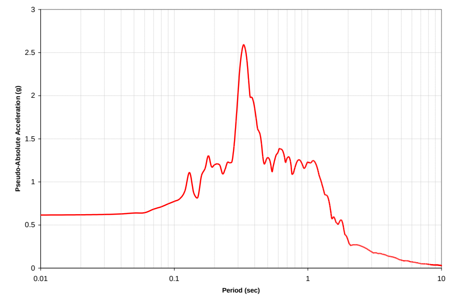
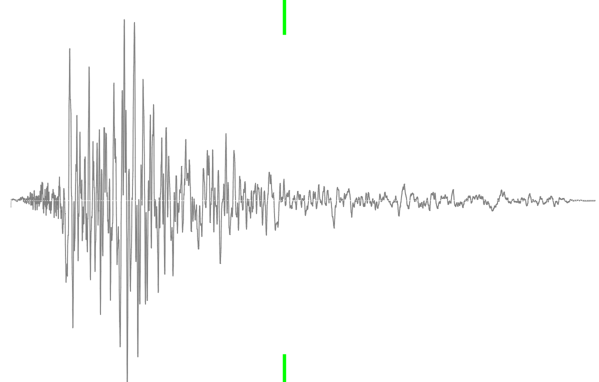
SHAKE2000

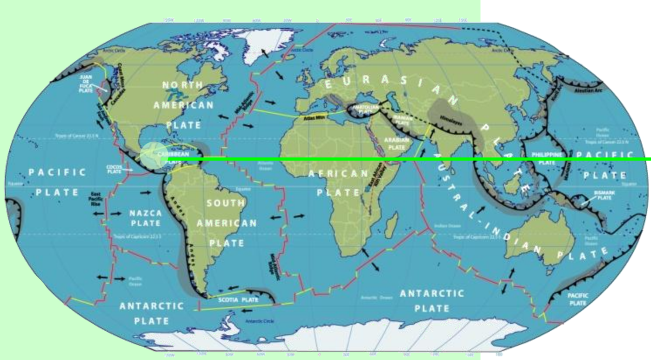
A Computer Program for the 1-D Analysis of Geotechnical Earthquake Engineering Problems

User's Manual

Gustavo A. Ordóñez







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A Computer Program for the 1-D Analysis of Geotechnical Earthquake Engineering Problems

By

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SHAKE2000

A Computer Program for the 1-D Analysis of Geotechnical Earthquake Engineering Problems

A software application that integrates

SHAKE

A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites

Per B. Schnabel, John Lysmer, H. Bolton Seed
University of California, Berkeley

and

SHAKE91

A Modified Version of SHAKE for Conducting Equivalent Linear Seismic Response Analyses of Horizontally Layered Soil Deposits

I.M. Idriss and J.I. Sun
University of California, Davis

with

ShakEdit

A Pre and Postprocessor for SHAKE and SHAKE91

Gustavo A. Ordóñez

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SHAKE2000

1. Introduction

The evolution of the computer program SHAKE is typical of other FORTRAN programs originally developed for the mainframe environment in the 1970s. At that time, punched computer cards served to input data and the program output consisted of reams of numbers and crude graphical displays from a line printer. In the 1980s, the program was ported to the PC environment. The initial code changes were those necessary simply to get an executable program that ran on the engineer's desktop computer. Subsequent modifications have "tweaked" the program. The thrust of these modifications has been to ease construction of the input file and to provide a number of default settings for program operation and output. However, in its essentials, today's SHAKE is largely unchanged from its mainframe incarnation. It still is not "user friendly", but most importantly it is a robust analysis tool proven in some twenty-five years of service.

Recent advances in computer technology, operating systems, and programming languages have allowed the development of computer programs that greatly simplify the process of entering input data and presenting the results in a more informative manner. Computer programs such as WESHAKE, ProShake and ShakEdit are examples of the trend towards the development of the next generation of user-friendly, Geotechnical Earthquake Engineering software. Thus, integrating an analysis program with a user-friendly interface facilitates and greatly enhances the interpretation of the dynamic behavior of a particular site. The integration of SHAKE and ShakEdit into an affordable, quality computer program is the next logical upgrade of the SHAKE computer program.

For those of you who are familiar with the many advances in dynamic analysis programs, you may wonder why invest this effort in a 33-year-old program for the one-dimensional, equivalent-linear analysis of site response? The short answer is that with a minimal input file, a "reasonable approximation" of the site response can be obtained with an analysis whose run time is a matter of seconds. Thus, the user has a powerful screening tool to gauge site response and then determine whether more sophisticated modeling is warranted. The development of WESHAKE by the Corps and ProShake by Dr. Steven Kramer, stand as a testament that others in the geotechnical community appreciate the intrinsic value in this venerable analysis procedure.

We see as the long-term goal of this program the development of a reliable, efficient, and user-friendly computer application that will help geotechnical earthquake engineers and researchers with the analysis of site-specific response and the evaluation of earthquake effects on soil deposits. Hence, the main objective in the development of SHAKE2000 is to add new features to transform it into an analysis tool for seismic analysis of soil deposits and earth structures. As such, the governing philosophy in developing this new version of SHAKE was to lay before the user a suite of tools designed to answer questions of interest to both academia and the consulting professional. We then expect that SHAKE2000 will have a dual role in geotechnical earthquake engineering. First, it will be used as a learning tool for students of geotechnical engineering. Second, it will serve practitioners of geotechnical earthquake engineering as a scoping tool to provide a first approximation of the dynamic response of a site. Depending upon the prediction of site response, the practitioner will judge whether more sophisticated dynamic modeling is warranted.

The following sections of this manual provide the user with a description of the SHAKE program. In the first sections, we have included the original documentation for the program to provide the user with the theoretical background followed in the development of SHAKE. Following this description of SHAKE, we have included a section about ShakEdit, the graphical user interface that was integrated with SHAKE to create this latest update. We then briefly describe the modifications to the original SHAKE source code for the development of SHAKE91 and SHAKE2000. The following section describes the methodology followed during a simplified seismic analysis, and the options used to perform this analysis with SHAKE2000. The second part of this manual starts with a step-by-step, quick tutorial intended to explain how to use SHAKE2000 by following a simple example that covers most of the features of the program. The last section of the manual describes each of the "forms" included in the program.

The development of SHAKE2000 is a work in progress. We would appreciate receiving suggestions about new features that users would like included in the program, information on modifications that are recommended to make the program easier to use, and information on any bug in the source code that needs to be fixed. SHAKE2000 will be continuously updated/upgraded based on input from users and developments in geotechnical earthquake engineering practice.

2. SHAKE

This section is a literal copy of the information provided in *SHAKE, A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites;* by Schnabel, P.B.; Lysmer, J.; and Seed, H.B. Report No. EERC 72-12, Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley, December 1972.

2.1 Introduction

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

The analytical procedure generally involves the following steps:

- Determine the characteristics of the motions likely to develop in the rock formation underlying the site, and select an accelerogram with these characteristics for use in the analysis. The maximum acceleration, predominant period, and effective duration are the most important parameters of an earthquake motion. Empirical relationships between these parameters and the distance from the causative fault to the site have been established for different magnitude earthquakes (Gutenberg and Richter, 1956; Seed et. al., 1969; Schnabel and Seed, 1972). A design motion with the desired characteristics can be selected from the strong motion accelerograms that have been recorded during previous earthquakes (Seed and Idriss, 1969) or from artificially generated accelerograms (Housner and Jennings, 1964).
- Determine the dynamic properties of the soil deposit. Average relationships between the dynamic shear moduli and damping ratios of soils, as functions of shear strain and static properties, have been established for various soil types (Hardin and Drnevich, 1970; Seed and Idriss, 1970). Thus, a relatively simple testing program to obtain the static properties for use in these relationships will often serve to establish the dynamic properties with a sufficient degree of accuracy. However more elaborate dynamic testing procedures are required for especial problems and for cases involving soil types for which empirical relationships with static properties have not been established.
- Compute the response of the soil deposit to the base-rock motions. A one-dimensional method of analysis can be used if the soil structure is essentially horizontal. Programs developed for performing this analysis are in general based on either the solution to the wave equation (Kanai, 1951; Matthiesen et al., 1964; Roesset and Whitman, 1969; Lysmer et al., 1971) or on a lumped mass simulation (Idriss and Seed, 1968). More irregular soil deposits may require a finite element analysis.

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

2.2 Theory

The theory considers the response associated with vertical propagation of shear waves through the linear viscoelastic system shown in Fig. 2. The system consists of *N* horizontal layers, which extend to infinity in the horizontal

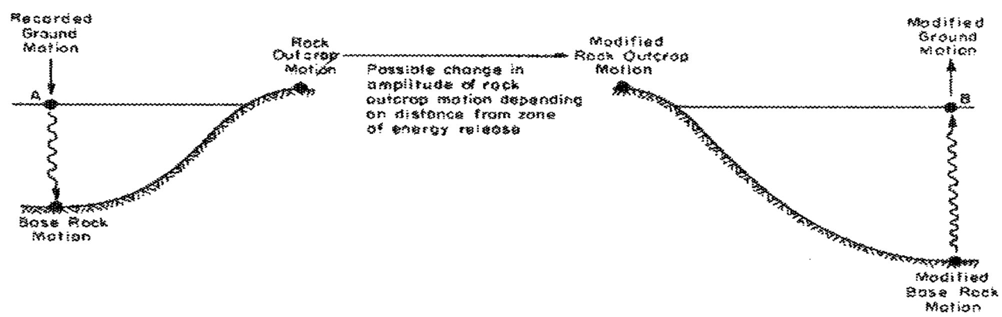


Figure 1: Schematic representation of procedure for computing effects of local soil conditions on ground motions (after Schnabel et al., 1972).

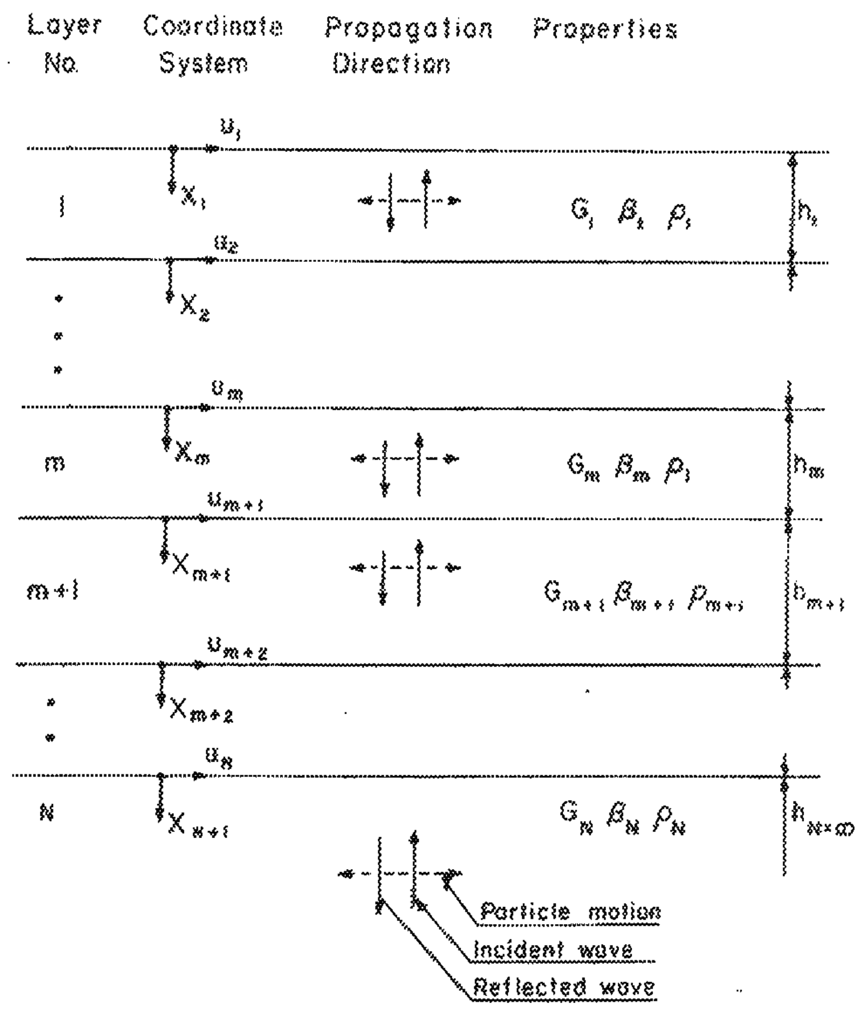


Figure 2: One-Dimensional System (after Schnabel et al., 1972).

direction and has a halfspace as the bottom layer. Each layer is homogeneous and isotropic and is characterized by the thickness, h, mass density, ρ, shear modulus, G, and damping factor, β.

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

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

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

which must satisfy the wave equation:

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

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

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

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

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

which has the general solution:

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

in which:

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

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

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

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

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

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

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

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

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

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

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

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

The shear stress on a horizontal plane is:

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

or by Eq. 8:

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

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

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

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

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

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

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

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

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

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

where α_m is the complex impedance ratio

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

which again is independent of frequency.

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

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

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

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

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

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

and by substituting Eqs. 9, 20 and 21:

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

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

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

$$\ddot{u}(\mathrm{x, t}) = \frac{\partial^2 u}{\partial t^2} = -\omega^2 \left(E e^{i(kx+\omega t)} + F e^{-i(kx-\omega t)} \right) \tag{23}$$

and strains by:

$$\gamma = \frac{\partial u}{\partial x} = ik \left(E e^{i(kx+\omega t)} - F e^{-i(kx-\omega t)} \right) \tag{24}$$

2.4 Ratio between rock outcrop motions and base rock motions

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

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

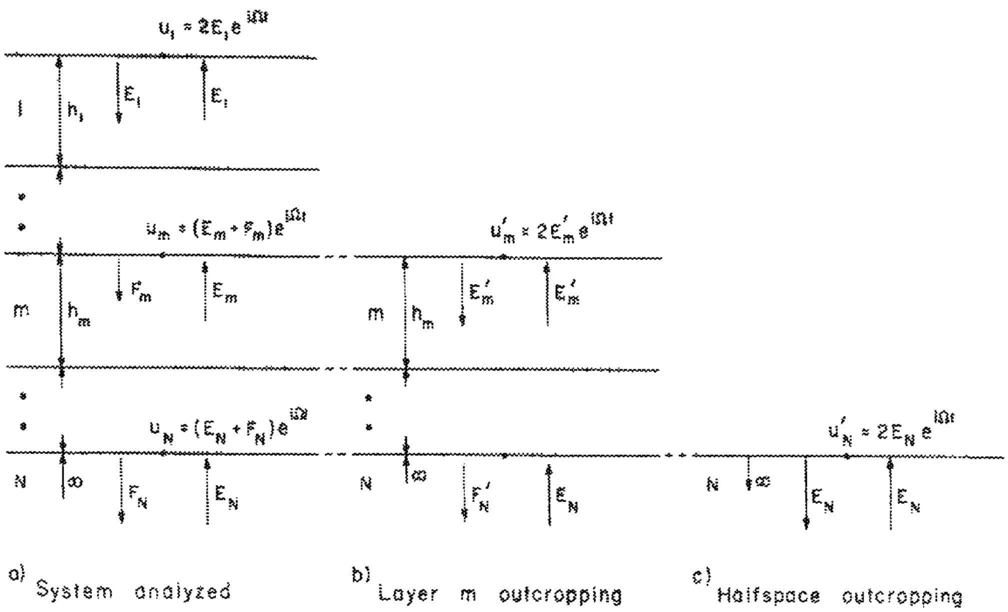


Figure 3: One-Dimensional System with Outcropping Layers (after Schnabel et al., 1972).

$$A_N^{'}(\omega) = \frac{u_N}{u_N^{'}} = \frac{e_N(\omega) + f_N(\omega)}{2e_N(\omega)} \tag{25}$$

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

$$A_{N,1}^{'}(\omega) = \frac{1}{e_N(\omega)} \tag{26}$$

If the halfspace is the rock formation underlying a soil deposit, Eq. 25 shows the ratio between the motion in the base rock and in the outcropping rock. The ratio between the amplitudes of the base rock motion and the outcropping rock motion is always less than 1, with minimum values at the resonance frequencies of the deposit. Transfer functions for the deposit used in the example are shown in Fig. 4. The amplitude of the base rock motion is only 65% of the amplitude of the rock outcrop motion at the fundamental frequency of the deposit. This difference is a function of the impedance ratio between the deposit and the rock and of the damping in the deposit.

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

An approximation for the free surface motion for one of the layers in the system, Fig. 3.b, may be obtained in the same way as for the halfspace, provided the incident wave component in the outcropping layer and in the layer within the system are equal, i.e. $E_m = E_m^{'}$. This is approximately the case when the properties of layer m and all layers below are equal in the two systems and when the impedance, $\rho_m V_m$, is of the same order of magnitude as for

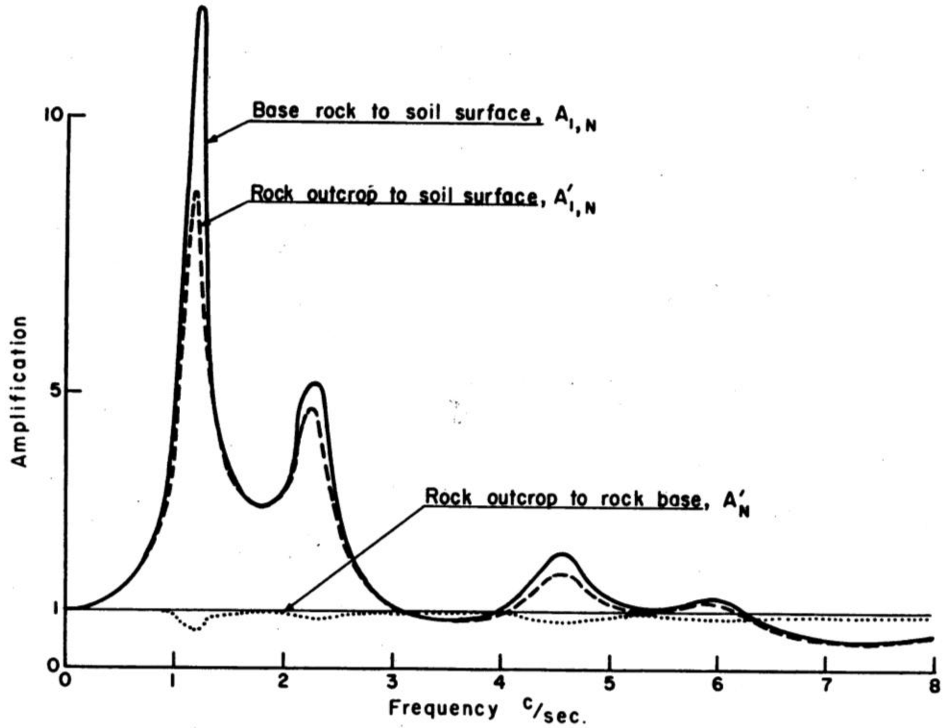


Figure 4: Transfer Functions (after Schnabel et al., 1972).

the halfspace. This is the case for example, in sedimentary rock layers overlying a crystalline rock base. For a more accurate solution, the motion in outcropping layers must be computed in a separate system from the motion in the halfspace.

2.5 Transient Motion

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

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

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

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

$$\omega_s = \frac{2\pi}{n \cdot \Delta t} \cdot s \tag{28}$$

a_s and b_s designate the complex Fourier coefficients:

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

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

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

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

The representation of a discrete motion with its Fourier transform gives an exact representation of the motion at the discrete points $t = j\,\Delta t,\ j = 0 \ldots n-1$. Cyclic repetition of the motion with the period $T = n\,\Delta t$ is implied in the solution. The solution applies, therefore, to an infinite train of identical accelerograms rather than the given single accelerogram. For systems with damping this is not of any significant consequence since the individual accelerograms can be separated by a quiet zone of zeros causing the responses from one cycle to damp out before the beginning of the next cycle.

The Fourier Transformation can be performed in several ways. The SHAKE program utilizes the Fast Fourier Transform algorithm developed by Cooley and Tukey (1965), which is faster by a factor n/log n over the conventional method. This technique computes all values in the series simultaneously. The method requires that the number of terms in the series be some power of 2. A typical analysis using an acceleration record of 800 terms with time step $\Delta t = 0.02$ seconds will use 1024 values in the Fast Fourier Transform, with all values between 800 and 1024 set equal to 0. This will satisfy both the requirements of a quiet zone after the acceleration record and that the total number of terms must be a power of two.

2.6 Description of the Program SHAKE

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

The following assumptions are implied in the analysis:

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

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

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

- Read the input motion, find the maximum acceleration, scale the values up or down, and compute the predominant period.
- Read data for the soil deposit and compute the fundamental period of the deposit.

- Compute the maximum stresses and strains in the middle of each sublayer and obtain new values for modulus and damping compatible with a specified percentage of the maximum strain.
- Compute new motions at the top of any sublayer inside the system or outcropping from the system.
- Print, plot and punch the motions developed at the top of any sublayer.
- Plot Fourier Spectra for the motions.
- Compute, print and plot response spectra for motions.
- Compute, print and plot the amplification function between any two sublayers.
- Increase or decrease the time interval without changing the predominant period or duration of the record.
- Set a computed motion as anew object motion. Change the acceleration level and predominant period of the object motion.
- Compute, print and plot the stress or strain time-history in the middle of any sublayer.

These operations are performed by exercising the various available options in the program. A list of these options is given in the following sections.

3. ShakEdit - Graphical User Interface

ShakEdit was originally developed as a 16-bit, Windows 3.1 application that provided a graphical interface for SHAKE. It was originally conceived as an aid to the user in the creation of the input file and the graphical display of the program's numeric output. It accomplished the first step by incorporating user-friendly screens to assist in entering the arcane input data for the differing SHAKE options. The second step required the development of routines for the processing and error checking of output data, and for displaying that output in forms familiar to the geotechnical engineer.

Notable features of ShakEdit as a preprocessor for SHAKE are the following:

- On-line help for every form used in the program.
- A database of material properties [Option 1].
- Incorporation of a number of equations used to estimate the maximum shear moduli, G_{max} [Option 2].

The solution of a particular problem requires use of realistic ground motions (loading), modeling site dynamics (response), and the interpretation and prediction of soil behavior subject to dynamic loading (analysis). To help the engineer in the solution of this problem, ShakEdit evolved from its original formulation as strictly a pre and postprocessor for SHAKE, to a computer program that the practicing engineer could employ to address geotechnical aspects of earthquake engineering of a project site. It presently includes the following:

- Numerous ground motion prediction equations for estimating peak horizontal acceleration and velocity with distance; and, for the pseudo acceleration and pseudo velocity response spectra.
- Design spectra such as NEHRP, IBC, UBC 1997, EuroCode and AASHTO. These spectra and those from ground motion prediction equations can be plotted simultaneously with the spectra computed with SHAKE.
- Calculation of permanent slope displacements due to earthquake shaking using the Newmark Method or the Makdisi-Seed Method.
- A postprocessor for SEISRISK III, a computer program for seismic hazard estimation developed by the USGS.
- Computation of cyclic stress ratio (CSR) based on 1) equivalent uniform shear stress using the peak shear stress computed with SHAKE; or, 2) the simplified equation by Seed & Idriss (1971).
- Estimation of the cyclic resistance ratio (CRR) required to initiate liquefaction using SPT, CPT, V_s and/or BPT test results.
- Calculation of settlement induced by earthquake shaking.
- An option to obtain the Peak Ground Acceleration from the gridded points used to make the 1996 USGS National Seismic Hazard Maps based on latitude and longitude input.
- Utilities to convert ground motion record files downloaded from the internet or obtained from other sources to a format compatible with SHAKE.

- An option to compute the response spectra for a ground motion.
- Evaluation of liquefaction induced ground deformation.
- Printing of the output results for each graph in table form for inclusion in reports or other documents.

The foregoing provides the engineer with a suite of tools that facilitates the translation of the output from SHAKE into predictions of liquefaction potential, and earthquake induced displacements of a site.

However, the most important feature of ShakEdit is its ability to graphically display the results from SHAKE and other analyses. For example, values of peak acceleration are displayed vs. depth; time history accelerations are displayed as values of acceleration vs. time; ground motion prediction equations are displayed as a log-log graph of acceleration vs. distance; etc.. Results from SEISRISK III can be displayed as contours, or 3-D surface graphs. The graphs can be imported into another application such as a word processor for preparing presentations or engineering reports.

The development process of SHAKE2000 is ongoing. The program is continuously updated/upgraded based on input from users and developments in geotechnical earthquake engineering practice.

