       5         0.460824E 01          0.59923
       6         0.554571E 01          0.34999
       7         0.636651E 01          0.33529
       8         0.706899E 01          0.24477
       9         0.765838E 01          0.15569
      10         0.814516E 01          0.05233
      11         0.854279E 01         -0.01033
      12         0.886573E 01         -0.01835
      13         0.912768E 01         -0.02432
      14         0.934019E 01          0.00350
      15         0.951203E 01          0.03056
      16         0.964904E 01          0.04667
      17         0.975450E 01          0.05389
      18         0.982976E 01          0.05956
      19         0.987505E 01          0.07185
      20         0.989018E 01          0.07498
    OVERALL DISSIPATION RATIO=     0.18726

-----TIME---=   562.99976
SETTLEMENT=    0.81084
WATER TABLE DEPTH=    58.45691

    NODE N.          EXCESS PP.       DISSIP. RAT.
       1         0.0                UNDEFINED
```

```
         2        0.394730E 00       0.88104
         3        0.786755E 00       0.84473
         4        0.117339E 01       0.79694
         5        0.155198E 01       0.86503
         6        0.191994E 01       0.77497
         7        0.227476E 01       0.76250
         8        0.261399E 01       0.72073
         9        0.293534E 01       0.67639
        10        0.323660E 01       0.62343
        11        0.351572E 01       0.58421
        12        0.377080E 01       0.56687
        13        0.400011E 01       0.55110
        14        0.420210E 01       0.55168
        15        0.437538E 01       0.55408
        16        0.451878E 01       0.55354
        17        0.463134E 01       0.55080
        18        0.471228E 01       0.54916
        19        0.476106E 01       0.55251
        20        0.477736E 01       0.55318
   OVERALL DISSIPATION RATIO=    0.65857

-----TIME---= 3562.99976
SETTLEMENT=    1.25832
WATER TABLE DEPTH=    57.63962

   NODE N.           EXCESS PP.       DISSIP. RAT.
         1        0.0               UNDEFINED
         2        0.285843E-02       0.99914
         3        0.569740E-02       0.99888
         4        0.849735E-02       0.99853
         5        0.112394E-01       0.99902
         6        0.139044E-01       0.99837
         7        0.164749E-01       0.99828
         8        0.189322E-01       0.99798
         9        0.212609E-01       0.99766
        10        0.234437E-01       0.99727
        11        0.254668E-01       0.99699
        12        0.273158E-01       0.99686
        13        0.289780E-01       0.99675
        14        0.304426E-01       0.99675
        15        0.316991E-01       0.99677
        16        0.327388E-01       0.99677
        17        0.335556E-01       0.99675
        18        0.341422E-01       0.99673
        19        0.344964E-01       0.99676
        20        0.346144E-01       0.99676
   OVERALL DISSIPATION RATIO=    0.99752
```