4. Program Execution

SHAKE2000 was developed to provide the user with a user-friendly interface for SHAKE and to add new features to transform it into an analysis tool for seismic analysis of soil deposits and earth structures. To this end, there are three ways that SHAKE2000 can be used.

One approach to work with SHAKE2000 is to use the different features included in the **Main Menu** form (see Figure 5) to work with an existing input file or output files.

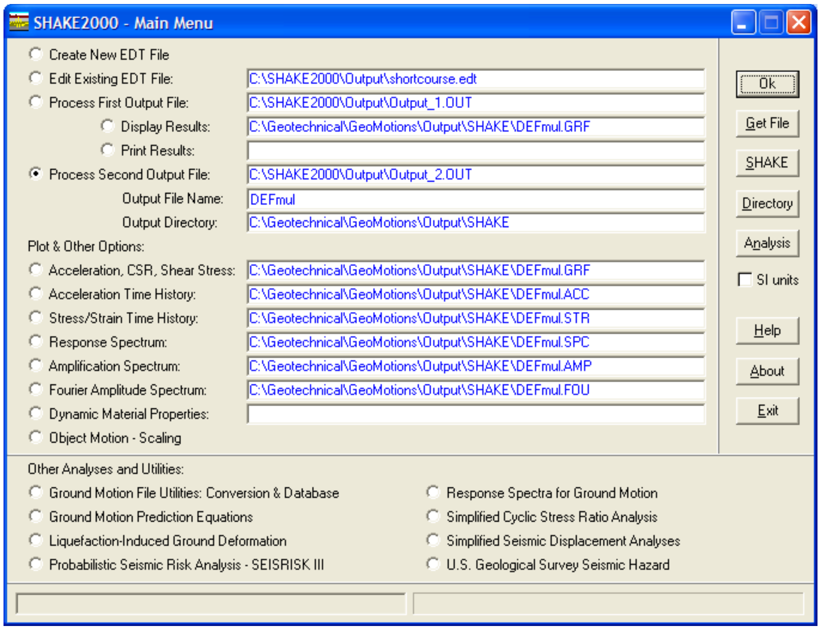


Figure 5: Main Menu form of SHAKE2000.

In this form, you can use the **SHAKE** command button to perform the earthquake response analysis and create the two output files. You can then use the **Process First Output File** and **Process Second Output File** options to obtain the most significant results from the output files. These results can be plotted with the **Plot Options** (e.g. **Peak Acceleration, CSR, Shear Stress**, etc.).

A second alternative is to use the options included in the **Earthquake Response Analysis** form (see Figure 6) by using either the **Create New EDT File** or the **Edit Existing EDT File** option in the **Main Menu** form. This form is mainly used to create a new working file for SHAKE2000, or to edit an existing file. You would first use the **Edit** command button to open different forms to enter/edit the data for each option that may be used for a SHAKE analysis. Then, use the **Add** button to select only those options you want to use in your analysis to create the input file, and the **SHAKE** button to perform the earthquake response analysis. After the analysis terminates, the **Process** button is used to obtain the most significant results from the output files. The results can be graphically presented by using the different **Plot Options**. This form does not include the options available in the **Main Menu** form to perform other seismic analyses.

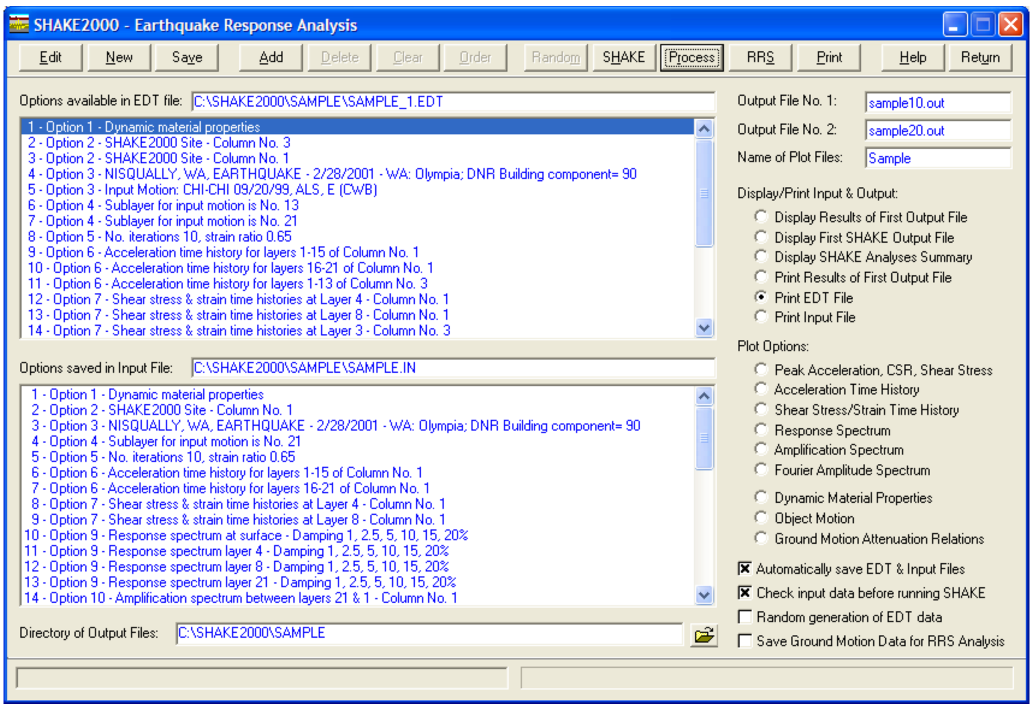


Figure 6: Earthquake Response Analysis form of SHAKE2000.

A third way SHAKE2000 can be applied as a tool in seismic analysis is to use any of the **Other Analyses** options in the **Main Menu** form (e.g. **Simplified Cyclic Stress Ratio Analysis (Seed & Idriss 1971)**) to perform other seismic analyses, or to provide the user with supporting data (e.g. **Ground Motion Prediction Equations**).

4.1 Problem Definition

SHAKE is a FORTRAN computer program originally developed based upon a batch-file format, i.e. a sequential series of options saved in an ASCII (i.e. text) input file control the operation of the program. Each option is formed by a number of “formatted” values, i.e. the values should be between specific columns. This was a major drawback in the execution of SHAKE because either a misplaced value could crash the program, or the program could yield erroneous results. This has been overcome with SHAKE2000, which includes user-friendly screens for each option that provide the user with a simple way of entering the data. SHAKE2000 automatically saves the values in their expected “positions” in the input file.

In Geotechnical Earthquake Engineering practice, a model of the problem to be analyzed with SHAKE is widely known as a SHAKE Column. For convenience, we will adopt this term for use in this User's Manual.

In order to set up a SHAKE Column to run an analysis with SHAKE2000, four components of the problem must be specified:

1. A one-dimensional (i.e. 1-D) representation of the soil profile, further divided into layers.
2. Material properties for each layer of the SHAKE Column (e.g. G/G_{max} and Damping Ratio vs. strain curves, unit weight, thickness, etc.).
3. An acceleration time history representative of the design/analysis earthquake, and the location where the motion is assigned in the SHAKE Column.
4. Selection of the results needed from the analysis.

Each of the above components is represented in SHAKE2000 by one or more options. A short description of the options that can be used to perform a SHAKE analysis is provided below. For a more detailed explanation of each option, please refer to the following section of this manual.

The options incorporated into SHAKE and supported in SHAKE2000 are as follows:

Option	Description
1	dynamic soil properties
2	data for soil profile
3	input (object) motion
4	assignment of object motion to the top of a specified sublayer or to the corresponding outcrop
5	number of iterations specified & ratio of uniform strain to maximum strain
6	sublayers at top of which peak accelerations & time histories are computed and saved
7	sublayer at top of which time history of shear stress or strain is computed and saved
9	response spectrum
10	amplification spectrum
11	Fourier amplitudes

These options can be divided in two groups:

- Input Options that provide SHAKE with input data: Options 1, 2, 3, 4 and 5.
- Analysis Options that direct SHAKE to use the input data to analyze the problem: Options 6, 7, 9, 10 and 11.

To create a SHAKE Column, the user needs to first collect some preliminary information such as detailed subsurface profile information (e.g. geotechnical exploration), and to evaluate seismic information and select appropriate design earthquake events (e.g. seismic hazard analysis). The former will provide the user with information about soil layer distribution and thickness, soil types, groundwater level, depth to bedrock, unit weight, shear wave velocities, SPTs, fines content, etc. The latter will provide the user with: an estimate of the peak ground acceleration at the site; an estimation of a target response spectrum; the assessment of the earthquake magnitude associated with this peak ground acceleration; and, the selection of representative acceleration time histories whose response spectrum reasonably match the target response spectrum, or selection of ground motions recorded from similar earthquakes for similar sites at comparable distances, or artificial ground motions, etc.. More detailed information about these preliminary steps is beyond the scope of this User's Manual, and can be obtained from several references in geotechnical earthquake engineering.

Once the above information has been collected, the user can start creating an input file for SHAKE. The first step is to divide the soil profile into "layers". These layers do not necessarily need to match the different stratigraphic units in the soil profile. However, a layer should not be formed by two different "soil types". For example, a soil profile is shown in Figure 7 with a layering distribution for the SHAKE Column. Note that there are 4 main stratigraphic units (i.e. soft silt, medium dense sand, medium dense to dense silty sand, and very dense sand and gravel). Each stratigraphic unit has been subdivided in "layers" that represent each unit in the SHAKE Column (e.g. the Soft Silt unit is now represented in the SHAKE Column by layers number 1 and 2). In this manual, a stratigraphic unit could be a soil or another material such as layer of waste in a landfill. A maximum of 200 layers can be used in a SHAKE Column.

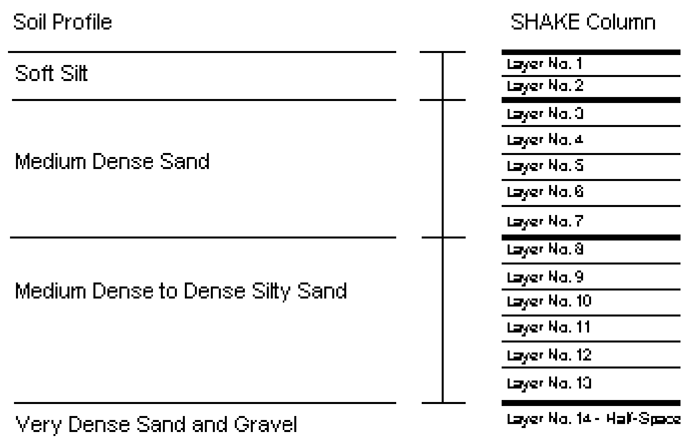


Figure 7: Example Soil Profile and SHAKE Column

The next step is the selection of dynamic material properties for each soil type. In SHAKE, the soil behavior under irregular cyclic loading is modeled by using modulus reduction (G/G_{max}) and damping (β) vs. strain curves. The data for these curves are entered in Option 1. Each curve is formed by up to 20 strain and G/G_{max} or β values. Information on curves for different materials has been published in different journals, and a few are included in the database of material properties provided with SHAKE2000.

These curves are entered sequentially in Option 1, and are assigned an index number based on the order they occupied in Option 1. For example, in option 1 of Figure 8 there are G/G_{max} and β curves for two materials: Sand and Rock. The Sand would be assigned an index number of 1 and the rock a 2. This indexing is used in option 2 to assign a set of curves to each layer in the SHAKE Column.

Following the selection of layers and dynamic material properties, the user needs to enter the specific data for each layer that form the SHAKE Column. This is done in Option 2. The data required for each layer include: the soil type which correspond to a set of G/G_{max} and β curves entered in Option 1above (e.g. if the layer in the SHAKE Column was part of a sand strata in the soil profile, and using the data in Option 1 shown in Figure 8, we will then assign a value of **1** for the soil type in this layer); the thickness of the layer; the maximum shear modulus (G_{max}) or the maximum shear wave velocity (V_s); an initial estimate of damping; and, the total unit weight of the material. For the calculation of G_{max}, SHAKE2000 includes several equations based on other input parameters (e.g. K_{2max}, N, q_c, etc.).

After the soil profile has been physically represented through options 1 and 2, the user needs to provide SHAKE with information about the ground motion to be applied to the SHAKE Column. This is done with options 3 and 4. Usually, the representative acceleration time history selected for the analysis is provided as a computer ASCII/text file. In option 3 the user enters data about this file such as maximum number of values (e.g. **3800** in Figure 8); path (e.g. directory in your hard disk where the file is saved, **sample** in Figure 8) and name of the file (**sample1.eq** in Figure 8); the way the values are read from the file (i.e. the format, for example **(8F9.6)** in Figure 8; also the ground motion file shown in Figure 9 has a format of 8F9.6, which means that the values are stored as 8 columns, or 8 values per line, each value formed by 9 figures, and of these 9 figures 6 form the decimal part of the value); number of header lines in the file (e.g. **1** in Figure 8, or **3** in Figure 9); and, the number of acceleration values per line in the file (e.g. **8** in Figure 8). Other information provided in Option 3 refers to the acceleration time history itself, such as the time interval between acceleration values (e.g. **0.01** in Figure 8); a multiplication factor for adjusting acceleration values (e.g. **1** in Figure 8) or the maximum acceleration to be used, i.e. the acceleration values read-in will be scaled to provide the maximum acceleration (in Figure 8 these columns were left blank); and, maximum frequency (i.e. frequency cut-off) to be used in the analysis (e.g. **15** in Figure 8).

```
SHAKE2000 Input File
Option 1 - Dynamic Soil Properties Set No. 1
    1
    2
    9    Sand S1     G/Gmax - S1 (SAND CP<1.0 KSC) 3/11 1988
    0.0001  0.000316     0.001   0.00316      0.01    0.0316       0.1     0.316
      1.00
      1.00     0.978     0.934     0.838     0.672     0.463     0.253      0.14
     0.057
    9    Sand        Damping for SAND, February 1971
    0.0001     0.001     0.003      0.01      0.03       0.1       0.3      1.00
     10.00
      1.00       1.6      3.12       5.8       9.5      15.4      20.9     25.00
     30.00
    8    Rock        G/Gmax - ROCK (Schnabel 1973)
    0.0001    0.0003     0.001     0.003      0.01      0.03       0.1      1.00
      1.00      1.00      0.99      0.95       0.9      0.81     0.725      0.55
    5    Rock        Damping for ROCK (Schnabel 1973)
    0.0001     0.001      0.01       0.1      1.00
       0.4       0.8       1.5      3.00       4.6
    2    1    2
Option 2 - SHAKE2000 Site - Column No. 1
    2
    1   10      SHAKE2000 Site - Column No. 1
    1    1      5.5       753.0     0.05      0.13
    2    1      3.3       890.0     0.05      0.13
    3    1      3.3       858.0     0.05      0.13
    4    1      3.3       945.0     0.05      0.13
    5    1      3.3       1146.0    0.05      0.13
    6    1      3.3       1470.0    0.05      0.13
    7    1      3.3       1683.0    0.05      0.13
    8    1      3.3       1737.0    0.05      0.13
    9    1      3.3       1867.0    0.05      0.13
   10    2                          0.05      0.15      2500.0
Option 3 - Input motion SAMPLE1.EQ
    3
 3800 4096      0.01     (8F9.6)
c:\shake2000\sample\sample1.eq
         1                  15    1    8
Option 4 - Sublayer for input motion is No. 10
    4
   10    1
Option 5 - No. iterations 10, strain ratio 0.65
    5
        10      0.65
Option 6 - Acceleration time history for layers 1-10 of Column No. 1
    6
    1    2    3    4    5    6    7    8    9   10
    0    1    1    1    1    1    1    1    1    1
    1    0    0    1    0    0    0    1    0    0
Option 7 - Shear stress & strain time histories at Layer 4 - Column No. 1
    7
    4    0    1      2048          SHAKE2000 Site - Column No. 1
    4    1    1      2048          SHAKE2000 Site - Column No. 1
Option 9 - Response spectrum at surface - Damping 1, 2.5, 5, 10, 15, 20%
    9
    1    0
    6    0      32.2
      0.01     0.025      0.05       0.1      0.15       0.2
Option 10 - Amplification spectrum between layers 10 & 1 - Column No. 1
   10
   10    1    1    0     0.125         Surface/half-space
Option 11 - Fourier spectrum for layers 1 & 10 of Column No. 1
   11
    1    0    2    3 2048
   10    1    2    3 2048
Execution will stop when program encounters 0
    0
```

Figure 8: Sample Input File for SHAKE

```
LOMA PRIETA EARTHQUAKE, LOS GATOS 10/18/89 - 90 degree - Near Fault Rock; PEER Ground Motion
LGPC       V   Loma Prieta Eqk,17 Oct 89, 37 01.32E, 122 00.61W,UCSC Station
No. Points: 5008    Time Step: 0.005 sec
-0.000029-0.000492-0.000793-0.000934-0.000959-0.000922-0.000866-0.000819
-0.000791-0.000782-0.000785-0.000794-0.000801-0.000804-0.000803-0.000798
-0.000792-0.000785-0.000779-0.000775-0.000771-0.000768-0.000765-0.000763
……………..
……………….
-0.033553-0.033664-0.033882-0.033816-0.032826-0.030158-0.025254-0.018188
-0.010279 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
```

Figure 9: Sample of a Ground Motion File

In Option 4 this motion is assigned at the top of a sublayer (e.g., **layer 10** in Figure 8), and is input as either a rock outcrop or at the bedrock-soil interface at the base of the SHAKE Column (e.g., bedrock-soil interface using a code of **1** in Figure 8).

The last of the Input Options is Option 5. As noted before, SHAKE uses an iterative procedure to calculate the shear moduli and damping corresponding to the computed shear strains. This process ends when the maximum number of iterations is reached or when convergence between the estimated and computed strain amplitudes occurs. Accordingly, the user enters a value for the maximum number of iterations (e.g. **10** in Figure 8). The other parameter entered in option 5 is the ratio between the effective and maximum strain (e.g. **0.65** in Figure 8). In each iteration, the strains used to obtain new values of strain-dependent modulus and damping ratio are a fraction of the peak strain computed from the previous iteration. From this option, results for maximum strain and maximum stress at the mid-point are obtained for each layer.

After the Input Options are created, you can use the Analysis Options to conduct a seismic site response analysis of the SHAKE Column. With these options you can obtain peak acceleration values and acceleration time histories at the top of specific layers (option 6), shear stress/strain time histories at the top of a layer (option 7), response spectra at the top of specific layers, amplification spectrum between any two layers (option 10), and Fourier spectrum at specific layers (option 11).

In option 6 the user first enters the number of the layers at which peak acceleration values and acceleration time histories are to be computed (e.g. **1 2 3 . …. 10** in Figure 8). Next, for each layer in the first row, a code describing the layer as an outcrop, or as within the soil profile, is entered in the second row (e.g. **0 1 1 ….. 1** in Figure 8). Then, in the last row you enter for each layer in the first row a **1** (one) to indicate if an acceleration time history at the top of the layer is to be computed and saved in the output file, or a **0** (zero) otherwise (e.g. **1 0 0 1 …. 0** in Figure 8). It is recommended that you include every layer of the SHAKE Column in this option. When you have more than 15 layers, then additional sets of option 6 can be used to include the remaining layers in groups of up to 15 layers.

Option 7 is used to obtain time histories of shear stress or shear strain at the top of a specified layer. You need to enter the number of the layer (e.g. **4** in Figure 8), a code of 0 (zero) to compute the strain time history or 1 (one) to compute the stress time history (e.g. **0** in Figure 8), the number of values of the time history to be saved in the output file (e.g. **2048** in Figure 8), and a label or identification that describes the time history (e.g. **SHAKE2000 Site – Column No. 1** in Figure 8). You can use the second line to either obtain the other time history (e.g. in Figure 8 the first row the strain time history was selected, so in the second row the stress time history will be computed), or obtain the stress or strain time history for a different layer.

Response spectra at the top of specified layers are obtained with Option 9. For this option, you need to enter first the layer at which the spectra are to be computed (e.g. **1** for the surface layer in Figure 8), then a code that defines the layer as an outcrop or within the soil profile (e.g. **0** in Figure 8 to define the layer as an outcrop). Then, enter the value for the acceleration of gravity (e.g. **32.2** in Figure 8), and finally the values of damping ratio for which spectra are to be computed (e.g. **0.01 0.025 …. 0.2** in Figure 8). In SHAKE2000, you don't need to enter the number of damping ratios used in the analysis. This number is changed automatically every time you enter or delete a value of damping ratio.

The next to last option is Option 10. This option is used to compute the amplification spectrum between any two layers. This spectrum is the ratio of the amplitude of motion at the top of the second layer divided by that at the top of the first layer. First, enter the data for the lower layer (e.g. **10** in Figure 8), a code to define the layer as outcrop or within (e.g. **1** in Figure 8 to define layer 10 as within), the number of the upper layer (e.g. **1** in Figure 8), an outcrop/within code for this layer (e.g. **0** in Figure 8 to define layer 1 as an outcrop), the frequency step for which the spectrum is calculated for 200 frequencies using this frequency step and starting with 0 (e.g. **0.125** in Figure 8), and finally a description of the spectrum (e.g. **Surface/half-space** in Figure 8).

The last option in SHAKE2000 is Option 11, Fourier Spectrum of motion in any specified layer. First, enter the number of the layer (e.g. **1** for the surface layer in Figure 8); then an outcrop/within code (e.g. **0** in Figure 8 to define the first layer as an outcrop); next a code of **2** to save the computed spectrum in the output file; then the number of times the spectrum is to be smoothed (e.g. **3** in Figure 8); and last, the number of values to be saved up to a maximum of **2048**. In this option, it is necessary that you enter information for two layers. Thus, provide data for a second layer on the second line of the form, or repeat the data for the first layer.

In short, to create an input file for SHAKE2000 you need to enter data for options 1, 2, 3, 4, and 5; and then select which analysis you want to conduct by entering data for options 6, 7, 9, 10 and/or 11. Then the options are saved, preferably in sequential order, to an input file that will be read by SHAKE. Note that all the options can be used as often as desired, to this end, SHAKE2000 allows you to create several sets of each option, up to a total of 32,000 sets for all of the options combined. In this way, you can create a database of options that you can later use to select from when creating the input file.

4.2 Options for SHAKE - Required Input Data

Following is a description of the operations performed by the different options, the required format for the input data, and explanations of some of the input parameters.

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

For example, in order to compute new motions in a soil deposit (Option 6), object motion (Option 3), soil profile data (Option 2), specification of location of object motion (Option 4), dynamic soil property-strain relation (Option 1), and strain iterations (Option 5 - if strain compatible properties are desired), must precede Option 6. Soil response for a new (additional) soil deposit may be obtained by repeating Options 2, 4, 5, and 6. The last-read soil deposit may be subjected to a new earthquake by repeating Options 3, 5 and 6.

A sample input file was shown in Figure 8, and will be used to further clarify the data in each option. For clarity, a few of the corresponding lines of data for each option are shown in bold-italic font. When the word ***`(blank)`*** is included in the data lines shown in the option description, it only means that one of two choices was selected, and that no value was included for the other choice. Please note that the column numbers are shown only for reference, and to help track errors that may exist in older input files that have not been created with SHAKE2000. Although the values in the input file need to be within specific column numbers, the user does not need to worry about the formatting because SHAKE2000 will take care of it.

As can be seen in Figure 8, each option starts with the following two lines:

Line No. 1	
columns 1 – 80	Identification information for this option (this line cannot be blank)
Line No. 2	
columns 1 – 5	Option Number

Specific information for each option is provided in the following. Most of the descriptions for each option have been taken literally from the SHAKE and SHAKE91 User Manuals, and other short course notes. However, Option 3 has been modified for SHAKE2000. Most options are also followed by a number of notes that describe in better detail some of the data. These notes are also taken from the SHAKE and SHAKE91 manuals and short course notes.

Option 1 - Dynamic Soil Properties

Figure 8:

```
Option 1 - Dynamic Soil Properties Set No. 1
    1
```

- first line after option number
columns 1 – 5 Number of materials included (maximum is 13)

Figure 8:

```
   2
```

then, for each material, the following input should be supplied:

first line
columns 1 – 5 number of strain values to be read (maximum is 20)
columns 6 – 71 identification for this set of modulus reduction values (see Note 1.1)

Figure 8:

```
    9    Sand S1     G/Gmax - S1 (SAND CP<1.0 KSC) 3/11 1988
```

second & consecutive lines
columns 1 – 80 strain values, in percent, beginning with the lowest value. Eight entries per line using consecutive lines (maximum is 20)

Figure 8:

```
   0.0001  0.000316     0.001   0.00316      0.01    0.0316       0.1     0.316
     1.00
```

columns 1 – 80 values of modulus reduction (G/G_{max}) each corresponding to the shear strain provided in the previous lines; these values should be in decimal not in percent.

Figure 8:

```
     1.00     0.978     0.934     0.838     0.672     0.463     0.253      0.14
    0.057
```

The second set for the same material will consist of identical information except that values of damping (in percent) are provided as illustrated.

Figure 8:

```
   9    Sand        Damping for SAND, February 1971
   0.0001     0.001     0.003      0.01      0.03       0.1       0.3      1.00
    10.00
     1.00       1.6      3.12       5.8       9.5      15.4      20.9     25.00
    30.00
```

After the last material set is completed, the following information is to be provided (Format: 16I5):
columns 1 – 5 number of materials to be used in this analysis
columns 6 – 10 first material number which will be used
columns 11 – 15 second material number to be used
. ...
. ... etc. until all materials are identified.

Figure 8:

```
    2     1     2
```

Values of G/G_{max} and β versus strain for these N materials will then be saved in output file No. 1. This feature was added for the convenience of the user who can include up to 13 sets of material properties in the input file but for any one analysis uses fewer than 13. This feature also provides a check that the intended material properties were utilized in the analysis.

Note 1.1: In SHAKE2000, you can enter a 12 character-long description of the material. This description will be saved at the beginning of the identification for the material (ID(L,I) above), but will be used by SHAKE2000 when displaying the table of results after processing the first output file. For example, in the description for the shear modulus curve, ***Sand S1*** will be entered in the material name field, and the ***G/Gmax - S1 (SAND CP<1.0 KSC) 3/11 1988*** in the material description field.

Option 2 - Soil Profile

Figure 8:

```
Option 2 - SHAKE2000 Site - Column No. 1
    2
```

- first line after option number

columns 1 – 5	soil deposit number; may be left blank
columns 6 – 10	number of sublayers, including the half-space (see Note 2.1)
columns 16 – 51	identification for soil profile

Figure 8:

```
    1    10      SHAKE2000 Site - Column No. 1
```

- second and subsequent lines; one line for each sublayer, including the half-space

columns 1 – 5	sublayer number
columns 6 – 10	soil type (corresponding to numbers assigned to each material in Option 1). [Note that if this material type is given as 0 (zero) for all sublayers, then the calculations are conducted for only one iteration using the properties (modulus, or shear wave velocity, and damping) specified in this input].
columns 16 – 25	thickness of sublayer, in feet or meters
columns 26 – 35	maximum shear modulus for the sublayer, in ksf or kN/m^2 (leave blank if maximum shear wave velocity for the sublayer is given)
columns 36 – 45	initial estimate of damping (decimal, see Note 2.2)
columns 46 – 55	total unit weight, in kcf or kN/m^3
columns 56 – 65	maximum shear wave velocity for the sublayer, in ft/sec or m/sec (leave blank if maximum shear modulus for the sublayer is given)

Figure 8:

```
    1     1     5.5        753.0      0.05       0.13       (blank)
    2     1     3.3        890.0      0.05       0.13       (blank)
.........
   10     2              (blank)      0.05       0.15       2500.0
```

For the half-space no thickness should be specified, thus there is not a value in the third column for layer number 10 above, and the fourth column is also blank because a value for shear wave velocity was entered for layer 10 as shown in column seventh. A maximum of 200 layers can be defined for a SHAKE Column.

Note 2.1: With the wave propagation method, the responses can be computed in a homogeneous layer of any thickness. A soil deposit will, however, have varying properties no only due to the variation in the soil itself but also due to the differences in the strain-level induced during shaking. Since the soil deposit must be represented by a set of homogeneous layers, each with a constant value of modulus and damping, the thickness of each layer must be limited based on the variation in the soil properties. For a fairly uniform deposit, a sublayer thickness increasing from about 5’ at the surface to 50-200’ below 100’ depth should give sufficient accuracy. Accuracy may be checked by making a trial run and comparing results with a subsequent run where more layers and/or sublayers are used.

Note 2.2: The damping is in general used as initial value on the first iteration for the computation of strain-compatible properties, but it can also be used directly to compute the responses for the values given, by omitting Option 5 and by defining the soil type as 0. The results are not highly sensitive to errors in the damping ratio and values selected between 0.05 to 0.15 will usually give strain-compatible values with 2 to 3 iterations.

Option 3 - Input (Object) Motion

Figure 8:

```
Option 3 - Input motion SAMPLE1.EQ
    3
```

- first line after option number

columns 1 – 5	number, NV, of acceleration values to be read for input motion (see Notes 3.1 and 3.2)
columns 6 – 10	number, MA, of values for use in Fourier Transform; MA should be a power of 2 (typically, this number is 1024, 2048 or 4096). Note that MA should always be greater than NV. The following may be used as a guide: for NV I 800, MA can be 1024, for NV I 1800, MA can be 2048 and for NV <= 3800, MA can be 4096.
columns 11 – 20	time interval between acceleration values, in seconds (see Note 3.3)
columns 21 – 32	format for reading acceleration values

Figure 8:

```
 3800 4096      0.01      (8F9.6)
```

- second line after option number

columns 1 – 72	name and path of file for input (object) motion

Figure 8:

```
c:\shake2000\sample\sample1.eq
```

- third line after option number

columns 1 – 10	multiplication factor for adjusting acceleration values; use only if columns 11 – 20 are left blank, i.e. you don’t enter a maximum acceleration value.
columns 11 – 20	maximum acceleration to be used, in g's; the acceleration values read-in will be scaled to provide the maximum acceleration specified in these columns; leave columns 11 - 20 blank if a multiplication factor is specified in columns 1 - 10
columns 21 – 30	maximum frequency (i.e. frequency cut-off)to be used in the analysis (see Notes 3.4 and 3.5)
columns 31 – 35	number of header lines in file containing object motion
columns 36 – 40	number of acceleration values per line in file containing object motion (see Note 3.6)

Figure 8:

```
         1                    15    1    8
```

Note 3.1: The acceleration values between NV and MA are set equal to 0 in the program. Cyclic repetition of the motion is implied in the Fourier transform and a quiet zone of 0's or low values are necessary to avoid interference between the cycles. For most problems, a quiet zone of 2-4 seconds is adequate with longer time required for profiles deeper than about 250 ft and/or damping values less than about 5 percent. If the NV parameter is relatively close to (but less than) a particular power of 2, skip the next immediate power of 2 and use the following value. For instance, if NV = 4000, it would be better to use MA = 8192, instead of 4096, to insure that a proper “quiet zone” between successive trains of accelerograms develops. To insure that no interference between each record is occurring, you can check the acceleration ratio for the quiet zone listed in the Option 6 section of the output file. This ratio should be close to zero. If not, use a large power of 2. Make sure MA > NV + 200. SHAKE2000 will allow you to enter a maximum value of 16000.

Note 3.2: Users should also be aware that the FFT routine implemented in SHAKE may become unstable if the total number of time history data points is more than 4096. For this reason the maximum number limit should not be increased (error report about SHAKE91 posted by Dr. Farhang Ostadan at the NISEE web site at http://www.eerc.berkeley.edu).

Note 3.3: A change in the time interval will change the predominant period of the motion. If the time interval and predominant period of the original motion are ΔT_1 and T_1, respectively, a new predominant period T_2 is obtained by changing the time interval to:

$$\Delta T_2 = \left(\frac{T_2}{T_1}\right)\Delta T_1$$

Note 3.4: Frequencies above 10-15 cps carry a relatively small amount of the energy in the earthquake motions, and the amplitude of these frequencies can often be set equal to 0 without causing any significant change in the responses within a soil system. Table 1 shows the maximum accelerations and strains in the soil system used in the example run, section 6 of the original SHAKE manual, computed for the Pasadena motion with time interval of 0.02 seconds and a maximum frequency of 25 c/sec. Results are also shown for the same motion with all amplitudes above 5 c/sec set equal to 0. The difference in maximum acceleration was less than 6.5% and in maximum strains less than 0.7% in the two cases. The difference in response spectral values was less than 1% for periods above 0.2 sec and less than 10% for periods from 0.0 to 0.2 sec. In the computation of responses in deep soil systems from a motion given near the surface of the deposit, errors in the higher frequencies will be amplified and may cause erroneous results. To avoid this source of error, the amplitudes of all frequencies above 10-20 cps may be set equal to 0, since these frequencies generally are of little interest and do not affect the response. Several runs should be performed with different amounts of the higher frequencies removed to investigate the effect on the response and to ensure a stable solution. Removal of the higher frequencies in a motion has a smoothening effect on the acceleration time history as shown in Figure 10 for a segment of the Pasadena Motion. In this case the maximum acceleration for the modified and original motions were approximately equal, but the maximum accelerations may decrease or increase with the removal of the higher frequencies depending on the shape of the acceleration curve near the maximum value.

Table 1: Effect of the Higher Frequencies on the Maximum Accelerations and Strains (after Schnabel et al., 1972)

Depth	Maximum acceleration, g’s		Difference %	Maximum strain, %		Difference %
	f_{max} = 25 c/sec	5 c/sec		f_{max} = 25 c/sec	5 c/sec	
0	0.0971	0.0962	0.9			
				0.00725	0.00724	0.1
7	0.0958	0.0949	0.3			
				0.1292	0.1283	0.7
20	0.0600	0.0599	0.1			
				0.0391	0.0390	0.3
30	0.0553	0.0556	0.6			
				0.0287	0.0287	-
42	0.0508	0.0507	0.2			
				0.00982	0.00989	0.7
62	0.0470	0.0469	0.2			
				0.0505	0.0504	0.2
80	0.0319	0.0299	6.3			
				0.0349	0.0348	0.3
100	0.0239	0.0235	1.7			
				0.0320	0.0319	0.3
120	0.0178	0.0189	6.2			

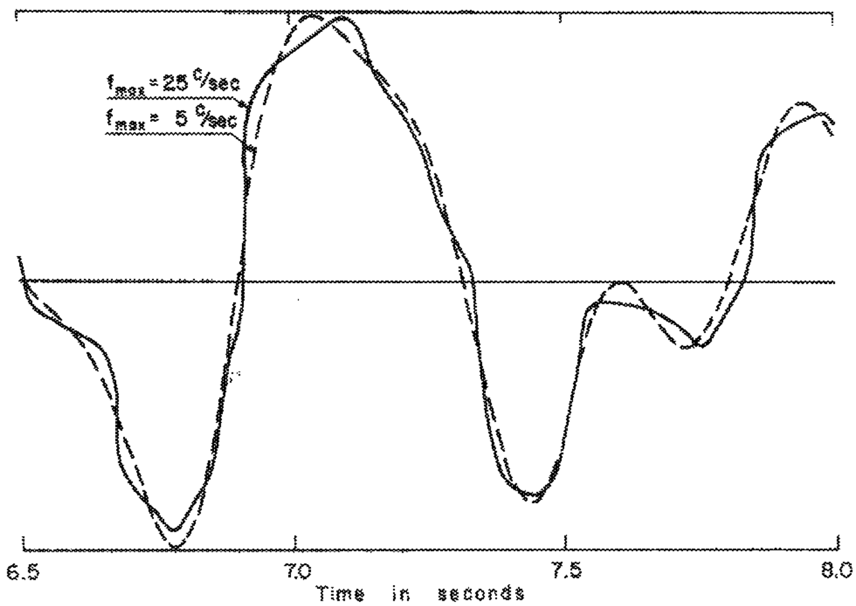


Figure 10: Effect of the higher frequencies on the acceleration time history (after Schnabel et al., 1972).

Note 3.5: The maximum frequency is chosen consistently with the time step, DT. The maximum frequency that can be analyzed is 1/(2 * DT). For example, if DT is 0.02 sec (which is commonly what many records have been digitized to), the maximum frequency, FMAX, would be 25 cps. It is usually ok not to include all of the high frequency motions (above say 20 cps or so) because they carry a relatively small portion of the total earthquake energy. In addition, the elimination of higher frequencies accounts for a shorter execution time. The manual illustrates this idea on Figure 5 of the original SHAKE manual (reproduced herein as Figure 10). FMAX = 20 cps is good for a 0.02 sec time step.

Note 3.6: *Please note that SHAKE91 permits the user to specify the format for the input time history. However, unless the time history points are arranged to have an even number of points per line, the input to the program will not be correct. For correct reading of the time history points, an even number of points should be given per line (i.e. 2, 4, 8, etc.).* (Error report about SHAKE91, posted by Dr. Farhang Ostadan at the NISEE web site at http://www.eerc.berkeley.edu).

Option 4 - Assignment of Object Motion to a Specific Sublayer

Figure 8:
```
Option 4 - Sublayer for input motion is No. 10
    4
```

- first line after option number
  columns 1 – 5 number of sublayer at the top of which the object motion is assigned
  columns 6 – 10 use 0 (zero) if the object motion is to be assigned as outcrop motion, otherwise use 1 (one) if the object motion is applied within the soil profile at the top of the assigned sublayer (see Note 4.1)

Figure 8:
```
   10     1
```

Note 4.1: Use 0 (zero) if the object motion is to be assigned as outcrop motion (refer to Section 2.2 of this manual for more information), otherwise use 1 (one) if the object motion is applied within the soil profile at the top of the assigned sublayer. Type of sublayer refers more to where the rock motion was recorded. Outcropping: motion was recorded on a rock outcrop. For motions recorded on rock WITHIN the soil profile or felt to represent the motion in the rock within the soil deposit. With a “1” the record will not be modified.

Option 5 - Number of Iterations & Ratio of Equivalent Uniform Strain to Maximum Strain

Figure 8:

```
Option 5 - No. iterations 10, strain ratio 0.65
    5
```

- first line after option number

columns 1 – 5	parameter used to specify whether the strain-compatible soil properties are saved after the final iteration; set = 1 if these properties are to be saved; otherwise leave columns 1 - 5 blank
columns 6- 10	number of iterations (see Note 5.1)
columns 11 – 20	ratio of equivalent uniform strain divided by maximum strain; typically, this ratio ranges from 0.4 to 0.75 depending on the input motion and which magnitude earthquake it is intended to represent. The following equation may be used to estimate this ratio:

$$ratio = \frac{M-1}{10}$$

in which M is the magnitude of the earthquake. Thus, for M = 5, the ratio would be 0.4, for M = 7.5, the ratio would be 0.65 ... etc. (see Note 5.2)

Figure 8:

```
        10       0.65
```

Note 5.1: The iterations stop when the specified maximum number of iterations (ITMAX) is reached or when the difference between the modulus and damping used and the strain-compatible modulus and damping values is less than the acceptable difference (ERR). Usually 3-5 iterations are sufficient to obtain an error of less than 5-10%. The values given as “new values” in the final iteration are used in all computations following Option 4, and the actual error is less than the error values given in the final iteration.

Note 5.2: The effective strain is used to compute new soil properties. The ratio between the effective and the maximum strain has been empirically found to be between 0.5 and 0.7. The responses, however, are not highly sensitive to this value and an estimate between 0.55 to 0.65 is usually adequate, with the higher value appropriate for giving more uniform strain histories.

Option 6 - Computation of Acceleration at Top of Specified Sublayers

Figure 8:

```
Option 6 - Acceleration time history for layers 1-10 of Column No. 1
    6
```

(Note that a maximum of fifteen sublayers can be specified at a time; if accelerations for more than 15 sublayers are desired, then Option 6 can be repeated as many times as needed).

- first line after option number

columns 1 – 75	array to indicate the numbers of the sublayers at the top of which the acceleration is to be calculated (one number every five columns)

Figure 8:

```
     1     2     3     4     5     6     7     8     9    10
```

- second line after option number

columns 1 – 75 — array to specify type of each sublayer: 0 (zero) for outcropping or 1 (one) for within the soil profile (one number every five columns, see Note 6.1)

Figure 8:

```
     0     1     1     1     1     1     1     1     1     1
```

- third line after option number

columns 1 – 75 — array to specify the mode of output for the computed accelerations: 0 (zero) if only maximum acceleration is desired or 1 (one) if both the maximum acceleration and the time history of acceleration are to be calculated and saved (one number every five columns)

Figure 8:

```
     1     0     0     1     0     0     0     1     0     0
```

Note 6.1: Refer to Section 2.2 of the SHAKE section on this manual for more information.

Option 7 - Computation of Shear Stress or Strain Time History at Top of Specified Sublayers

Figure 8:

```
Option 7 - Shear stress & strain time histories at Layer 4 - Column No. 1
     7
```

(Note that a maximum of two sublayers can be specified; if stress or strain time histories for more than two sublayers are desired, then Option 7 can be repeated as many times as needed).

- first line after option number

columns 1 – 5	number of sublayer
columns *6*- 10	set equal to 0 (zero) for strain or 1 (one) for stress
columns 11 – 15	set equal to one to save time history of strain or stress
columns 16 – 20	leave blank
columns 21 – 25	number of values to be saved; typically this should be equal to the number NV (see Option 3 above)
columns 26 – 35	leave blank
columns 36 – 65	identification information

Figure 8:

```
    4    0    1      2048           SHAKE2000 Site - Column No. 1
```

- second line after option number

same as the above line for the second sublayer

Figure 8:

```
    4    1    1      2048           SHAKE2000 Site - Column No. 1
```

Note that the time histories of shear stresses or strains are calculated at the top of the specified sublayer. Thus, if the time history is needed at a specific depth within the soil profile, that depth should be made the top of a sublayer. The time history of stresses or strains is saved in the second output file. This option should be specified after Option 6.

Option 9 - Response Spectrum

Figure 8:
```
Option 9 - Response spectrum at surface - Damping 1, 2.5, 5, 10, 15, 20%
    9
```

- first line after option number

columns 1 – 5	sublayer number
columns 6 – 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within

Figure 8:
```
    1    0
```

- second line after option number

columns 1 – 5	number of damping ratios to be used
columns 6 – 10	set equal to 0 (zero)
columns 11 – 20	acceleration of gravity: 32.2 ft/sec^2 for English units or 9.81 m/sec^2 for SI units.

Figure 8:
```
    6    0      32.2
```

- third line after option number

columns 1 – 60	array for damping ratios (in decimal, one value every 10 columns)

Figure 8:
```
      0.01     0.025      0.05       0.1      0.15       0.2
```

Note 9.1: *The acceleration response spectra computed by the internal routine of SHAKE occasionally may have larger discrepancies in the higher frequency range. Use with caution if high frequency response is critical to your project* (error report posted by Dr. Farhang Ostadan in the NISEE web site).

Option 10 - Amplification Spectrum

Figure 8:
```
Option 10 - Amplification spectrum between layers 10 & 1 - Column No. 1
   10
```

- first line after option number

columns 1 – 5	number of first sublayer
columns 6 – 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
columns 11 –15	number of second sublayer
columns 16 – 20	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
columns 21 – 30	frequency step (in cycles per second); the amplification spectrum is calculated for 200 frequencies using this frequency step and starting with 0
columns 31 – 78	identification information

Figure 8:
```
   10    1    1    0     0.125         Surface/half-space
```

[The amplification spectrum is the ratio of the amplitude of motion at the top of the second sublayer divided by that at the top of the first sublayer].

If the amplification spectrum is desired for two other sublayers, Option 10 can be repeated as many times as needed.

Option 11 - Fourier Spectrum

Figure 8:
```
Option 11 - Fourier spectrum for layers 1 & 10 of Column No. 1
   11
```

- first line after option number

columns 1 – 5	number of the sublayer
columns 6 – 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
columns 11 –15	set equal to 2 (two) if spectrum is to be saved to file
columns 16 – 20	number of times the spectrum is to be smoothed
columns 21 – 25	number of values to be saved

Figure 8:
```
    1    0    2    3 2048
```

A second line is always needed when using Option 11. Thus, the user should either provide a second line for another sublayer or repeat the information provided in the first line in a second line.

Figure 8:
```
   10    1    2    3 2048
```

The following expression (Schnabel et al., 1972) is used to smooth the Fourier spectrum:

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

in which A_i is the amplitude of the spectrum for the i^{th} frequency.

It may be noted that calculation of Fourier amplitudes for a specific accelerogram is best accomplished in an auxiliary program.

Program Termination:

- Execution will stop when program encounters zero (0)

Figure 8:
```
    0
```

4.3 SHAKE2000's EDT File

In this section, we will explain the main working file in SHAKE2000. This file is identified by the extension *.EDT. This file is a database file that stores the data for the different options for SHAKE2000. You can have several sets of data for each option, e.g., 8 sets of option 1 data, 6 sets of option 2, etc., up to a total of 32,000 for all of the options combined. Then, you select from this database those options that you want to use in the analysis and save them in an input file for SHAKE.

The difference between an *.EDT file and other files is that the options are saved sequentially, beginning with option 1, and so on. For example, an EDT file for SHAKE2000 could be composed by the options shown in Figure 11.

The purpose of the *.EDT file is to create a database of options. The SAMPLE.EDT file shown in Figure 11 contains 1 set of option 1 data, 2 sets of option 2 data, 4 sets of option 6 data, 6 sets of option 9 data, etc..

```
Option 1 -- Dynamic material properties
    :
Option 2 -- Soil profile with landfill included - Profile No. 1
    :
Option 2 -- Soil profile without landfill - Profile No. 2
    :
Option 3 -- Input motion: SAMPLE1.EQ
    :
Option 3 -- Input motion: SAMPLE2.EQ
    :
Option 4 -- Sublayer for input motion is No. 29
    :
Option 4 -- Sublayer for input motion is No. 25
    :
Option 6 -- Acceleration time history for layer: 6 - Profile No. 1
    :
Option 6 -- Acceleration time history for layer: 21 - Profile No. 1
    :
Option 6 -- Acceleration time history for layer: 15 - Profile No. 2
    :
Option 6 -- Acceleration time history for layer: 21 - Profile No. 2
    :
Option 7 -- Shear stress & strain time histories at Layer 6 - Profile No. 1
    :
Option 7 -- Shear stress & strain time histories at Layer 21 - Profile No. 1
    :
Option 7 -- Shear stress & strain time histories at Layer 2 - Profile No. 2
    :
Option 7 -- Shear stress & strain time histories at Layer 21 - Profile No. 2
    :
Option 9 -- Response spectrum at surface - Damping 1, 2.5, 5, 10, 15, 20%
    :
Option 9 -- Response spectrum layer 10 - Damping 1, 2.5, 5, 10, 15, 20%
    :
Option 9 -- Response spectrum layer 14 - Damping 1, 2.5, 5, 10, 15, 20%
    :
Option 9 -- Response spectrum layer 20 - Damping 1, 2.5, 5, 10, 15, 20%
    :
Option 9 -- Response spectrum layer 25 - Damping 1, 2.5, 5, 10, 15, 20%
    :
Option 9 -- Response spectrum layer 29 - Damping 1, 2.5, 5, 10, 15, 20%
    :
Option 10 -- Amplification spectrum between layers 29 & 1 - Profile No. 1
    :
Option 10 -- Amplification spectrum between layers 25 & 1 - Profile No. 2
    :
Option 11 --Fourier spectrum between layers 1 & 29 - Profile No. 1
    :
Option 11 -- Fourier spectrum between layers 1 & 25 - Profile No. 2
    :
Execution will stop when program encounters 0
    0
```

Figure 11: SAMPLE.EDT File for SHAKE2000

By selecting specific options from this database, you could create different input files for SHAKE2000. For example, you could create an input file, as shown on Figure 12, wherein the same soil profile is analyzed using two different object motions. Notice the difference in the way the options are ordered in Figures 11 and 12. The options in Figure 11 are ordered sequentially, beginning with option 1. Those on Figure 12 are ordered in a way that tells SHAKE to conduct two analyses for the same soil profile.

To create an *.EDT file, you have two options. First, you may start from scratch by choosing the **Create New EDT File** option from the main menu. Second, you can edit an existing file by choosing the **Edit Existing EDT File** option. The former will create a file with a set of each option, and use default values for each. You will have to enter your project's specific data for each option using the editing forms provided with SHAKE2000. The latter allows you to simply modify existing data without the need to retype data that is similar to each project, like the dynamic material properties.

```
Start of first   Option 1 - Dynamic material properties
analysis             :
                 Option 2 - Soil profile with landfill included - Profile No. 1
                     :
                 Option 3 - Input motion: SAMPLE1.EQ
                     :
                 Option 4 - Sublayer for input motion is No. 29
                     :
                 Option 5 - Number of Iterations & Strain Ratio Set No.  1
                     :
                 Option 6 - Acceleration time history for layer: 6 - Profile No. 1
                     :
                 Option 6 - Acceleration time history for layer: 21 - Profile No. 1
                     :
                 Option 7 - Shear stress & strain time histories at Layer 6 - Profile No. 1
                     :
                 Option 9 - Response spectrum at surface - Damping 1, 2.5, 5, 10, 15, 20%
                     :
                 Option 10 - Amplification spectrum between layers 29 & 1 - Profile No. 1
                     :
                 Option 11 - Fourier spectrum between layers 1 & 29 - Profile No. 1
                          :
Start of second  Option 2 - Soil profile with landfill included - Profile No. 1
analysis             :
                 Option 3 - Input motion: SAMPLE2.EQ
                     :
                 Option 4 - Sublayer for input motion is No. 29
                     :
                 Option 5 - Number of Iterations & Strain Ratio Set No.  1
                     :
                 Option 6 - Acceleration time history for layer: 6 - Profile No. 1
                     :
                 Option 6 - Acceleration time history for layer: 21 - Profile No. 1
                     :
                 Option 7 - Shear stress & strain time histories at Layer 6 - Profile No. 1
                     :
                 Option 9 - Response spectrum at surface - Damping 1, 2.5, 5, 10, 15, 20%
                     :
                 Option 10 - Amplification spectrum between layers 29 & 1 - Profile No. 1
                     :
                 Option 11 - Fourier spectrum between layers 1 & 29 - Profile No. 1
                     :
                 Execution will stop when program encounters 0
                     0
```

Figure 12: Sample input file.

Once you have edited the data for each option, you can create an input file for SHAKE. Choose which options you want to include in your file with the **Earthquake Response Analysis** form, as explained in the tutorial. Then, use the ***Save*** command button to save the options in the order you selected, e.g. as shown in Figure 12. To differentiate the input file from the database file, you should give it a different name and extension. The file does not need to have the EDT extension; however, by default, when using the **Edit Existing EDT File** option, SHAKE2000 will present you with a list of files that end with this extension.

4.4 Processing Output Files in SHAKE2000

During execution of the SHAKE analysis routine, two output files are created. The first file stores input data like material properties, soil profile data, etc., output results like strain compatible properties, peak acceleration, and response, amplification and Fourier spectrum data. The second output file stores acceleration and stress/strain time histories.

First, we will explain how SHAKE2000 processes the first output file created by SHAKE, and separates the results into data groups to create the graphics files. For example, with the data shown in Figure 12, you will conduct two different analyses for the same soil profile. For the first analysis, the SAMPLE.EQ object motion is used, and for the second analysis, a different object motion named SAMPLE2.EQ is used. When SHAKE2000 processes the first output file, it will assume that when the data for Option 1 are found then a new set of results will follow. This set of results will be named **Analysis**, and will have a number, beginning with 1 for the first set.

Referring to the data shown in Figure 12, SHAKE2000 will start processing the first output file, and will find the first group of Option 1 data. Thus, the results that follow (i.e. for options 2, 3, 4, 5, 6, 7, 9, 10 and 11) will be grouped under the name of **Analysis No. 1**. Information on the different options that form each analysis is saved in an ASCII text file, identified with the ***.ANZ** extension, in the same directory where the other output files are stored.

To further identify this data group, the set is given a **Soil Profile Identification** name, which is the identification for the soil profile entered in Option 2. For our example, it will be **Soil profile with landfill included - Profile No. 1**. It is also given a profile number, or **Soil Deposit No.**, which is the soil deposit number entered in Option 2. To complete the group identification, an **Earthquake** name, which is the name of the object motion file entered in Option 3, is included. Thus, for the first set of results, SHAKE2000 will include the following header in the graphics files:

Soil Profile Identification: Soil profile with landfill included - Profile No. 1
Soil Deposit No.: 1
Analysis No.: 1
Earthquake: SAMPLE\SAMPLE1.EQ

A similar procedure is used for the second group of results, or the one computed using the second object motion. SHAKE2000 will assume that this group starts with the second set of output data for Option 2. This second analysis will be identified by:

Soil Profile Identification: Soil profile with landfill included - Profile No. 1
Soil Deposit No.: 1
Analysis No.: 2
Earthquake: SAMPLE\SAMPLE2.EQ

SHAKE2000 would then process the two output files and save the results in a series of files that will be used with the plot options. The first file created, identified with the extension *.GRF, will contain results from options 5 and 6. Specifically, the layer number, depth to middle of layer, strain-compatible soil properties, maximum strain and maximum stress obtained after the last iteration of option 5, and, the maximum acceleration and depth to top of layer from option 6.

The next file, identified with the *.ACC extension, will save the acceleration time history computed for the layers, as specified in option 6. Stress/Strain time histories for layers, specified with option 7, will be stored in the file with the extension *.STR. Response spectrum data for specific layers and damping values, set through option 9, will be stored in the file with the extension *.SPC. The file with the extension *.AMP will store the data for the amplification spectra computed by option 10. Fourier amplitude spectrum data computed with option 11, are stored in the file with the extension *.FOU. All these files are ASCII text files, thus, they can be used with other software (e.g. Excel, 1-2-3, etc.), to plot the results.

You could process the second output file before you process the first file. However, some information that is obtained from processing the first file such as the project name, the time step, and the analysis number will not be known. Thus, when you process the second file first, this information will not be added to the *.ACC and *.STR files. Further, values of 0.02 and 1 will be assumed for the time step and soil deposit number, respectively.

4.5 Averaging Results

When you conduct more than one analysis, as explained above, you may obtain average curves for the results. For example, using the data in Figure 12, two analyses of the same soil profile were conducted using two different object motions. Accordingly, two sets of results were obtained and saved for further processing by SHAKE2000 in the graphics files. Now, you can use the results for each analysis and obtain, for example, an average curve for the maximum acceleration on each layer, as explained in the quick tutorial.

You can obtain average curves for the following results from option 5: Strain-Compatible Damping, Strain-Compatible Shear Modulus, Maximum Shear Strain, and Maximum Shear Stress; and from option 6, for the Maximum Acceleration. The average curve can be obtained only if the soil profile is the same for each analysis, i.e., the number of layers and the thickness of each layer is the same. A form will be displayed showing the different sets of results that may be used for averaging results. Each set will be identified, as explained on the previous page. Therefore, it is up to you to select which analyses you would like to use to obtain averages.

A similar procedure is used to obtain average response spectrum for a specific layer of the soil profile. For example, using the data in Figure 12, response spectra were obtained for layer 1 in each analysis. Thus, when choosing the option to obtain averages you will be given a menu that shows each set identified by the **Analysis** number, the soil deposit number as **Profile No.**, the **Soil Profile Identification**, and the **Earthquake** name as shown below. You can then select which analyses you would like to use for averaging the spectra.

Analysis No. 1 - Profile No. 1 - Soil profile with landfill included - sample\sample1.eq
Analysis No. 2 - Profile No. 1 - Soil profile with landfill included - sample\sample2.eq

A note of caution is due here. The above menu would show all of the analyses for which there is a response spectrum for the layer and damping ratio you selected. For example, if to the data in Figure 12 we added a third analyses for the soil profile itself, i.e., the landfill was not included, and option 9 was used to obtain response spectrum for layer 1, the menu for the average spectrum will show you three options:

Analysis No. 1 - Profile No. 1 - Soil profile with landfill included.
Analysis No. 2 - Profile No. 1 - Soil profile with landfill included.
Analysis No. 3 - Profile No. 1 - Soil profile.

Now, layer number 1 (e.g. ground surface) for analysis number 3 is not the same as layer 1 (e.g. top of landfill) for analyses 1 and 2. Thus, to obtain an average response spectrum for layer 1, you should only select the first two analyses.

4.6 Partial Seismic Hazard Analysis with SHAKE2000

A Seismic Hazard Analysis (SHA) is conducted to determine the ground motion parameters to be used for a seismic site response analysis. There are three main steps in a SHA: 1) identification of the seismic sources capable of strong ground motions at the project site; 2) evaluation of the seismic potential for each capable source; and 3) determination of the intensity of the design ground motions at the project site. This section will briefly explain how SHAKE2000 can be used in the third step. Further information on steps one and two is beyond the scope of this User's Manual.

Two ways of characterizing the intensity of the design ground motion, i.e. peak ground acceleration (PGA) and acceleration response spectra can be determined from:

1. Published codes and standards. In SHAKE2000, you can retrieve the Peak Ground Acceleration with 2%, or 5%, or 10% probability of exceedance in 50 years, from the files of gridded points used to make the USGS National Seismic Hazard Maps.
2. A deterministic SHA. A series of ground motion prediction equations are included in SHAKE2000 that can be used to evaluate the peak ground acceleration and the acceleration response spectrum.
3. A probabilistic SHA. A pre and post-processor for the computer program SEISRISK III is included with SHAKE2000. SEISRISK III is a computer program developed by the USGS, and is used to compute maximum ground motion levels that have a specified probability of not being exceeded during fixed time periods.

A third characterization of the intensity of the design ground motion, earthquake magnitude and distance is beyond the scope of this User's Manual.

After an appropriate PGA or spectrum has been selected, the next step is to select a representative time history to perform the seismic response analysis of the site. There are a few procedures used to select a representative time history. In the following, one of these will be briefly covered to demonstrate how SHAKE2000 can be used as a tool in the selection.

1. Select a record from an actual earthquake, or an artificially generated motion that closely matches a target response spectrum. The response spectrum for a ground motion can be computed with SHAKE2000, and compared to target spectra such as NEHRP, IBC, UBC, AASHTO, or from ground motion prediction equations.

The main objective in the development of SHAKE2000 is to add new features to SHAKE to transform it into an analysis tool for seismic analysis of soil deposits and earth structures. We expect that SHAKE2000 will have a dual role in geotechnical earthquake engineering. First, it will be used as a learning tool for students of geotechnical engineering. Second, it will serve practitioners of geotechnical earthquake engineering as a scoping tool to provide a first approximation of the dynamic response of a site. Depending upon the prediction of site response, the practitioner will judge whether more sophisticated dynamic modeling is warranted. To this end, Figure 13 shows a simplified flow chart for the solution of the seismic analysis of soil deposits and/or earthen structures. In the figure, we have noted those steps in the process for which a solution is available in SHAKE2000. We have also noted those steps for which a computerized solution can be included, or modified, in SHAKE2000.

5. Modifications to the SHAKE Source Code

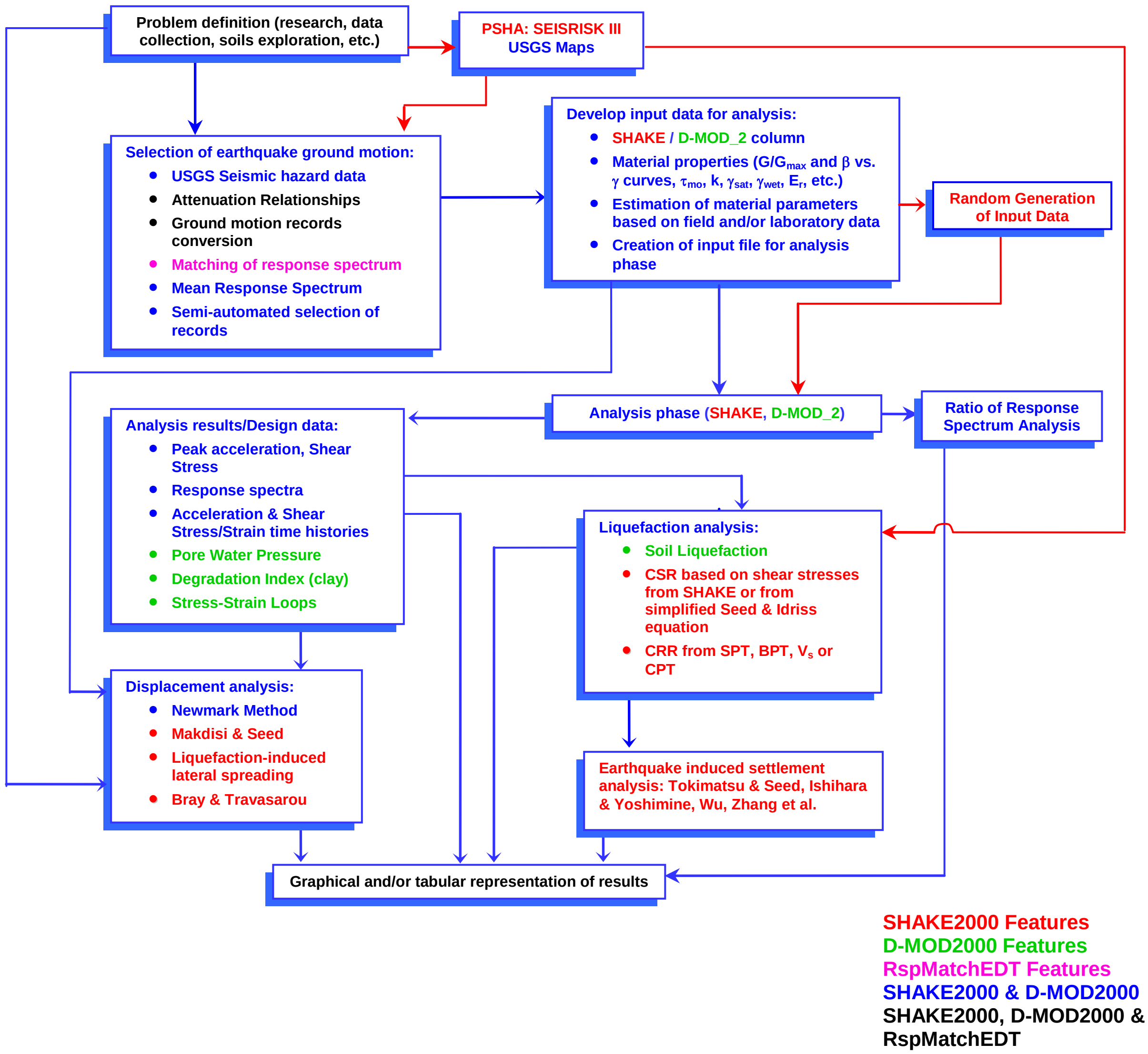
Idriss and Sun modified the SHAKE source code during the development of SHAKE91. The main modifications incorporated in SHAKE91 included the following:

- The number of sublayers was increased from 20 to 50.
- All built-in modulus reduction and damping relationships were removed. The user specifies up to 13 different relationships as part of the input data to the program.
- The maximum shear wave velocity or the maximum modulus is entered by the user.
- The object motion is read from a separate file.
- Other clean-up included: renumbering of options, elimination of infrequently used options, user specified periods for calculating spectral ordinates ... etc.

For the latest update of SHAKE, we have performed a number of modifications that were needed to improve the performance of the program and to better integrate SHAKE and ShakEdit. These include:

- The name and path of the input and output files used are passed to the SHAKE routine, thus, the user will no be longer asked to provide this information.
- Permit the overwriting of existing output files.
- Increase the number of points allowed in the earthquake time history.
- Modify the structure of Option 3 to accommodate file names and paths of up to 72 characters for the ground motion file.
- The commands to save the results of Options 2, 5 and 6 to the output file have been modified to increase the number of decimal figures that are printed.
- Increase the size of the string variable for the path to the ground motion file in Option 3.
- Error trapping that minimizes the likelihood of a fatal failure of SHAKE2000 due to an error during execution of the SHAKE routine.
- The number of layers was increased from 50 to 200.

The following flow diagram shows the most of the features included in SHAKE2000 and those also included in D-MOD2000 and RspMatchEDT and how they can be used together to conduct a seismic site response analysis.



It is important to point out that due to the newest modifications to the source code, the input files created with SHAKE2000 will not be compatible with previous versions of SHAKE. However, input files previously used for SHAKE91 can be used with SHAKE2000.

While advanced users and researchers prefer manipulation of the individual output files, the majority of the users prefer SHAKE2000 graphing options. The best way to learn these options (and the program) is to follow the step by step tutorial saved in the Manual folder.

If you require additional help with running the program, you may e-mail to:

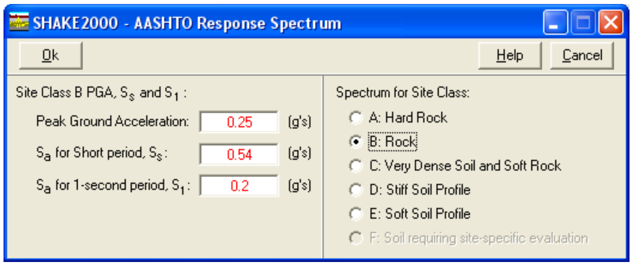
support@geomotions.com

It is recommended to attach the *.EDT file to any e-mails when requesting technical support. This will help us to identify the cause of any problems and/or to better understand the questions.

Free updates of the program can be downloaded from our web site at:

SHAKE2000 Program Forms

AASHTO Response Spectrum



This form is used to select the options and/or enter the data necessary to plot a response spectrum in accordance with AASHTO Guide Specifications for LRFD Seismic Bridge Design (FHWA, 2011).

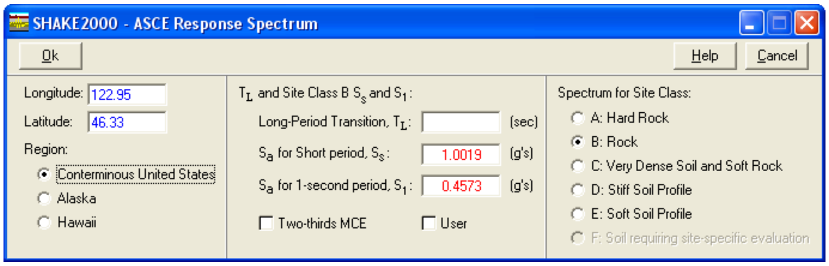
The procedure followed to obtain the spectrum starts by first entering spectral accelerations at short period, S_s, and at 1-second period, S_1; and peak ground acceleration values based on the ground Motion maps included with the guide specifications. These values are entered in the S_s, S_1 and Peak Ground Acceleration text boxes respectively.

Next, select the site class by choosing one of the **Site Class** options.

When obtaining a target response spectrum, click on the **Plot** command button to first create a plot of the spectrum, then close the graph form and click on **Ok** to return to the target spectrum form.

After you have entered the above input information, click on the **Ok** button to compute the spectrum and to return to the **Response Spectrum Plot Menu** form. If you click on the **Cancel** button, you will return to the plot menu form without modifying the input information if any had been selected previously.

ASCE Response Spectra



This form is used to select the options and/or enter the data necessary to plot a response spectrum in accordance with the 2010 ASCE approach (ASCE, 2010). The program can use the USGS online data; or, the user can enter the T_L, S_S and S_1 values manually.

If you want to use the USGS online data to obtain the spectral accelerations S_s and S_1, enter the coordinates of your site in the Longitude and Latitude text boxes. There is no need to enter a negative sign for the longitude value as required by the online USGS website. The spectral values for the four grid points that surround your site are retrieved from the files, and if necessary, the values interpolated between the four grid points. The S_s and S_1 values are displayed in their corresponding text boxes on the form.

To enter the values of S_s and S_1 manually, first click on the **User** check box to select it. Then, enter the value for S_s on the text box next to the **S_a for Short period, S_s** label; and, the value for S_1 on the text box next to the **S_a for 1-second period, S_1** label.

Then select one of the **Site Class** options.

The long-period transition period, T_L, needs to be entered in the **Long-Period Transition, T_L** text box.

By default the program will compute the MCE spectrum. If you need to use the design spectrum, click on the **Two-thirds MCE** check box to select it. When the spectrum is plotted, either the **2/3 MCE** or **MCE** word will be shown on the plot label to indicate which spectrum is being used.

Next, select the site class by choosing one of the **Site Class** options.

If the **User** option is not selected to manually enter the coefficients, the program will use the data provided by the USGS website at:

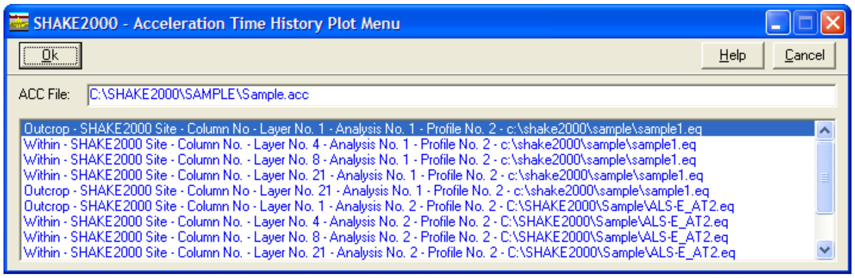
http://earthquake.usgs.gov/hazards/designmaps/usdesign.php

Alternatively, you can obtain the most-up-to-date parameters using the on-line application at:

http://earthquake.usgs.gov/designmaps/us/application.php

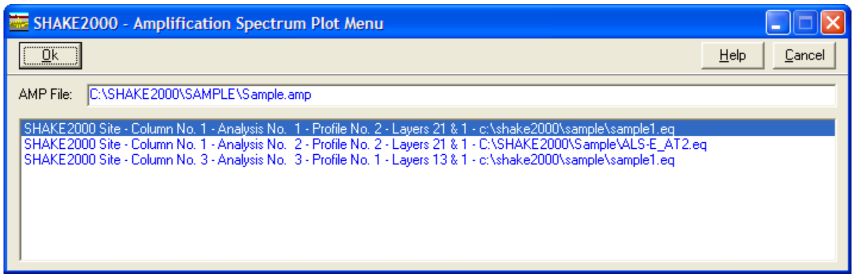
After you have entered the above input information, click on the **Ok** button to compute the spectrum and to return to the **Response Spectrum Plot Menu** form. If you click on the **Cancel** button, you will return to the plot menu form without modifying the input information if any had been selected previously.

Acceleration Time History Plot Menu



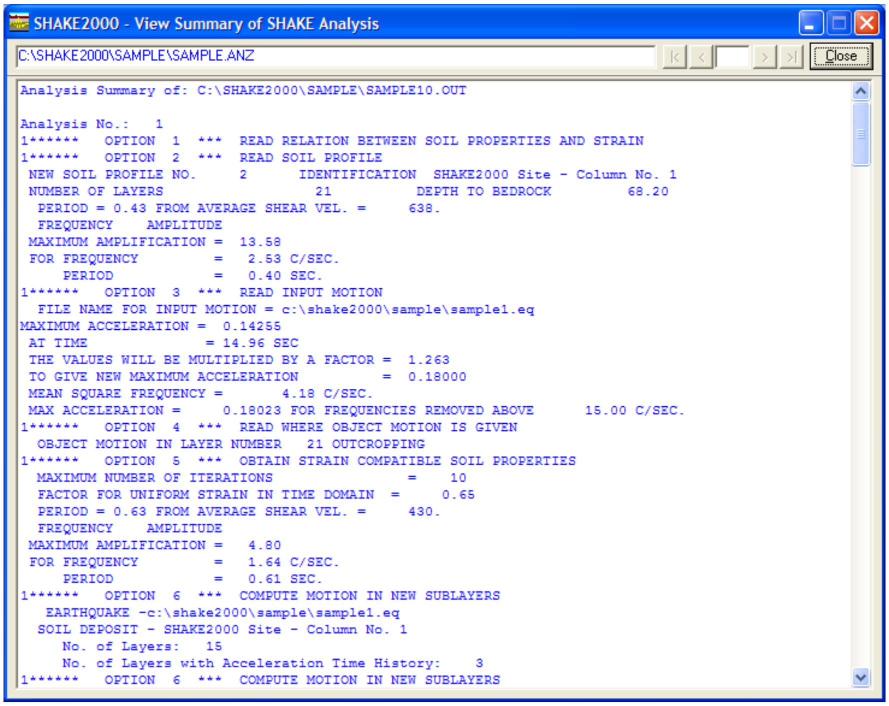
A list of the different acceleration time histories computed with Option 6 is displayed on this window. To select a history, click on it, and then click on the **Ok** button. Alternatively, you can double click on the history. The **Cancel** button is used to return to the graph window without choosing a history.

Amplification Spectrum Plot Menu



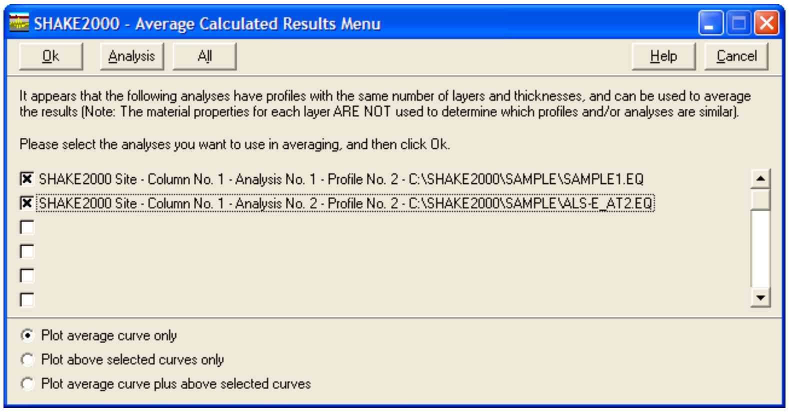
A list of the different plots is displayed on this window. To select a plot, click on it, and then click on the **Ok** button. Alternatively, you can double click on the plot. The **Cancel** button is used to return to the graph window without choosing a plot.

Analysis Summary



This form displays a summary of the different options included in each analysis and found in the first and second output files created by SHAKE. To return to the previous form, click on the **Close** button.

Average Calculated Results Menu



This form will display a list of sets of results that may be used to obtain average curves for damping, shear stress, shear strain, shear modulus, or peak acceleration. Each element on the list represents an analysis conducted with SHAKE2000 for which results were obtained with options 5 and 6. The label that SHAKE2000 uses to represent each element is formed by the identification for the soil profile and soil deposit number used in Option 2, and by an analysis number defined by SHAKE2000 based on the order that the results occupy on the first output file.

For example, the options displayed on this form would be something like:

Column No. 1 - Analysis No. 1 - Profile No. 2
Column No. 1 - Analysis No. 2 - Profile No. 2

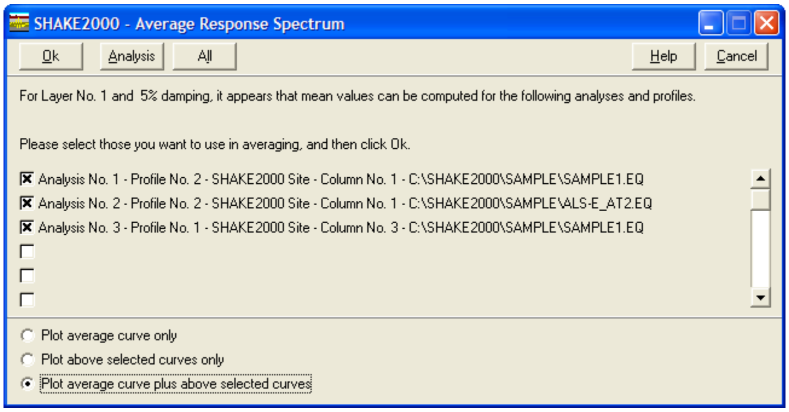
For analysis No.1, you used an object motion named SAMPLE1.EQ, and for analysis No. 2, an object motion named SAMPLE2.EQ. Thus, the results yielded by each analysis are different. You would select each analysis by clicking on the check box next to each element of the list. Then, select one of the options on the bottom section of the form. To plot the curves, click on the **Ok** button to display the graphics.

The **Analysis** button is used to display a summary list of the different options that form each analysis group. The results contained in the first and second output files generated from the execution of SHAKE2000 are grouped in sets, or analysis, depending on the order of the different options.

The **All** command button will select all of the plots available.

When plotting the PGA vs. Depth graph, the average options will be disabled if values of the incident PGA are included in any of the plots.

Average Response Spectrum



This form will display a list of sets of results that may be used to obtain average curves for response spectrum. Each element on the list represents an analysis conducted with SHAKE2000 for which results were obtained with option 9.

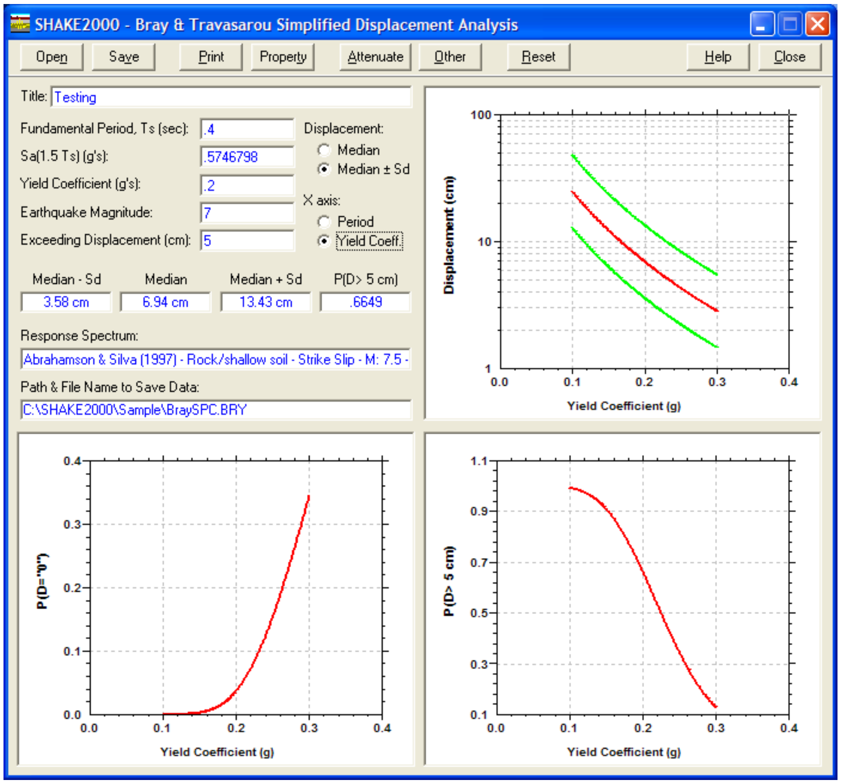
For example, the options displayed on this form would be something like:

Analysis No. 1 - Profile No. 2
Analysis No. 2 - Profile No. 2
Analysis No. 3 - Profile No. 1

For analysis No.1 you used an object motion named SAMPLE1.EQ, and for analysis No. 2, an object motion named SAMPLE2.EQ. Thus, the results yielded by each analysis are different. You would select each analysis by clicking on the check box next to each element of the list, and then select an option from the bottom section of the form. To plot the curves, click on the **Ok** button.

The **Analysis** button is used to display a summary list of the different options that form each analysis group. The results contained in the first and second output files generated from the execution of SHAKE2000 are grouped in sets, or analysis, depending on the order of the different options.

Bray & Travasarou Simplified Displacement Analysis



This form is used to estimate permanent displacements induced by earthquake loading using the simplified method proposed by Bray & Travasarou (2007).

The parameters for the model are entered in the respective text boxes. For more detailed information on the method and the parameters used, please refer to Bray & Travasarou (2007).

By default, the graphs on the form will display the results based on the yield coefficient. To switch to a period based graph, you will need to use a response spectrum using either a ground motion attenuation relation or a spectrum computed from an acceleration time history.

The **Attenuate** command button is used to display the **Ground Motion Prediction Equations** form. A response spectrum for an acceleration time history can be computed using the response spectra for ground motion form displayed using the **Other** command button.

When using a response spectrum, the spectral acceleration at 1.5 times T_s will be obtained from the spectrum and it cannot be manually modified by the user. Similarly, when using a spectrum from ground motion prediction equations, the earthquake magnitude will be set equal to the magnitude used in the attenuation relation and cannot be manually modified.

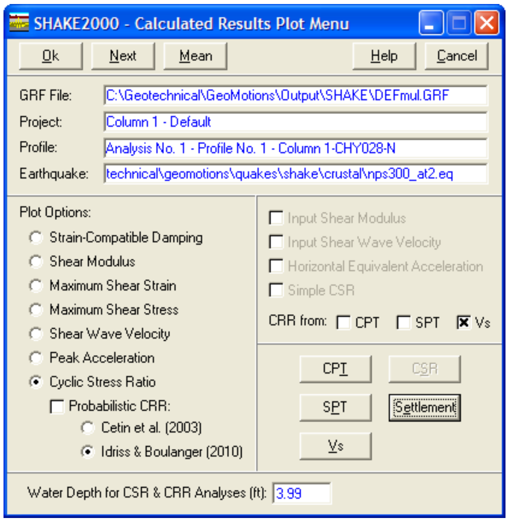
To switch between period or yield coefficient graphs, click on the respective option of the **X Axis** list.

To print a copy of the graphs, a summary of the input data and results or to copy the graph to the Windows Clipboard for use by other applications, click on the **Print** command button to display the **Print Menu** form.

The properties of a graph (e.g. symbol color, axis values, etc.) can be modified using the property pages of the graphics server. To display the property pages for a graph, first left-click on any point of the graph and then click on the **Property** command button.

The **Reset** command button will delete all the information on the form. The **Save** command button is used to save the data in a text file for future use. These data can be retrieved using the **Open** command button.

Calculated Results Plot Menu



The values for these options are stored in the *.GRF file. To choose a plot, place the cursor on the option and click the left button on the mouse. Click **Ok** to display the graph.

Options:

Strain-Compatible Damping: Select this option to plot strain-compatible damping at the midpoint of the sublayer versus Depth.

Shear Modulus: This option is used to plot the strain-compatible shear modulus at the midpoint of the sublayer versus depth. The **Input Shear Modulus** option can be used to plot the input values of shear modulus from option 2.

Maximum Shear Strain: Select this option to plot the calculated shear strain at the midpoint of the sublayer versus depth.

Maximum Shear Stress: A plot of maximum shear stress at the midpoint of the sublayer versus depth is displayed when this option is selected.

Shear Wave Velocity: The strain compatible shear wave velocity is plotted using this option. The **Input Shear Wave Velocity** option can be used to plot the input values of shear wave velocity from option 2.

Peak Acceleration: This option is used to plot the maximum acceleration at the top of the sublayer versus the depth. The **Horizontal Equivalent Acceleration** option can be used to plot the profile of horizontal equivalent acceleration together with the maximum acceleration profile. For more information on the horizontal equivalent acceleration, please refer to Bray et al (2005).

Cyclic Stress Ratio: Plot of the ratio between the equivalent uniform shear stress to the vertical effective stress (or CSR curve). The equivalent uniform shear stress is taken as 65% of the peak cyclic shear stress computed with SHAKE. When you select this option, the **SPT - BPT**, **CPT**, **Vs** and **CSR** command buttons are enabled. The depth to water table displayed is the value entered in Option 2 and is used to estimate the effective stress using the total unit weights from Option 2, and saved in the *.GRF file.

The **SPT – BPT**, **CPT** and **Vs** command buttons will display the respective **Cyclic Resistance Ratio using** form used to estimate the cyclic resistance ratio, or the capacity of the soil to resist liquefaction, based on standard or

Becker penetration test, cone penetration test, or shear wave data, respectively. Once you have calculated the CRR causing liquefaction using SPT or CPT data, the **CRR from SPT**, **CRR from CPT**, or **CRR from Vs** check box will be enabled and an **x** will appear in the box. This indicates that the CSR and CRR curves (i.e. the one computed using the shear stress from SHAKE and the one obtained based on SPT results) will be plotted together. If you do not want to plot the CRR curve, click on the check box to deselect it (i.e. the **x** will no longer appear in the check box).

The **CSR** command button is used to calculate the cyclic stress ratio using the simplified equation proposed by Seed and Idriss in 1971. Use this button to display the **Simplified Cyclic Stress Ratio** form. By default, SHAKE2000 will use the peak ground acceleration at the top of the soil column from Option 6, and the unit weights and depths from Option 2 for the current set to compute the CSR's. You can still add or delete data; however, the new data will not be used to modify the data in Option 2. After you enter data in this form, and upon returning to the **Calculated Results Plot Menu** form, the **Simple CSR** check box will be enabled, and an **x** will appear in the box. This indicates that the CSR curve calculated with the simplified equation will be plotted simultaneously with the CSR curve calculated using the SHAKE results. To conduct a separate simplified CSR analysis, use the **Simplified Cyclic Stress Ratio Analysis (Seed & Idriss 1971)** option of the **Main Menu** form.

Updated correlations for the evaluation of liquefaction using SPT data have been recently presented by Cetin et al. (1999) and Seed et al. (2001). This updated approach also includes a probabilistic evaluation of liquefaction. This alternative approach can be used to evaluate liquefaction potential by clicking on the **Probabilistic CRR** check box to select it. Further information on this approach is included in the **Probabilistic and Deterministic Liquefaction Analysis Using SPT** section of this manual. Two methods are available for probabilistic liquefaction analysis using SPT data: **Cetin** (Seed et al., 2003) and **I & B** (Idriss & Boulanger, 2010).

Settlement Analysis: The **Settlement** command button is enabled after you have performed the CRR analysis. This button will open the **Settlement Analysis** form used to enter the data necessary to estimate the settlement in the soil column due to earthquake shaking. The input data used in the liquefaction analysis (i.e. $N_{1,60}$, CSR) and the results (e.g. factor of safety against liquefaction) are used together with the equivalent uniform shear strain to do the settlement analysis. You can also perform a settlement analysis for a soil column of dry soil, however you still need to use the **Cyclic Resistance Ratio** form to enter the SPT data for the column, and make sure that the depth to the water table is greater than the depth to the bottom layer of the soil column.

To plot average results: For a specific profile, you can obtain average curves for the above options from the results of the SHAKE **analysis using the same soil profile (i.e. a profile with the same number of layers and each layer of the same thickness)**. For example, say that you want to obtain average curves for a profile number 1 that is formed by 29 layers. For the first analysis you will use the object motion saved as SAMPLE1.EQ. The input file will look like this for the first analysis:

1	Option 1
2	Option 2: profile No. 1
3	Option 3: SAMPLE1.EQ
4	Option 4: Object motion on layer 29
5	Option 5: 10 iterations, 0.65 strain ratio
6	Option 6
7	Option 7
8	Option 9: Spectra for 1, 2.5, 5, 10, 15, 20% damping.
9	Option 10:
10	Option 11:

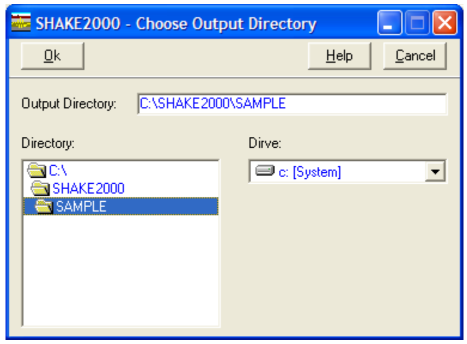
To obtain average results, you need to conduct a second analysis. Say that the second time you would like to use a different object motion that is saved as SAMPLE2.EQ. Then your input file, after including the options for the second analysis will look like:

1	Option 1
2	Option 2: profile No. 1
3	Option 3: SAMPLE1.EQ
4	Option 4: Object motion on layer 29

5	Option 5: 10 iterations, 0.65 strain ratio
6	Option 6
7	Option 7
8	Option 9: Spectra for 1, 2.5, 5, 10, 15, 20% damping.
9	Option 10:
10	Option 11:
11	Option 2: profile No.1
12	Option 3: SAMPLE2.EQ
13	Option 4: Object motion on layer 29
14	Option 5: 10 iterations, 0.65 strain ratio
15	Option 6
16	Option 7
17	Option 9: Spectra for 1, 2.5, 5, 10, 15, 20 damping.
18	Option 10:
19	Option 11:

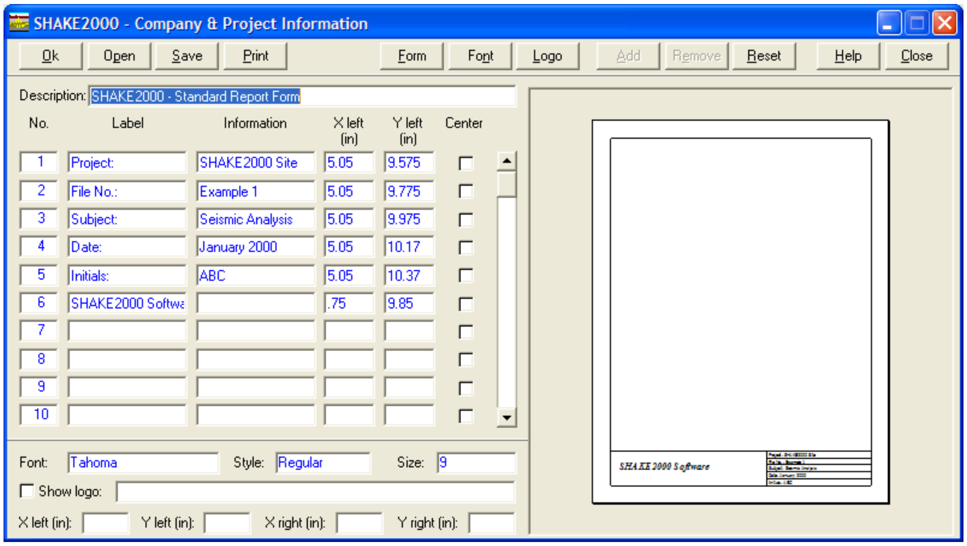
After executing SHAKE and processing the first output file, the *.GRF file will contain the results for profile No. 1 obtained from the two analyses. To plot an average curve, first you need to select one of the above options by clicking on the option button. Once you do this, the **Ok** and **Mean** command buttons will be enabled. Click on the **Mean** button to display the **Average Calculated Results Menu** form. The **Mean** command button is disabled when the **Cyclic Stress Ratio** option is selected.

Choose Output Directory



This form is used to select the directory where the output files generated by SHAKE2000 will be stored. There is a directory list box that shows the directories of the current drive, and a drive list box that can be used to change drives. Once you have selected a directory, click on the **Ok** button to return to the **Main Menu** or the **Earthquake Response Analysis** form. The output directory will be shown on the output directory cell.

Company & Project Information



This form is used to enter textual information about your company and/or project that will be printed together with your graph and form.

The information that can be entered on this form is divided into two groups: 1) information that is constant such as your company name, address, etc.; and, 2) information that changes from project to project such as project number, date, etc.

When you create your own forms, you can enter a description for the form on the text box next to the **Description** label. This description can be up to 80 characters long, and will not be shown on the form.

To enter information on the form, first type in information for the **Label** column. This label is expected to be constant, e.g. "Project No.:". Then enter the information that changes in the text box for the **Information** column, e.g. "99-1035". Then enter the X and Y coordinates where the text will be printed on the paper. The origin of coordinates, i.e. X = 0 & Y = 0, is the upper left corner of the paper sheet. The string of text formed by the information on the **Label** and **Information** columns will be printed starting at the point defined by X and Y. If you want to print the string centered at this point, then click on the check box of the **Center** column to select it (an **x** is shown on the check box when this option is selected). The string will be vertically centered with respect to the Y coordinate.

To change the font type, size, or style of a string, click on the **Font** command button to display the font dialog form. Select a different font, size, or style and then click on **Ok** to return to the form. The information for the string's font will be displayed on the **Font**, **Style**, and **Size** text boxes. Every time you move the cursor to a text box on the **Label** or **Information** columns, the characteristics of the font for the string will be displayed on the respective text boxes.

You can also display a logo on the page at a specific location. The position of the logo is determined by the coordinates for the upper-left and bottom-right corners of a rectangle as entered in the coordinate text boxes at the bottom of the form. This logo should be a bitmap, metafile or an icon type file. To select a logo, click on the **Logo** command button to display the file dialog window, select a file, and then click on the **Open** command button. Then, enter the coordinates for the box where in the logo will be displayed.

The example described in the following paragraph is for a letter size paper (8.5" x 11") and portrait orientation. To change paper type or orientation, click on the **Printer** command button to display the printer dialog window. For this example, first place the cursor on the text box next to the **Description** label. Type in a description for the information, e.g. “SHAKE2000 standard form”. Press the *Tab* key to move the cursor to the text box on the **Label** column for string No. 1, and enter **Project**. Next, press the *Tab* key twice to move the cursor to the text box on the **X left** column and enter 6.05. Press the *Tab* key once, and enter 9.575 on the **Y left** column. Note that the string is now shown on the bottom right corner of the form. Next, follow the same procedure to enter the following:

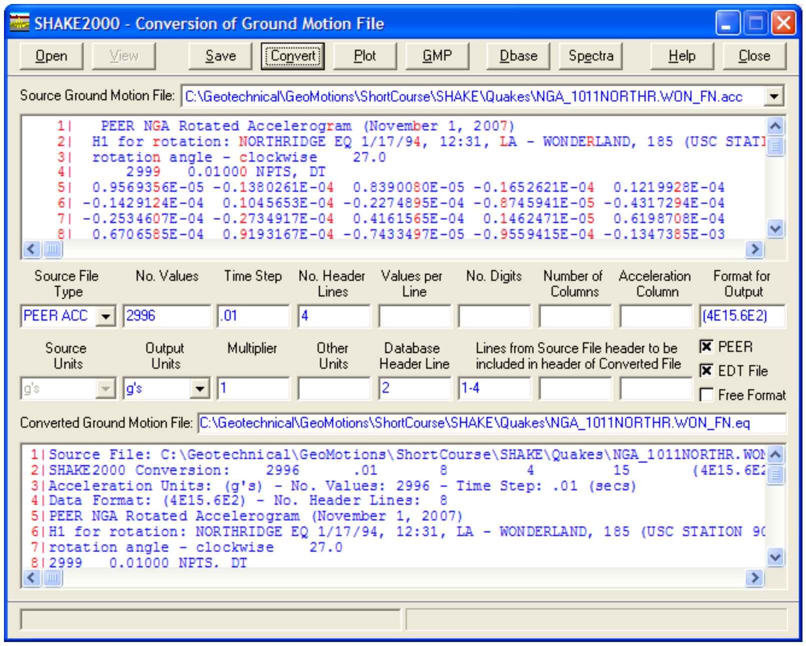
Label	X left	Y left
File No.:	6.05	9.775
Date:	6.05	9.975
Initials:	6.05	10.17

The coordinates in this example are such that the text will print on the bottom right corner of the form created in the example of the **Report Form Development** section of this manual.

After you have entered the information, click on the **Save** command button to save the data on an ASCII text file. The data can be retrieved for future use using the **Open** command button.

Each time you place the cursor on either the **Label** or **Information** columns the **Add** and **Delete** command buttons are enabled. If you want to add data for a new line, place the cursor on the line where the new line will be located, and click on the **Add** button. A new line will be created, and the coordinates and thickness for the new line will be the same as those for the line immediately below. Now, you need to modify the information for the coordinates and thickness for the new line. The **Delete** button is used to delete a line from the form. Place the cursor on either the **Label** or **Information** columns, and then click on the **Delete** button. The data for the line will be removed from the form, and the information for the other lines updated accordingly. The **Reset** command button will delete the information for all of the lines.

Conversion of Ground Motion File



This form is used to convert ground motion files to a format compatible with SHAKE; or to a format and units compatible with other software applications. The ground motion file used as input in SHAKE is usually formed by a series of acceleration values in g's saved in a formatted way that is compatible with the Format statement used in the FORTRAN programming language. Today, the user can obtain ground motion records from a wide number of sources. However, these files are not uniform in their formatting or processing. For example, ground motion files can be downloaded through the Internet that are saved in units other than g's such as cm/sec^2. Other records may include values for acceleration, velocity, and displacement in the same file, each as a column of data. Thus, the main purpose of this form is to extract the acceleration data from the file, convert them to g's and save them to a formatted text file that can be used by SHAKE.

This form has two other functions. First, it can be used to enter information about a new ground motion file and then add the information to the database of ground motion files used by SHAKE2000. Second, the user can access the form used to edit information about a ground motion file in the database.

Conversion of a ground motion file involves the following steps: 1) opening the original or source ground motion file; 2) defining the way the data in the source file are to be read; and, 3) defining the way the data will be written to the new converted ground motion file.

For the first step, use the **Open** command button to display the **Open Source Ground Motion File** dialog form, change to a different folder and/or subdirectory if necessary, and click on the file that needs to be converted to select it. This file needs to be a text or ASCII file. Then click on the **Open** command button of the dialog form to open it. After a few seconds, the first few lines of the file (up to 99 lines) will be displayed on the top list box of the form.

The first three characters displayed in red are the numbers of each row of data in the file followed by a "|". These characters are not part of the source file and are only shown to number the rows. After the row numbers, the alphanumeric characters that constitute the information saved in the file for each row are shown. Note that the characters are displayed as blue on a white background, and that every tenth character is displayed in red. However, if the tenth character is a "blank space" then the character is not shown. This is done to guide the user when defining the order of the data in the file.

During the second step, you need to define the way the data in the source file are to be read. To this end, there are seven options available in SHAKE2000: **Other**, **PEER**, **USGS**, ***.HEA file**, ***.AHL file**, ***.AVD file** and **RSPMATCH**, **PEER AT2** and **PEER ACC**. The first option is used to manually define the way the data are to be read. The **PEER** and **USGS** options are used to automatically convert files downloaded from the respective web sites; and, the ***.HEA file**, ***.AHL file** and ***.AVD file** options are used to convert specific files created by SHAKE2000. The **RSPMATCH** option is used to convert files created by the RSPMATCH program. To select one of these options, click on the down-arrow of the **Source File Type** list to display the list of options, and select the option that applies to your file.

The **PEER** option is used to convert files downloaded from the PEER Strong Motion Database at:

http://peer.berkeley.edu/smcat/search.html

The **PEER AT2** option is used to convert files downloaded from the PEER Strong Motion Databases at:

http://peer.berkeley.edu/nga/search.html
http://peer2.berkeley.edu/peer_ground_motion_database/site

The **PEER ACC** option is used to convert files downloaded from the PEER Ground Motion Database at:

http://peer2.berkeley.edu/peer_ground_motion_database/site

The **USGS** option is used to convert files created with the Interactive Deaggregation feature of the United States Geological Survey (USGS) web site at:

http://eqint.cr.usgs.gov/eq-men/html/deaggint2002-06.shtml

If necessary, the files downloaded from either web site, **PEER** or **USGS**, should be saved as Text files. This is done by first, selecting the **Save As…** option of the **File** menu in your web browser. Second, by selecting the **Text File (*.txt)** option of the **Save as type** option list.

The **PEER** and **EDT File** options work with the **PEER AT2** and **PEER ACC** options of the **Source File Type** list. When the **PEER** option is selected, you can select a number of AT2 or ACC files simultaneously. On the **Open Source Ground Motion File** dialog form, click on the first file and then press the shift key and click on the last file. All of the files between the first and last files will be selected. To select more than one file, but not in a continuous way, use the ctrl key instead. All of the files will be automatically converted. Selecting the **EDT File** option allows you to save the information about the converted files as Option 3 in an EDT file. You will be asked to enter the file name and select a path to create the file. After converting the files, click on the down arrow for the **Source Ground Motion File** list to select a file from the list to plot or to view the conversion results.

When using the **PEER** or **USGS** option, some basic information needed to read the source file is displayed on some of the text boxes. For PEER files, it is assumed that the first 4 lines in the file are the header, and that the acceleration values in the file are in g's. Further, the program will assume that the fourth line of the header section includes the number of acceleration values and the time interval between acceleration values. Hence, the program will use the value next to the NPTS= string for the number of acceleration values, and the value next to the DT= string for the time interval. For example, in the section of the ground motion file downloaded from the PEER website shown below, it is assumed that there are 11800 acceleration values and that the time interval is 0.005 seconds.

```
PEER STRONG MOTION DATABASE RECORD. PROCESSING BY PACIFIC ENGINEERING.
CHI-CHI 09/20/99, ALS, E (CWB)
ACCELERATION TIME HISTORY IN UNITS OF G. FILTER POINTS: HP=0.1 Hz LP=30.0 Hz
NPTS= 11800, DT= .00500 SEC
   .9029319E-05   .9034156E-05   .9026870E-05   .9016792E-05   .9034652E-05
```

If the formatting or the information in the file do not match these assumptions, then it is recommended to use the **Other** option as explained below.

The **USGS** option is similar to the **PEER** option in that specific information is searched to determine the number of acceleration values and the time interval. However, the USGS files do not have a fixed number of header lines. Accordingly, USGS files are first read to determine the number of header lines, and at the same time, determine the number of acceleration values and time interval. To this end, the program will first search for the "**npw2, dt, total duration =**" string. For example:

```
   npw2, dt, total duration =  16384 0.00500  81.9
```

When this string is found, it is assumed that the time interval is the second value, e.g. 0.005 sec for the string above. The program will then search for the "**Begin Scaled Accelerogram Data**" string and assume that the acceleration values start one line after this position. The program will count the number of lines of data until it finds the "**END OF AGRAM DATA**" string. It is also assumed that the acceleration values are in cm/sec^2 units. Once the number of header lines, acceleration values and time interval are determined, the program will proceed to convert the ground motion file.

Please note that the USGS files contain data for 6 seismograms. For example:

```
   am0, am0b_m0fa=   1.642E+25  0.000E+00
   npw2, dt, total duration =  16384 0.00500  81.9

  *** Begin Scaled Accelerogram Data ***
      T     A1(cm/s2)          A2          A3           A4           A5           A6
  0.0000   8.2623E-04  2.9951E-04  3.0377E-04  2.8430E-04 -3.0169E-04  4.7918E-04
```

In the above section of a USGS file, the first column corresponds to the time for the acceleration value, and the A1 through A6 columns each correspond to a different seismogram. By default, the program will read the acceleration values for the first column of acceleration data, i.e. the A1 column. If you wish to obtain the data for any of the other acceleration columns, change the value on the **Acceleration Column** text box as explained below.

The ***.AHL file** option is used to convert files with the AHL extension (for **A**cceleration **H**istory at **L**ayer), i.e. files created by SHAKE2000 from the same acceleration time histories requested in Option 6 of SHAKE. The ***.HEA file** option is used to convert files with the HEA extension (for **H**orizontal **E**quivalent **A**cceleration), i.e. files created by SHAKE2000 from the shear stress time histories requested in Option 7 of SHAKE. For more information about these files, refer to the **Earthquake Response Analysis** section of this manual. The ***.AVD file** option will convert files with the AVD extension (for **A**cceleration **V**elocity **D**isplacement), i.e. files created using the **Save to file** option of the **Plot Object Motion** form. In this last option, by default, the acceleration data in column 2 of the file will be converted. If you would like to use the baseline-corrected acceleration values instead, change the number in the **Acceleration Column** text box to **5**. For any other type of file, it is recommended to use the **Other** option.

The third option used to convert files is **Other**. With this option, you can choose one of two alternatives: 1) Free Format Data: The data are separated by blank spaces and can be read sequentially one after another or by using a specific sequence; or, 2) Formatted Data: The data can be obtained by reading a specific number of characters (with or without blank spaces) sequentially or by using a specific sequence. Please note that if the data are separated by characters other than blank spaces, such as "," or "tabs", then the data may not be read properly.

- **Free Format Data:** If the data are separated by at least one, or more blank spaces, then select the **Free Format** option. Next, enter the number of acceleration values that are to be read from the file in the text box below the **No. Values** label. Then, enter the time interval between acceleration values in the text box below the **Time Step** label. This value is used when plotting the converted motion and when adding the information about the source or converted files to the database. Usually the first few lines in the source file provide information about the motion such as earthquake magnitude, station, etc.; these lines are considered herein as the header lines. Also, this is the number of lines that need to be skipped before reaching the section of the file where the acceleration values are located. Enter the number of header lines in the text box below the **No. Header Lines** label.

If you selected the **Free Format** option, skip the next two text boxes and place the cursor on the text box below the **Number of Columns** label. When reading the acceleration values in free format, the values should be ordered in one of two ways. Either each row of data is formed only by values of acceleration; or, on each row of data, there are also other values. For the second type, each row of data may have a column for period, acceleration, velocity, and displacement. For example, in the section of the ground motion file below, each row of data is formed only by acceleration values. There are 10 values of acceleration (in cm/sec^2) in each row:

```
SAMPLES/SEC=100 FILTER TYPE=BUTTERWORTH  CORNER= 0.10 ORDER=3 DATA TYPE=AC
NO OF POINTS=  6228, UNITS=CM/SEC**2
-0.16   -0.16   -0.16   -0.16   -0.17   -0.18   -0.20   -0.20   -0.20   -0.22
-0.25   -0.27   -0.28   -0.27   -0.27   -0.29   -0.32   -0.35   -0.38   -0.39
```

If your source file is of the above type, skip the **Number of Columns** and **Acceleration Column** boxes, and place the cursor on the text box below the **Format** label. On the other hand, each row of data on the file below has one value for time, acceleration, velocity and displacement:

```
m0444r01  8.0 25.6  147.6   75.9   0.65
  sec      cm/sec**2   cm/sec      cm
  0.00   -0.1934E+00  0.0000E+00  0.0000E+00
  0.01   -0.1938E+00 -0.1900E-02  0.0000E+00
```

If the source file is of this second type, enter the total number of columns of data on each row. For example, for the above example you would enter a **4**. Next, place the cursor on the text box below the **Acceleration Column**. In this text box, you enter the number of the column that forms the acceleration value. In the above example this is the second column, thus you would enter a **2**. Then place the cursor on the **Format** text box.

- **Formatted Data:** If you did not select the **Free Format** option, then you need to provide either the number of values per row and the length as number of characters of the values; or, the number of data columns per row, the number of the column with the acceleration values and the length as number of characters of the columns.

  For the first alternative, you need to define the way the values are separated in each row by indicating the number of values per row and the number of characters that form each value. The number of characters should be the same for every value. For example:

  4 values per row, each value is 15 characters long including blank spaces and exponent:
```
 -.1059027E-04  -.1461820E-04  -.1690261E-04  -.1506594E-04
```

  8 values per row, each value is 9 characters long including blank spaces:
```
  0.00000 -0.00434  0.00860  0.00540 -0.00565 -0.00944 -0.00369 -0.00669
```
  8 values per row, each value is 9 characters long:
```
-0.000001-0.000002-0.000001-0.000001 0.000000 0.000001 0.000000-0.000001
```

  After you have entered the data for number of values, time step, and number of header lines, place the cursor on the text box below the **Values per Line** label, and enter the number of values that are included in each line of data (for the above examples: **4**, **8**, **8**, respectively). Next, place the cursor on the text box below the **No. Digits** label and enter the number of characters that form each value (for the above examples: **15**, **9**, **9**, respectively). Then enter the rest of the information as described previously.

For the second alternative, you need to provide the number of data columns on each row, the number of the acceleration column, and the number of characters that form each column. For example:

```
m0444r01  8.0 25.6  147.6   75.9   0.65
      sec      cm/sec**2   cm/sec      cm
      0.00   -0.1934E+00  0.0000E+00  0.0000E+00
      0.01   -0.1938E+00 -0.1900E-02  0.0000E+00
```

In the above section of a ground motion file, there are 4 columns of data per row (one each for time, acceleration, velocity and displacement), the second column is the acceleration value, and each value is 12 characters long including blank spaces and exponent. Thus, after entering data for number of values, time step, and number of header lines, place the cursor on the text box below the **No. Digits** label and enter the number of characters that form each value (e.g. **12**). Then, place the cursor on the text box below the **Number of Columns** label and enter the total number of columns of data on each row. For the above example, you would enter a **4**. Next, place the cursor on the text box below the **Acceleration Column**. In this text box, you enter the number of the column that forms the acceleration value. In the above example this is the second column, thus you would enter a **2**. To continue with the conversion of the file, enter the rest of the information as described previously.

In the third step, you will define how the data will be written to the converted file. First, define the format, i.e. the way the data are written to the file, of the acceleration values. The format string tells SHAKE2000 and SHAKE how to read the ground motion values from the file. This string is based on the syntax used in the Format statement of the FORTRAN computer language. In this statement edit descriptors specify how the values are read. In this feature of SHAKE2000 the only two edit descriptors supported by SHAKE2000 are:

F*w.d*	Real values
E*w.d* [E*e*]	Real values with exponents

In these descriptors, the field is ***w*** characters wide, with a fractional part ***d*** decimal digits wide, and an optional exponent width of ***e***. Remember that the field ***w*** also includes any blank spaces. You can also indicate that a given data format is repeated a number of times. For example, 8F9.6 repeats a nine-character real value with six decimal digits descriptor eight times. The first character on the format field should be a "**(**" and the last character a "**)**", e.g. (8F9.6). Examples of data saved in the ground motion files included with SHAKE2000 and the format used to define them follow:

Format: (4E15.8E2) or (4E15.8):
```
 -.10590270E-04 -.14618200E-04 -.16902610E-04 -.15065940E-04
```

Format: (8F9.5):
```
  0.00000 -0.00434  0.00860  0.00540 -0.00565 -0.00944 -0.00369 -0.00669
```

Format: (8F10.6):
```
 -0.000001 -0.000001 -0.000001 -0.000001  0.000000  0.000000  0.000000  0.000001
```

If you use the "E" descriptor and do not provide a value for exponent width, "e", SHAKE2000 will use a default value of 2. *Please note that SHAKE91 permits the user to specify the format for the input time history. However, unless the time history points are arranged to have an even number of points per line, the input to the program will not be correct. For correct reading of the time history points, an even number of points should be given per line (i.e. 2, 4, 8, etc.).* (Error report about SHAKE91, posted by Dr. Farhang Ostadan at the NISEE web site at http://www.eerc.berkeley.edu). In other words, the number of acceleration values in each row of a ground motion file used by SHAKE should be an even number.

In a few cases, and depending on the number of decimal figures used for the acceleration values in the converted file, the velocity or displacement time histories computed by double integration of the converted acceleration time history may not be correct, e.g. they may increase or decrease without bounds. Accordingly, it is recommended to use as many decimal figures as possible when converting the file. However, due to the nature of the programming language used to create SHAKE, the acceleration time history values are limited to a maximum of 8 decimal figures. Hence, it is recommended to use the default value of (8F12.8) for the **Format Output** string when creating the converted file. Using this formatting string on several examples appears to provide an adequate conversion that yields velocity/displacement time histories similar to those provided with the original, processed ground motion record.

Next, you need to select a factor to convert the acceleration values in the source file to units compatible with SHAKE, i.e. fractions of acceleration of gravity (g's), if necessary; or, to other units if you wish to use the converted data as input for another software application. This can be done by selecting a factor that represents the units of the acceleration data in the source file from the list of options shown on the **Source Units** list box; and, by selecting the units of the converted file from the list of options shown on the **Output Units** list. After selecting the units, a multiplication factor will be displayed on the **Multiplier** box. This is the multiplication factor that will be used to convert the values from the units shown on the **Source Units** list box to the units shown on the **Output Units** list box. For example, to convert values of acceleration from cm/sec^2 to g's, you need to divide each value by 980.665 cm/sec^2; which is equivalent to multiplying each value by 1/980.665 = 0.00102. In the program, this is done by selecting the **cm/sec^2** option of the **Source Units** list and the **g's** option of the **Output Units** list, respectively.

If the accelerations in the source file are in units that are not shown in the list, select the **Other** option of the **Source Units** list, and then enter a multiplication factor in the **Multiplier** text box. This multiplication factor should be appropriate to convert the source acceleration data to the units shown on the **Output Units** list. For example:

```
WESTERN WASHINGTON EARTHQUAKE   APR 13, 1949 - 1156 PST                 55
EPICENTER  47 06 00N,122 42 00W                                         31
INSTR PERIOD   0.0770 SEC  DAMPING   0.574                              42
NO. OF POINTS   1094  DURATION   89.16 SEC                              42
UNITS ARE SEC AND G/10.                                                 23
RMS ACCLN OF COMPLETE RECORD   0.2455 G/10.                             43
ACCELEROGRAM IS BAND-PASS FILTERED BETWEEN   0.070  AND  25.000  CYC/SEC
4454  INSTRUMENT AND BASELINE CORRECTED DATA
AT EQUALLY-SPACED INTERVALS OF   0.02   SEC.
PEAK ACCELERATION     161.63023  CMS/SEC/SEC AT  10.9400 SEC
-152        29       -51      -309      -364      -125       134       111        17
-176      -147       -49        86        88       -69      -103       -75       -65
-234      -176        27        86        26        42        26      -185      -181
```

The fifth line of the header section indicates that the units are seconds and G/10, and from the tenth line you can see that the acceleration values are given in cm/sec^2. Thus, to convert the values to g's, you need first to divide each value by 10, and then divide the result by 980.665. For example for the first value of -152:

$$\frac{\left(\frac{-152}{10}\right)}{980.665} = -0.015500$$

However, this is equivalent to multiplying each value by a factor of (1 / 9806.65) or 0.000102. Thus, you would enter a value of 0.000102 in the **Multiplier** text box.

If you select the **Other** option of the **Output Units** list, you can enter a description of the other units (e.g. *gals*) in the **Other Units** text box.

The **RSPMATCH** option of the **Output Units** list is used to convert files to a format compatible with the RSPMATCH computer program.

After selecting the multiplication factor, place the cursor on the text box below the **Database Header Line** label (or **Option 3 Set ID – Line** label, if converting a file for use in Option 3 of SHAKE). Here you would enter a value that represents the line from the header section that will be used to identify the converted file in the database of ground motion files or in the set identification of Option 3. For example, for the above record, you could use the first line to be included in the database, thus you would enter a **1**.

The last information needed before you convert the file is the number of the lines from the header section in the source file that you would like to include in the converted file. To do this, place the cursor on the first text box below the **Lines from Source Header to be included in Converted Ground Motion File** label. Here you can select a specific line, or select a range of lines. To select one line, just enter the number of the line in the text box. For example to select the first line from the source file enter a **1**.

To select a range of lines, enter the number of the first line in the range followed by a "**-**" and then the number of the last line in the range. For example, if you would like to select the first five lines of the header in the source file, you would enter **1-5** in the text box. There are 3 text boxes in this section that you can use to select different lines from the header section. By default, the first four lines in the header of the converted file will be created by SHAKE2000. The first line will include the name and path of the source file; and, the second line will include the units of the acceleration values, the number of acceleration values in the converted file (which may be slightly different from the original number in the source file), the time step of the acceleration time history, and the format string used to write the data to the file. These four lines will provide valuable information if the file is used with a different software application.

After you have entered the above information, you need to enter the name and path of the converted file. A default file name and path are shown on the box next to the **Converted Ground Motion File** label. If you would like to select a different file, first click on the **Save** command button to display the **Save Converted Ground Motion File** dialog form. Enter the name of the file on the text box next to the **File name** label, or use the mouse to select a file by highlighting it. Then click on the **Save** command button to return to the conversion form. Now, click on the **Convert** command button to convert the source file to the units and format you selected. After a few seconds, the first few lines (up to 99) of the converted file will be shown on the bottom list box.

After you have converted the file, you can plot the resulting motion using the **Plot** command button. You can also add the information about this motion in the database of ground motions using the **Dbase** command button. Refer to the **Edit/Add Ground Motion File Information** section of this manual for further information.

The **Spectra** command button is used to display the **Response Spectra for Ground Motion** form. This form can be used to compute the response spectra for the converted ground motion.

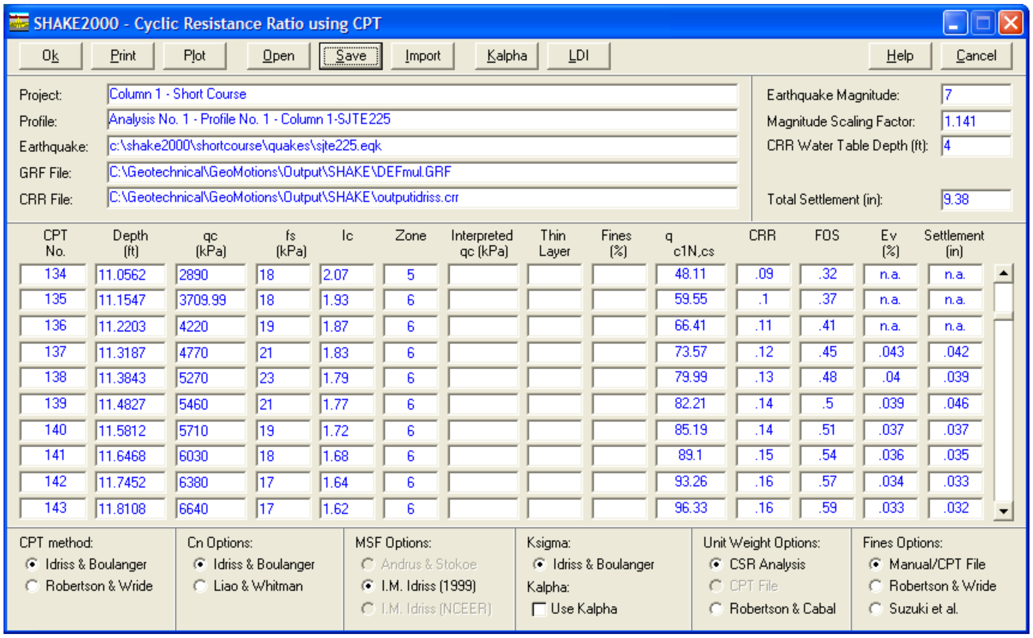
Adding Information about a Ground Motion File to the Database: To do this, first click on the **Ground Motion File Utilities: Conversion & Database** option of the Main Menu form to select it. Then, click on the **Ok** button to display the conversion form. Next, click on the **Open** command button to display the **Open Source Ground Motion File** dialog form. Change to the folder and subdirectory where the file is located if necessary, click on the file to highlight it, and then use the **Open** button to open the file and return to the conversion form. After a few seconds, the first few lines of the file (up to 99 lines) will be shown on the top list box of the form.

Once the file is opened, you need to enter as a minimum the information requested in the **No. Values**, **Time Step**, **No. Header Lines**, **Values per Line**, **Format** and **Database Header Line** text boxes as described in the previous section. Note that in this case, the information that you enter in the **Format** text box refers to the file that you want to add to the database. If you do not enter a value for values per line, this information will be obtained from the data entered in the format text box. After entering this information, click on the **Dbase** command button to display the **Edit/Add Ground Motion File Information** form. Refer to that section on this manual for further information.

Editing the Database of Ground Motion Files: This form also allows you to access the form used to edit the information available in the database of ground motion files. For more information about the database, refer to the **Database of Earthquake Records** section of this manual. To access the editor form, click on the **Dbase** command button to display the **Edit/Add Ground Motion File Information** form. Refer to that section of this manual for more information about editing the database. Please note that to access the database form, you don't need to open a file first.

Ground Motion Parameters: Various parameters used to characterize a ground motion can be obtained by using the **GMP** command button. These parameters include peak ground acceleration, Arias Intensity, Root-Mean-Square of the acceleration time history (RMSA), bracketed duration, Trifunac & Brady duration, predominant period, average period and mean period. More information on these parameters is provided in the **Ground Motion Parameters** section of this manual.

Cyclic Resistance Ratio using Cone Penetration Test (CPT) Data



This form is used to evaluate the cyclic resistance ratio (CRR) required to initiate liquefaction based on Cone Penetration Test (CPT) data. There are two methods that can be used to evaluate the CRR: Robertson & Wride (Robertson and Wride, 1998; Youd and Idriss, 1997; Youd et al., 2001); and, Idriss & Boulanger (2008).

In this form, it is assumed that the user is familiar with the methodology followed to conduct a liquefaction analysis using CPT data. For further information on the methods used in this form, please refer to the specific references.

CPT data for the evaluation of CRR is entered by importing the data from a CPT data file. Nowadays, results from a CPT sounding are recorded in digital form and stored in magnetic form for future use with post-processing computer software. The user can setup SHAKE2000 to read these files and use the information saved in them to evaluate the CRR. However, it is necessary that these files be ASCII or text files. To read the information on these files, or to enter the CPT data manually, click on the **Import** command button to display the **Import data from CPT File** form. With this form, the user can read files with different formats (i.e. the way in which the data are organized as columns).

For any method, data inputting begins by entering the earthquake magnitude in the **Earthquake Magnitude** text box. By default, a value of 7.5 is set by SHAKE2000. Press the *Tab* key once, or use the mouse to place the cursor on the **Magnitude Scaling Factor** text box. The magnitude correction factor is automatically computed, using the values recommended by the author selected on the **MSF options** section, and displayed on the **Magnitude Scaling Factor** box.

The depth to the water table cannot be changed in this form. In order to use a common depth to the water table when conducting different analyses simultaneously (i.e. SPT, CPT and CSR), the depth to water table can only be changed either on the **Simplified CSR** form or the **Calculated Results Plot Menu** form. When conducting simultaneous liquefaction analyses using SPT and CPT data, then both the depth to the water table and the earthquake magnitude should be the same for both analyses. If this is not the case, the most recent analysis conducted will be retained in the computer memory, and the other analysis will need to be conducted again to reflect the change on either of these parameters.

For the calculation of the cyclic resistance ratio, the water depth shown in the **CRR Water Table Depth** text box is used to compute the effective pressure.

Depending on the type of analysis you are conducting, the cyclic stress ratio induced by the ground motion is computed as:

- CSR = cyclic shear stress / effective overburden pressure; where the cyclic shear stress is computed as 65% of the peak cyclic shear stress (Kramer, 1996). The peak cyclic shear stress is obtained from the last iteration of Option 5 in SHAKE. This stress is at the mid point of the layer, thus, for other depths, the stresses are linearly interpolated. The effective overburden pressure is computed using the unit weights read from Option 2 of SHAKE, and using the depth to water table entered by the user. Or,
- For the simplified cyclic stress ratio analysis, these data are obtained using the options selected in the **Simplified Cyclic Stress Ratio Analysis** form.

The information for the analysis, selected on the **Calculated Results Menu** form or entered in the **Simplified Cyclic Stress Ratio Analysis** form, is shown on the upper left corner of the screen.

When using results from a SHAKE analysis, both the Idriss & Boulanger and Robertson & Wride methods will be enabled. To select a different analysis method, click on the corresponding method in the **CPT method** options. The values for CRR will be recalculated and shown in the **CRR** column. When using data from a simplified CSR analysis, only one method will be enabled based on the options selected in the simplified CSR form.

Values of magnitude scaling factor (MSF) can be calculated using the equations provided in the MSF Options: **I.M. Idriss (NCEER)** (Youd and Idriss, 1997, 2001), **I.M. Idriss (1999)** (Idriss, 1999), and **Andrus & Stokoe** (Youd et al., 2001).

By default, the **Robertson & Cabal** (Robertson and Cabal, 2010) option is used to estimate the values for unit weight. Note that for this purpose, the program will use q_c to estimate the unit weight. If a cyclic stress ratio analysis has been conducted before, then the default option to estimate the unit weights will be **CSR Analysis**. Accordingly, the unit weights entered in the CSR analysis (either in the **Simplified Cyclic Stress Ratio** form; or, in Option 2 when conducting a SHAKE analysis) are used to estimate the unit weights for every CPT point based on the depth of the point. This option will not be enabled if data are not available for the simplified CSR analysis. A third option, **CPT File**, can be selected if the values for unit weight are to be read from a CPT file using the **Import data from CPT file** form.

For the Idriss & Boulanger method, two options are provided to calculate the overburden correction factor (C_N): **Idriss & Boulanger** (Idriss and Boulanger, 2004) and **Liao & Whitman** (Liao and Whitman, 1986). As recommended in Youd et al. (2001), a maximum value of 1.7 will be set for C_N by the program.

To correct for fines content, the CPT values for the Idriss & Boulanger method corrected to equivalent clean sand penetration resistance using the equation provided in Idriss and Boulanger (2008) and the fines content entered manually in the **% Fines** column, or the estimated apparent fines from Robertson and Wride (1998) or Suzuki et al. (Idriss and Boulanger, 2008). In the manual method of entering the CPT data the fines content can be entered manually in the text box for the **% Fines** column. Alternatively, the apparent fines content can be estimated by selecting the **Robertson & Wride** or the **Suzuki et al.** option. Please note that by selecting one of these curves, it is assumed that the curve applies to the entire soil column.

When using the Idriss & Boulanger method, K_σ will be computed using the equation provided in Idriss and Boulanger (2008). Similarly, for the Idriss and Boulanger method to estimate the correction factor for initial shear stress, or K_α, first click on the **Use Kalpha** check box to select it, and then on the **Kalpha** command button to display the **Kalpha Correction Factor** form. K_σ or K_α will not be used for the Robertson & Wride method.

The liquefaction-induced lateral displacement can be estimated using the method proposed by Zhang et al. (Zhang et al., 2004). After the factors of safety are calculated, use the **LDI** command button to compute the lateral displacement index and to display the **Liquefaction-Induced Ground Deformation** form.

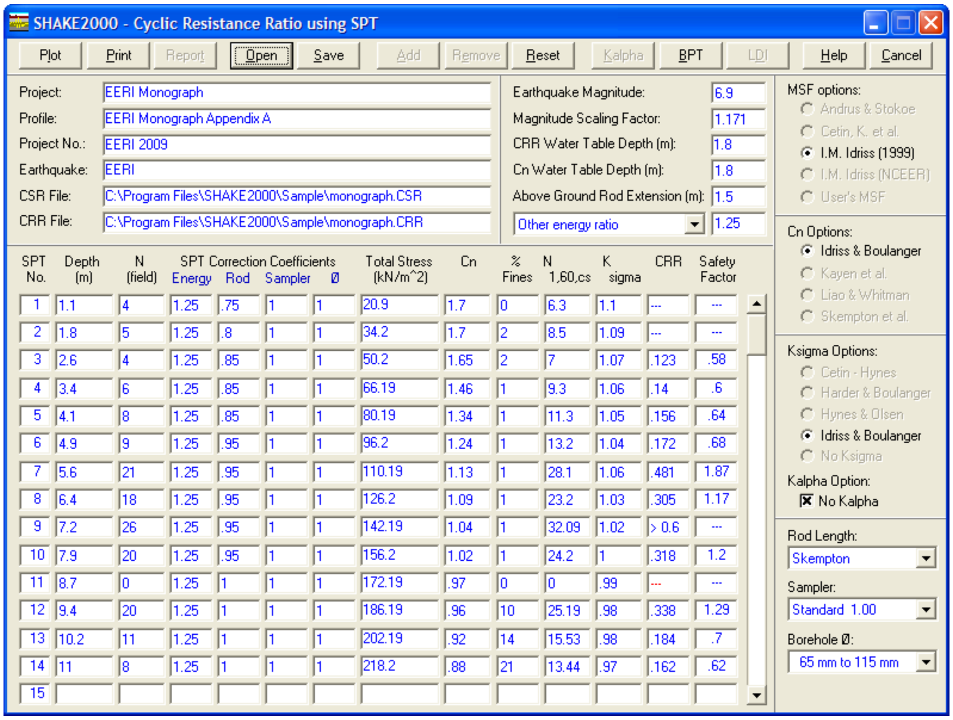
Fore more detailed information about the different variables, equations, and method of settlement calculation, please refer to Idriss & Boulanger (2008, 2010) and Zhang et al. (2002).

The results can be saved on an ASCII file using the **Save** command button. The file uses the *.CRR extension by default. An Excel *.CSV file will be automatically created using the same name as the CRR file and saved at the same location. The **Open** button can be used to retrieve these data from the file. In addition to the data shown on the form, the cyclic resistance ratio computed using the results from SHAKE2000 is also saved.

To plot the cyclic resistance ratio curve, click on the **Plot** command button. The form will display a series of graphs that summarize the CPT input data and the results of the liquefaction analysis. A graph of the soil column with soil type information is also displayed.

The **Print** command button is used to print the results of the cyclic resistance ratio analysis as a table. When you click on the command button, the **Print Results of Cyclic Resistance Ratio Analysis** form is displayed. For the different print options, see the **Print Results of Cyclic Resistance Ratio Analysis** section of the User's Manual.

Cyclic Resistance Ratio using Standard Penetration Test (SPT) Data



SPT No.	Depth (m)	N (field)	Energy	Rod	Sampler	Ø	Total Stress (kN/m^2)	Cn	% Fines	N 1,60,cs	K sigma	CRR	Safety Factor
1	1.1	4	1.25	.75	1	1	20.9	1.7	0	6.3	1.1	---	---
2	1.8	5	1.25	.8	1	1	34.2	1.7	2	8.5	1.09	---	---
3	2.6	4	1.25	.85	1	1	50.2	1.65	2	7	1.07	.123	.58
4	3.4	6	1.25	.85	1	1	66.19	1.46	1	9.3	1.06	.14	.6
5	4.1	8	1.25	.85	1	1	80.19	1.34	1	11.3	1.05	.156	.64
6	4.9	9	1.25	.95	1	1	96.2	1.24	1	13.2	1.04	.172	.68
7	5.6	21	1.25	.95	1	1	110.19	1.13	1	28.1	1.06	.481	1.87
8	6.4	18	1.25	.95	1	1	126.2	1.09	1	23.2	1.03	.305	1.17
9	7.2	26	1.25	.95	1	1	142.19	1.04	1	32.09	1.02	> 0.6	---
10	7.9	20	1.25	.95	1	1	156.2	1.02	1	24.2	1	.318	1.2
11	8.7	0	1.25	1	1	1	172.19	.97	0	0	.99	---	---
12	9.4	20	1.25	1	1	1	186.19	.96	10	25.19	.98	.338	1.29
13	10.2	11	1.25	1	1	1	202.19	.92	14	15.53	.98	.184	.7
14	11	8	1.25	1	1	1	218.2	.88	21	13.44	.97	.162	.62
15													

This form is used to evaluate the cyclic resistance ratio (CRR) required to initiate liquefaction based on Standard Penetration Test (SPT) results, as recommended by Seed et al. (1983, 1985), and recently reviewed in the Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils (Youd and Idriss, 1997; Youd et al., 2001); and, Idriss and Boulanger (2004, 2006, 2008). Further information on the evaluation of cyclic resistance ratio using SPT data is given by Kramer (1996) and Idriss & Youd (1997). It is recommend that you review the references listed at the end of this manual for more information on the procedure followed to estimate the cyclic resistance ratio using SPT results, the correction factors, the coefficients that are applied, and the limitations on the applicability of each method.

The methodology used in SHAKE2000 to evaluate liquefaction is based on the equation for factor of safety against liquefaction for magnitude 7.5 earthquakes:

$$FS = \left(\frac{CRR_{7.5}}{CSR}\right) \times MSF \times K_\sigma \times K_\alpha$$

Where:
- $CRR_{7.5}$ = Cyclic Resistance Ratio determined for magnitude 7.5 earthquakes
- CSR = Cyclic Stress Ratio induced by ground motion
- MSF = Magnitude Scaling Factor to adjust the base curve for magnitudes other than 7.5
- K_σ = Correction factor for high overburden stresses
- K_α = Correction factor for static shear stresses

There are three methods used to estimate $CRR_{7.5}$: 1) using the simplified base curve recommended for calculation of $CRR_{7.5}$ from SPT data, developed by Seed et al. (1985) and recently modified, as indicated by Youd and Idriss (1997) and Youd et al. (2001, 2003); 2) using the deterministic correlation proposed by Seed et al. (Seed et al., 2001, 2003); and, 3) using the proposed relationship by Boulanger and Idriss (Boulanger and Idriss, 2003). The method by Cetin & Seed (Seed et al., 2001, 2003; Cetin and Seed, 2004, Cetin et al., 2004) is selected when the **Cetin & Seed**

(2000) option of the **Stress Reduction Factor** options in the **Simplified Cyclic Stress Ratio Analysis** form is selected. The relationship by Boulanger and Idriss is selected when the **Idriss & Boulanger** option of the **Cn Options** is used. For this third method, the proposed relations for C_N and K_σ are used (Boulanger and Idriss, 2003). $N_{1,60}$ is the field-measured SPT, N_m, corrected by the following factors:

$$N_{1,60} = N_m C_N C_E C_B C_R C_S$$

Where: N_m = field-measured standard penetration resistance
C_N = factor to correct N_m for overburden pressure
C_E = correction for hammer energy ratio
C_B = correction for borehole diameter
C_R = correction for rod length
C_S = correction for samplers with or without liners

Different options for the above correction factors are explained below.

The cyclic resistance ratios are also adjusted for high overburden pressure and can be adjusted by the user for static shear stress. For high overburden pressure, Youd et al. (2001) recommend to use the K_σ correction factor obtained from the curves developed by Hynes and Olsen. For static shear stress, the user has the option to use the curves recommended in the NCEER proceedings (Youd and Idriss, 1997) developed by Boulanger et al. to obtain K_α.

The lower bound of range of acceptable magnitude scaling factor, MSF, when using the **User's MSF** option for magnitudes smaller than 7.5 is defined by the equation proposed by Idriss (Youd and Idriss, 1997):

$$MSF = \left(\frac{M_w}{7.5}\right)^{-2.56}$$

and the upper bound by the equation proposed by Andrus and Stokoe (Youd and Idriss, 1997):

$$MSF = \left(\frac{M_w}{7.5}\right)^{-3.3}$$

For magnitudes greater than 7.5 the factors recommended by Idriss (Youd and Idriss, 1997; Youd et al., 2001) or Cetin, K. et al (2004) are used in the program.

Depending on the type of analysis you are conducting, the cyclic stress ratio induced by the ground motion is computed as:

- CSR = cyclic shear stress / effective overburden pressure; where the cyclic shear stress is computed as 65% of the peak cyclic shear stress (Kramer, 1996). The peak cyclic shear stress is obtained from the last iteration of Option 5 in SHAKE. This stress is at the mid point of the layer, thus, for other depths, the stresses are linearly interpolated. The effective overburden pressure is computed using the unit weights read from Option 2 of SHAKE, and using the depth to water table entered by the user. Or,
- For the simplified cyclic stress ratio analysis, these data are obtained from the **Simplified Cyclic Stress Ratio Analysis** form.

The information for the analysis, selected on the **Calculated Results Menu** form or entered in the **Simplified Cyclic Stress Ratio Analysis** form, is shown on the upper left corner of the screen.

To begin, enter the earthquake magnitude in the **Earthquake Magnitude** text box. By default, a value of 7.5 is set by SHAKE2000. Press the *Tab* key once, or use the mouse to place the cursor on the **CRR Water Table Depth** text box. The magnitude correction factor is automatically computed, using the values recommended by the author selected on the **MSF options** section, and displayed in the **Magnitude Scaling Factor** box. Press the *Tab* key once to place the cursor on the **Cn Water Table Depth** text box. The effective overburden pressure used to calculate C_N should be the pressure that was effective at the time the SPT test was conducted (Youd and Idriss, 1997). The water table entered in the **Cn Water Table Depth** text box will be used to compute the effective pressure applied in the calculation of C_N. For the calculation of the cyclic resistance ratio, the water depth shown in the **CRR Water Table Depth** text box is used instead for the effective pressure. Similarly, if an overburden fill is added in the CSR analysis when using the simplified approach, the increase in pressure due to the overburden fill will not be considered when normalizing the SPT data.

To select the correction for hammer energy efficiency, C_e, click on the arrow to open the list of energy ratios for SPT and then select an SPT method. Use the *Tab* key to move the cursor to the text box next to the list. An average value to correct the measured penetration resistance (N value) for 60% rod energy will be displayed (Seed et al., 2003; Youd et al., 2001). For each method, you can enter a value within the range shown. You could also enter a different value by choosing the **Other energy ratio** option from the list, and then entering the value in the text box.

There are two other correction factors that apply to the SPT. These are shown on the lower right corner of the form. The **Rod Length** list shows the correction factors for different lengths of the drill rods. Seed et al. (1985) recommend a value of 0.75 for N-values measured at depths between 0 to 10 feet (0 to ≈3 meters). This correction is chosen by clicking on the **Seed's 0.75 for <= 10'** (or **3 m**). The third option, **Skempton**, allows you to correct according to different lengths of the rod as recommended by Skempton (1986). An "above ground rod extension" value can be entered in the **Above Ground Rod Extension** text box. This value will be added to the depth of the SPT value when computing the C_R coefficient, but it will not be added to the depth on any other computation where depth is required.

Please note that there are no specific guidelines as to the use of, and/or values for the above ground rod extension. For example, Cetin et al. (2004) in the development of their method indicated that " *except for cases where rod "stickup" (protrusion) above the top of the borehole was recorded, rod protrusion of ~1.2 m (~4 ft) above the top of the borehole was assumed for donut hammers and for the USGS safety hammers, and rod protrusion of ~2.1 m (~7 ft) was assumed for all other safety hammers"*. Idriss & Boulanger (2008) do not include recommendations for the rod length extension; however, they used a value of 1.5 m on the example included in their publication. In the program, the values in Cetin et al. and Idriss & Boulanger will be used as "starting point". The value will also be changed when selecting a different type of hammer for the energy ratio coefficient. However, the user should verify that these values are applicable to his/her own application. It is recommended to review the references for each method to determine its applicability and the values recommended.

The **Sampler** list shows correction factors for the case when the sampler is used without liners, as recommended by Seed et al. (1985), Skempton (1986), or Cetin et al. (2004, 2006).

Every time you select a different energy correction factor, sampler, or rod length option, the correction factors will be automatically updated and displayed on the respective data columns.

Next, place the cursor on the **Depth** column and enter the depth for the measured penetration resistance (N) value. Use the *Tab* key or the mouse to place the cursor on the **N (field)** column. The vertical total stress will be automatically computed based on the total unit weights and layer thickness used either in option 2 of SHAKE or in the values entered in the simplified CSR form. The stresses will be displayed in the **Total Stress** column.

The overburden correction factor (C_N) computed using the equation selected on the **Cn Options**, is displayed in the **Cn** column. In addition, the values for SPT correction factors for energy, rod, and sampler are displayed. The correction factor for effective overburden pressures greater than 1 tsf (or 95.76 kN/m^2) will be displayed in the **K_{sigma}** column. If the **No Ksigma** option of the **Ksigma Options** is selected, a value of **1.0** would be shown. The depth value should be less than the depth to the half space layer if using the CRR form with results from a SHAKE analysis; or, less than the depth to the midpoint of the final layer of the soil column if using the CRR form with the **Simplified Cyclic Stress Ratio Analysis** option. If the depth value for the SPT is greater, then the program will not accept data for the current SPT.

Enter the measured penetration resistance, or N value. The $N_{1,60}$, or the measured N value normalized to an overburden pressure of 1 tsf (or 95.76 kN/m^2) and corrected to an energy ratio of 60%, will be calculated and shown on the **$N_{1,60}$** column. Press the *Tab* key until the cursor moves to the **% Fines** column and enter the percentage of fines, if any. After placing the cursor on the next column, the cyclic resistance ratio required to initiate liquefaction will be obtained from the respective chart and shown on the **CRR** column. The ratio is interpolated based on the percent fines and $N_{1,60}$ values if necessary, and modified for a different earthquake magnitude using the magnitude scaling factor. Enter the remaining data for the other N values.

Values of magnitude scaling factor (MSF) for earthquakes up to 7.5 are calculated using either the equation by I.M. Idriss (**I.M. Idriss** options), Cetin et al., or by Andrus and Stokoe (**Andrus & Stokoe** option). The fourth option, **User's MSF**, will allow you to enter a value between the low (i.e. from Idriss equation) and high (i.e. from Andrus & Stokoe equation) limits. After selecting this option, place the cursor on the text box next to the **Magnitude Scaling Factor** label, and type in a new value. This value will be checked to verify that it falls within the recommended range. If other than the **User's MSF** option is selected, the MSF will be recalculated with the equation for the new option.

Four options are provided to calculate the overburden correction factor (C_N): **Liao & Whitman** (Liao and Whitman, 1986); **Skempton et al.** (Skempton, 1986; Jamiolkowski et al., 1985; Fear and McRoberts, 1995); **Kayen et al.** (Kayen et al., 1992 as referenced in Youd et al., 2001); and **Idriss & Boulanger** (Boulanger and Idriss, 2003). Every time you select one of these options, the data on the form will be automatically recalculated. This automatic recalculation also takes place when the earthquake magnitude, energy ratio correction factor, or depth to water table values is modified. As recommended in Youd et al. (2001), a maximum value of 1.7 will be set for C_N by the program. The equations by Liao & Whitman and by Kayen et al. are recommended for current engineering practice (Youd et al., 2001). The equations by Skempton et al. and Jamiolkowski et al. are kept in the program to maintain compatibility with previous versions of SHAKE2000. The equation by Skempton is used for effective vertical stress less than 1 tsf (or 95.76 kN/m^2), and the equation by Jamiolkowski et al. for stress greater than or equal to 1 tsf (or 95.76 kN/m^2).

As recommended by Seed and Harder (1990), the cyclic resistance ratio obtained from the chart will be "*... corrected for conditions with initial effective overburden stresses greater than 1 tsf*". In SHAKE2000, the correction factor for effective overburden pressures greater than 1 tsf (or 95.76 kN/m^2), or K_σ, can be estimated from either the relationship by Harder & Boulanger (Youd and Idriss, 1997); from the relationship by Cetin-Hynes (Cetin et al., 2004); from the proposed equation by Hynes and Olsen (Youd et al., 2001); or, from the recently proposed relations by Idriss & Boulanger (Idriss and Boulanger , 2003a,b; Boulanger and Idriss, 2003).

The equation developed by Hynes and Olsen (as referenced in Youd et al., 2001) can be used to obtain K_σ when you select the **Hynes & Olsen** option; and, is also the equation recommended for current engineering practice (Youd et al., 2001). When using this equation, the relative density, D_r, values are approximated based on the $N_{1,60cs}$ value. This approximation is based on the relationship between D_r and $N_{1,60}$ proposed by Torrey et al. (NUREG, 2000) for in-situ, clean sandy soils not placed recently. The **Harder & Boulanger** option has been kept in the program to maintain compatibility with previous versions of SHAKE2000. When the **No Ksigma** option is selected, a value of 1.0 will be automatically set for all correction factors, and the factor will not modify the cyclic resistance ratio obtained from the chart. The **Idriss & Boulanger** option will only be enabled when the **Idriss & Boulanger** option of the **C_n Options** is selected. The **Cetin – Hynes** option is used when following the procedure recommended in Cetin et al. (2004), and is enabled when the **Cetin, K. et al.** MSF option is selected.

To estimate the correction factor for initial shear stress, or K_α, click on the **No Kalpha** check box to deselect it, and then on the **Kalpha** command button to display the **Kalpha Correction Factor** form. Please note that Youd and Idriss (1997) and Youd et al. (2001) recommend that K_α not be used for routine engineering practice.

Becker penetration test (BPT) blow count values can be used to conduct a liquefaction analysis by first converting the blow counts to equivalent SPT N_{60} values, and then following the procedure described in this section. To use BPT blow counts, click on the **BPT** command button to display the **SPT from Becker Penetration Test (BPT) Data** form. Using this form, the BPT blow counts can be converted to equivalent N_{60} values by using one of a number of correlations. Please refer to the **SPT from Becker Penetration Test (BPT) Data** section of this manual for further information. Please note that when using BPT blow counts, you need to use the **SPT from Becker Penetration Test (BPT) Data** form to edit the depth and/or BPT blow count values. Further, the energy correction options will be disabled, and a default value of 1 will be set for the energy correction ratio.

When conducting a liquefaction analysis following the method recommended in the 1996 NCEER and 1998 NCEER/NSF Workshops (Youd et al., 2001), the liquefaction-induced lateral displacement can be estimated using the method proposed by Zhang et al. (Zhang et al., 2004). After the factors of safety are calculated, the **LDI** command button will be enabled. Please note that you may need to first plot the CSR/CRR vs. depth curves before the **LDI** command button is enabled. Click on this button to compute the lateral displacement index and to display the **Liquefaction-Induced Ground Deformation** form.

Every time you place the cursor on a SPT row, the **Add** and **Remove** command buttons are enabled. If you want to add data for a new SPT, place the cursor on the row of data above which the new SPT is located, and click on the **Add** button. A new row will be created, and the values in the new row will be the same as those for the row immediately below. Now, you need to modify the values for the new SPT. The **Remove** button is used to delete a SPT from the soil column. Place the cursor on any column of the SPT you want to delete, and then click on the **Remove** button. The data for the SPT will be removed from the soil column, and the values for the other SPTs updated accordingly.

The results can be saved on an ASCII file using the **Save** command button. The file uses the *.CRR extension by default. The **Open** button can be used to retrieve these data from the file. In addition to the data shown on the form, the cyclic stress ratios computed are also saved. This value is the ratio at the same depth as the N value. Thus, it is obtained by interpolating between values at the midpoint of the soil layers used in SHAKE or in CSR analysis.

To plot the cyclic resistance ratio curve, click on the **Plot** command button. This button is enabled after data for at least one SPT value are entered. The factor of safety against liquefaction can be displayed by clicking on the **FSL** command button on the graph window. After you plotted the curves, the **Report** command button is enabled. This button is used to display the **Plot SPT Data** form. This form will display a series of graphs that summarize the SPT input data and the results of the liquefaction analysis. You can also display a graph of the soil column with soil type information.

The **Print** command button is used to print the results of the cyclic resistance ratio analysis as a table. When you click on the command button, the **Print Results of Cyclic Resistance Ratio Analysis** form is displayed. For the different print options, see the **Print Results of Cyclic Resistance Ratio Analysis** section of the User's Manual.

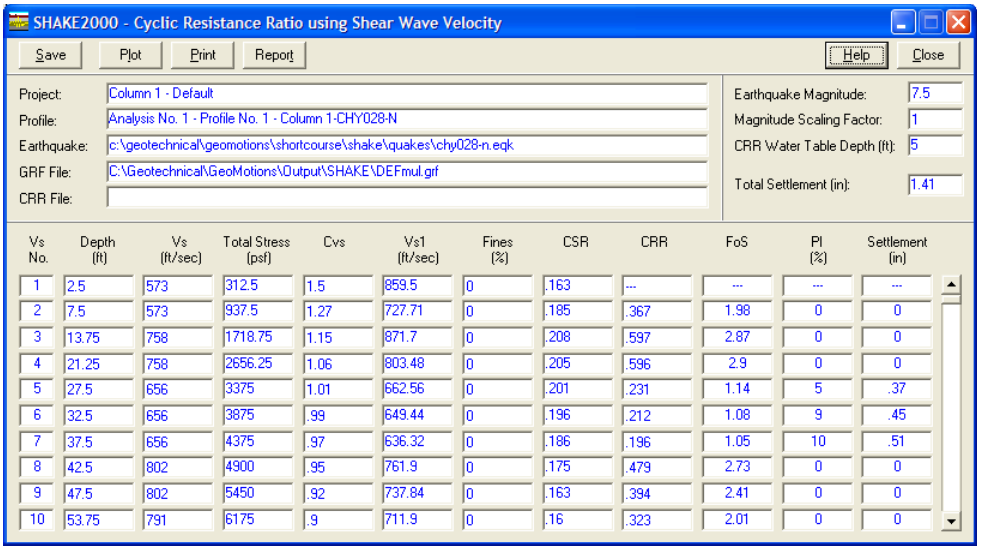
To clear all the data from the form, use the **Reset** command button. The current data will be deleted and default values for some of the variables will be displayed.

Notes:

- When the depth to the water table is lower than the depth to the SPT, then "- - -" will be shown on the cyclic resistance ratio column. Also, "> 0.5" is shown for those points on the chart located where the cyclic resistance ratio curves become vertical lines. These points will not be shown on the plot, and a gap on the curve is shown for the latter.
- The value of CRR shown on the form is the value adjusted to the earthquake magnitude used in your analysis.
- When conducting simultaneous liquefaction analyses using SPT and CPT data, then both the depth to the water table and the earthquake magnitude should be the same for both analyses. If this is not the case, the most recent analysis conducted will be retained in the computer memory, and the other analysis will need to be conducted again to reflect the change on either of these parameters.
- The acceptable range of earthquake magnitude is 5.0 to 8.5.
- The maximum and minimum values for K_σ depend on the equation selected.
- Depth values should be greater than zero, and less than the depth to the half space for a SHAKE analysis; or to midpoint of the last layer of the soil column for the simplified CSR analysis.
- When SHAKE2000 recalculates the data after modifying a parameter (e.g. new depth to water table), those values that were entered manually will not be modified. If you would like to use the value computed by SHAKE2000 instead of the value entered manually, delete the current value, and then press the *Tab* key to move the cursor to a different column. The computed value will be displayed after the cursor is moved to a different column.

- When opening a file that saves Cyclic Resistance Ratio data from a previous analysis, the data will be recalculated to reflect the current stress conditions for the current analysis. The data saved in the file will not be modified, but the data displayed on the screen may be different due to the recalculation process. If the depth for any SPT value in the file is greater than the depth to the base layer, the file will be closed, and no more data will be read.
- The cyclic resistance ratio can be entered manually. To do this, place the cursor on the **CRR** column, and enter the value. This value of CRR should be adjusted to the earthquake magnitude used in your analysis, K_α and for effective overburden stress. The text color for this value will be changed to red. Alternatively, you can delete the computed value. Please note that although the values of CRR and FSL will be plotted, settlement for the respective layers will not be computed. This option allows you to modify the CSR value, or delete it, in the event there are layers in the soil profile that do not liquefy, or for which the procedure described herein does not apply. The value of CRR will be computed again if a value of N is entered in the respective column.

Cyclic Resistance Ratio using Shear Wave Velocity (Vs) Data


SHAKE2000 - Cyclic Resistance Ratio using Shear Wave Velocity

Save | Plot | Print | Report | Help | Close

Project: Column 1 - Default
Profile: Analysis No. 1 - Profile No. 1 - Column 1-CHY028-N
Earthquake: c:\geotechnical\geomotions\shortcourse\shake\quakes\chy028-n.eqk
GRF File: C:\Geotechnical\GeoMotions\Output\SHAKE\DEFmul.grf
CRR File:

Earthquake Magnitude: 7.5
Magnitude Scaling Factor: 1
CRR Water Table Depth (ft): 5
Total Settlement (in): 1.41

Vs No.	Depth (ft)	Vs (ft/sec)	Total Stress (psf)	Cvs	Vs1 (ft/sec)	Fines (%)	CSR	CRR	FoS	PI (%)	Settlement (in)
1	2.5	573	312.5	1.5	859.5	0	.163	---	---	---	---
2	7.5	573	937.5	1.27	727.71	0	.185	.367	1.98	0	0
3	13.75	758	1718.75	1.15	871.7	0	.208	.597	2.87	0	0
4	21.25	758	2656.25	1.06	803.48	0	.205	.596	2.9	0	0
5	27.5	656	3375	1.01	662.56	0	.201	.231	1.14	5	.37
6	32.5	656	3875	.99	649.44	0	.196	.212	1.08	9	.45
7	37.5	656	4375	.97	636.32	0	.186	.196	1.05	10	.51
8	42.5	802	4900	.95	761.9	0	.175	.479	2.73	0	0
9	47.5	802	5450	.92	737.84	0	.163	.394	2.41	0	0
10	53.75	791	6175	.9	711.9	0	.16	.323	2.01	0	0

This form is used to evaluate the cyclic resistance ratio (CRR) required to initiate liquefaction based on Shear Wave Velocity (V_s) data, as recommended by Kayen et al. (2013). It is recommend that you review these references for more information on the procedure followed to estimate CRR using V_s results, the correction factors, and the coefficients that are applied.

The methodology used in SHAKE2000 to evaluate liquefaction is based on the equation for factor of safety against liquefaction for magnitude 7.5 earthquakes:

$$FS = \left(\frac{CRR_{7.5}}{CSR}\right) \times MSF$$

Where: $CRR_{7.5}$ = Cyclic Resistance Ratio determined for magnitude 7.5 earthquakes
CSR = Cyclic Stress Ratio induced by ground motion
MSF = Magnitude Scaling Factor to adjust the base curve for magnitudes other than 7.5

Please note that the above equation is slightly different than the one recommended in recent literature, in which the MSF factor is applied to the CSR value. However, the above approach is used to maintain uniformity with the CRR analyses using SPT and CPT data.

The $CRR_{7.5}$ value is determined using the equations recommended for calculation of $CRR_{7.5}$ based on the stress-corrected shear wave velocity, V_{s1}, for the Kayen et al. (2013) method.

To obtain V_{s1cs}, the field measured V_s value is first corrected to account for overburden stress as recommended by Kayen et al. (2013) by:

$$V_{s1} = V_s\ C_{vs} = V_s \left(\frac{P_a}{\sigma_v^{'}}\right)^{0.25}$$

Where: P_a = reference stress of 100 kP_a or about atmospheric pressure
$\sigma_v^{'}$ = initial effective overburden stress

The cyclic stress ratio induced by the ground motion is computed as CSR = cyclic shear stress / effective overburden pressure; where the cyclic shear stress is computed as 65% of the peak cyclic shear stress (Kramer, 1996). The peak cyclic shear stress is obtained from the last iteration of Option 5 in SHAKE. This stress is at the mid point of the layer, thus, for other depths, the stresses are linearly interpolated. The effective overburden pressure is computed using the unit weights read from Option 2 of SHAKE, and using the depth to water table entered by the user.

The information for the analysis, selected on the **Calculated Results Menu** form is shown on the upper left corner of the screen.

To begin, enter the earthquake magnitude in the **Earthquake Magnitude** text box. By default, a value of 7.5 is set by SHAKE2000. Press the *Tab* key once, or use the mouse to place the cursor on the **CRR Water Table Depth (ft)** text box. The magnitude correction factor is automatically computed, using the values recommended by the author selected on the **MSF options** section, and displayed in the **Magnitude Scaling Factor** box. For the calculation of the cyclic resistance ratio, the water depth shown in the **CRR Water Table Depth (ft)** text box is used for the calculation of the effective pressure.

The value of CRR is calculated after each value used in the above equation is entered. This value of CRR shown is the value adjusted to the earthquake magnitude. Please note that the program will compute CRR for each soil; however, if a soil is not liquefiable you can remove the CRR by placing the cursor on the text box and pressing **Delete**. This way the CRR and factor of safety for this layer will not be shown.

To correct for fines content, enter the fines content in the **Fines (%)** column.

Settlement is approximated by the method proposed by Yi (2010). The settlement results are only provided as a guide and will not be plotted or saved to a file.

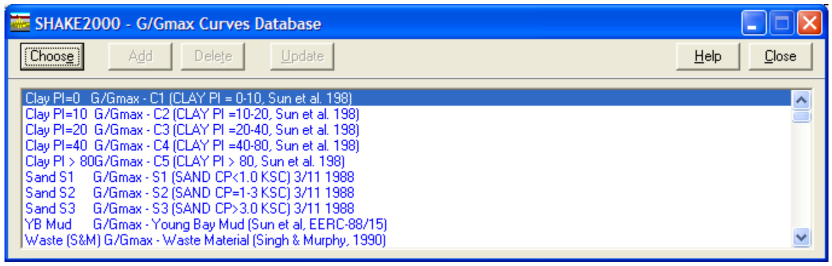
The results can be saved on an ASCII file using the **Save** command button. The file uses the *.CRR extension by default. The **Open** button can be used to retrieve these data from the file. In addition to the data shown on the form, the cyclic stress ratios are also saved.

To plot the cyclic resistance ratio curve, click on the **Plot** command button. After the curves are plotted, the **Report** command button is enabled. This button is used to display the **Plot V_s Data** form. This form will display a series of graphs that summarize the V_s input data and the results of the liquefaction analysis. You can also display a graph of the soil column with soil type information.

The **Print** command button is used to print the results of the cyclic resistance ratio analysis as a table. When you click on the command button, the **Print Results of Cyclic Resistance Ratio Analysis** form is displayed. For the different print options, see the **Print Results of Cyclic Resistance Ratio Analysis** section of the User's Manual.

The depth to the water table cannot be changed on this form. In order to use a common depth to the water table when conducting different analyses simultaneously (i.e. SPT, CPT, V_s and CSR), the depth to water table can only be changed on the **Option 2** form.

Database of Damping Ratio Curves



When editing an existing *.EDT file, you can add damping ratio curves, one at a time, using the **New** and then the **MAT** command buttons of the **Option 1 Editor** form. When you click on the button, the **Database of Damping Ratio Curves** form will be displayed as shown above. The listing of all the damping ratio curves available in the **shakey2k.mat** material database file will be shown in the list box.

To select a damping curve, click on the material to highlight it, and then on the **Choose** command button. You will return to the **Option 1 Editor** form. You will be asked if you want to replace the current material properties data with the ones just selected. You can also double-click on the material to select it and return to the **Option 1 Editor** form.

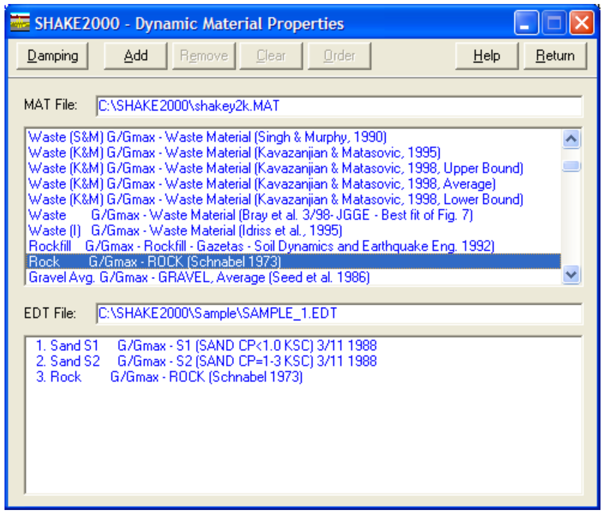
The current damping data entered in the Option 1 form can be added to the database of material properties. First click on the **Dbase** command button on the Option 1 editor form. Then, click on the **Add** command button. You will be asked if you would like to add the data to the position highlighted in the list of materials.

Data for a specific material can be deleted from the database. To do this, highlight the material to be deleted and then click on the **Delete** command button. You will be asked if you wish to continue with deletion of this material.

Periodically, we will post in the SHAKE2000 web site, a file that includes properties for other materials that became available in the technical literature, or that were contributed by users of the program. After this file is downloaded, click on the **Update** command button. You will be asked if you would like to continue with updating of the database. If you click on **Yes**, the new data will be added to the end of the file.

This form is also used to select a damping curve for the Makdisi & Seed simplified displacement analysis.

Database of Dynamic Material Properties



This form is used to select the shear modulus reduction and damping ratio curves for the current set of Option 1.

MAT File's Option List: When this form is displayed, the top list box will show the Modulus Reduction Curves (G/G_{max}) that are included in the *.MAT file, and the first curve will be highlighted. This list is used to select the materials that will be included in the current data set of Option 1 for the *.EDT file. The vertical scroll bars on the right side of the list box can be used to scroll between the options. To select a curve, click on it to highlight it, and then click on the **Add** button. You can also double click on the curve to add it to the materials list.

The **Order**, **Remove** and **Clear** buttons are not enabled, i.e. they are grayed out. These buttons are enabled when a curve from the selected materials list is selected. After selecting a curve, a number will be shown next to the identification on the bottom list box. This number is the position of the material in Option 1, i.e. the material number.

EDT File's Materials List: This list box will show the curves that will be included in the current set of Option 1. If no curves have been selected before this form is displayed, then this list box will be empty. Once you have selected the curves, you can reorganize them with the **Order** button, delete any with the **Remove** button, and delete all the material curves from this list box with the **Clear** button.

To switch between the Modulus Reduction and the Damping Ratio curves, click on the **Damping** button. This button will change to **Moduli** when the Damping Ratio curves are being displayed.

After you have selected the different materials, click on the **Return** command button to return to the Option 1 editor form. You will be asked if you want to use the materials chosen for the current set of Option 1. Click on **Yes** to accept them, or on **No** to remove them.

The database file is a text file named **SHAKEY2K.MAT**, and it is created in the directory where you installed SHAKE2000. This file can be edited with a text processor, so that you can add materials to the database file. However, you should keep the format of the file as shown below.

Format of SHAKE2YK.MAT:

```
SHAKE2000 ".MAT" File
Dynamic Material Properties Database
Number of Modulus Reduction Curves:   2
Number of Damping Ratio Curves:       3
```

```
Option 1 -- Dynamic material properties: Modulus Reduction Curves

   10      Clay PI=0   (CLAY PI = 0-10) Modulus Reduction Curves Feb. 1988
0.0001    0.001     0.00316   0.01      0.0316    0.1       0.316     1.
3.16      10.
1.        0.974     0.915     0.786     0.574     0.312     0.16      0.06
0.02      0.006
    9      Sand CP<1   (SAND CP<1.0 KSC)  Modulus Reduction Curves 3/11 1988
0.0001    0.000316  0.001     0.00316   0.01      0.0316    0.1       0.316
1.
1.        0.978     0.934     0.838     0.672     0.463     0.253     0.14
0.057

Option 1 -- Dynamic material properties: Damping Ratio Curves

   10      Clay         Damping CLAY  May 24 - 1972
0.0001    0.001     0.00316   0.01      0.0316    0.1       0.316     1.0
3.16      10.0
2.0       2.5       3.5       4.75      6.5       9.25      13.75     20.0
26.0      29.0
    9      Sand         Damping SAND, February 1971
0.0001    0.001     0.003     0.01      0.03      0.1       0.3       1.
10.
1.        1.6       3.12      5.8       9.5       15.4      20.9      25.
30.
    8      Gravel       Damping Ratios for Gravelly Soils - Seed et al 1988
0.0001    0.0003    0.001     0.003     0.01      0.03      0.1       0.3
0.5       1.        1.75      3.        5.5       9.5       15.5      21.
```

The first and second lines (i.e. ***SHAKE2000 ".MAT" File*** & ***Dynamic Material Properties Database***) should not be modified. Two curves for modulus reduction and three for damping are shown in the above example. Thus, a 2 is shown in the ***Number of Modulus Reduction Curves:*** line, and a 3 in the ***Number of Damping Ratio Curves:*** line. If you add a new curve, increase the number accordingly. You can also delete curves, and will need to decrease the number accordingly. You can also reorganize the sets in a different order; however, the format of the data should be kept the same.

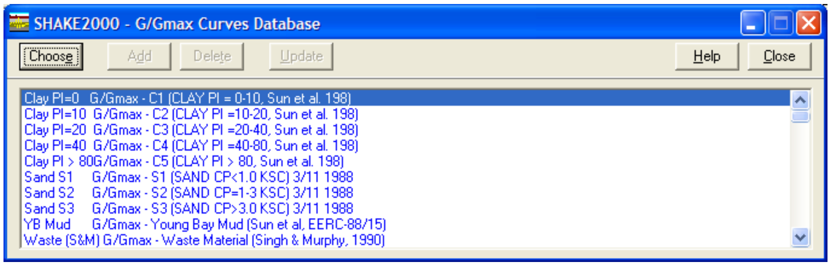
There is a **blank line** after the number of curves lines, then a line that identifies the section for the Modulus Reduction Curves (i.e**.,** ***Option 1 -- Dynamic material properties: Modulus Reduction Curves***), followed by another **blank line**. The modulus reduction (G/G_{max}) data for each material are entered next. Each material follows the format described in the SHAKE2000 manual for option 1. In the first line (e.g. ***10 Clay PI=0 (CLAY PI = 0-10) Modulus Reduction Curves Feb. 1988***), enter the number of strain values to be read in columns 1 - 5 (e.g. ***10***). In columns 10 through 80 enter the identification for this set of modulus reduction values (e.g. ***Clay PI=0 (CLAY PI = 0-10) Modulus Reduction Curves Feb. 1988***). This identification label is formed by two segments. In columns 10 to 21 enter a label that can be used to identify the material (e.g. ***Clay PI=0***), and that together with the information entered in columns 22 to 80 (e.g. ***(CLAY PI = 0-10) Modulus Reduction Curves Feb. 1988***), will form the identification label for the material in the SHAKE2000 option 1 data. The information entered in columns 10 to 21 will be included in the table of results to help you identify each soil layer with a material name. In the second and consecutive lines enter the strain values, in percent, beginning with the lowest value (e.g. ***0.0001 0.001 0.00316 0.01 0.0316 0.1 0.316 1.***). Enter eight values per line using a format of **8F10.0**, with a maximum of 8 values per line. It is also recommended that the numbers be right justified. After entering the strain values, enter the values for Modulus Reduction (G/G_{max}), each corresponding to the shear strain provided in the previous lines, using the same format of **8F10.0** (e.g. ***1. 0.974 0.915 0.786 0.574 0.312 0.16 0.06***).

After the last set of Modulus Reduction data, there is a **blank line**, and then the identification line for the section of the file where the damping ratio curves are saved (i.e**.** ***Option 1 -- Dynamic material properties: Damping Ratio Curves***). This line is followed by a blank line. The damping data for each material are entered next. Each material follows the format described in the SHAKE2000 manual for option 1. In the first line (e.g. ***10 Clay Damping CLAY May 24 - 1972***), enter the number of strain values to be read in columns 1 - 5 (e.g. ***10***). In columns 10 through 80 enter the identification for this set of damping values (e.g. ***Clay   Damping CLAY May 24 - 1972***). In the second and consecutive lines enter the strain values, in percent, beginning with the lowest value (e.g. ***0.0001   0.001   0.00316   0.01   0.0316   0.1   0.316   1.0***). Enter eight values per line using a format of **8F10.0**, with a maximum of 8 values per line. After entering the strain values, enter the values for damping, each corresponding to the shear strain provided in the previous lines, using the same format of **8F10.0** (e.g. ***2.0   2.5   3.5   4.75   6.5   9.25   13.75   20.0***).

After modifying the file, don't forget to update the number of curves for Modulus Reduction and Damping.

Some of the curves included with SHAKE2000 where obtained from the following references: Sukhmander Singh and Bruce J. Murphy (1990); Kavazanjian, E. Jr.; Matasovic, N.; and Caldwell, J. (1998).; Idriss, I.M.; Fiegel, Gregg; Hudson, Martin B.; Mundy, Peter K.; and Herzig, Roy (1995); Gazetas G. and Dakoulas, P. (1992); Seed, H.B.; Wong, R. T.; Idriss, I.M.; and Tokimatsu, K. (1986); Vucetic, M. and Dobry, R. (1991); Rollins, K.M.; Evans, M.D.; Diehl, N.B. and Daily, W.D. III (1998); Yegian, M.K.; Harb, J.N. and Kadakal, U. (1998); Makdisi, F.I. and Seed, H.B. (1978); Schnabel, P.B. (1973); Seed, H.B. and Idriss, I.M. (1970); Sun, J.I.; Golesorkhi, R. and Seed, H.B. (1988), Wehling et al. (2003); Darendeli, M. (2001); EPRI (1993); Roblee and Chiou (2004); Martirosyan et al. (2003); Singh and Donovan (1977); Matasovic, N. (1993); and, Zekkos et al. (2008).

Database of G/G_{max} Curves



When editing an existing *.EDT file, you can add new G/G_{max} curves, one at a time, using the **New** and then the **MAT** command buttons of the **Option 1 Editor** form. When you click on the button, the **G/G_{max} Curves Database** form will be displayed as shown above. The listing of all the G/G_{max} curves available in the **shakey2k.mat** material database file will be shown in the list box.

To select a G/G_{max} curve, click on the material to highlight it, and then on the **Choose** command button. You will return to the **Option 1 Editor** form. You will be asked if you want to replace the current material properties data with the ones just selected. You can also double-click on the material to select it and return to the **Option 1 Editor** form.

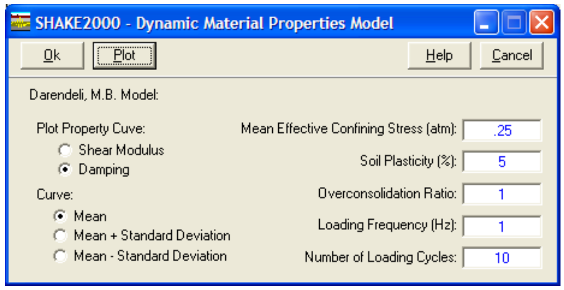
The current G/G_{max} data entered in the Option 1 form can be added to the database of material properties. To do this, first click on the **Dbase** command button and then on the **Add** command button. You will be asked if you would like to add the data to the position highlighted in the list of materials.

Data for a specific material can be deleted from the database. To do this, highlight the material to be deleted and then click on the **Delete** command button. You will be asked if you wish to continue with deletion of this material.

Periodically, we will post in the SHAKE2000 web site, a file that includes properties for other materials that became available in the technical literature, or that were contributed by users of the program. After this file is downloaded, click on the **Update** command button. You will be asked if you would like to continue with updating of the database. If you click on **Yes**, the new data will be added to the end of the file.

This form is also used to select a G/G_{max} curve for the Makdisi & Seed simplified displacement analysis.

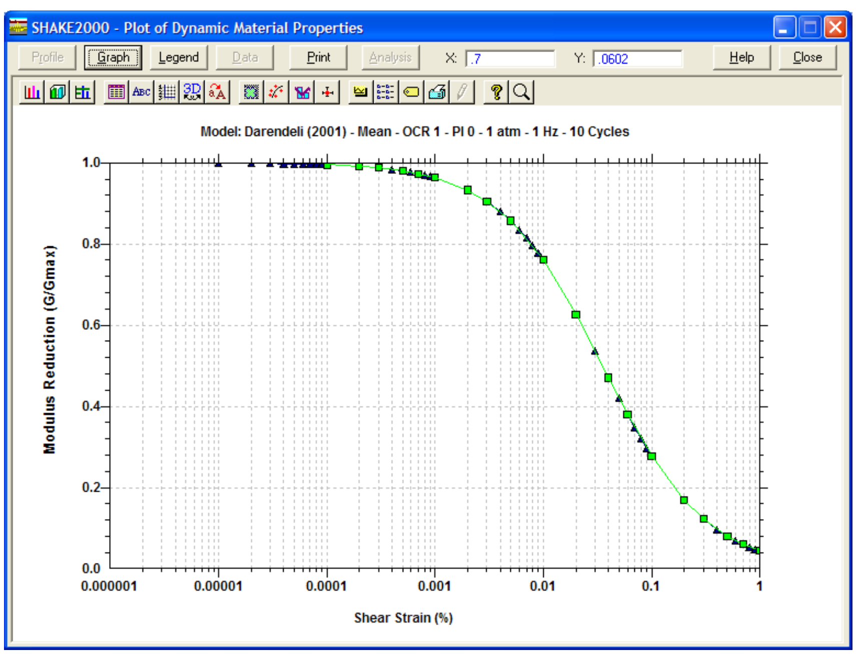
Dynamic Material Properties Model



This form is used to enter the input data for different relationships for estimating normalized shear modulus and material damping ratio of soils. The relationships included with SHAKE2000 are those developed by Darendeli, M.B. (2001); Ishibashi and Zhang (1993); and, Zhang, Andrus and Juang (Zhang et al., 2005; Andrus et al., 2003; Zhang et al., 2008).

For the **Darendeli** relationship, it is necessary to enter values for the mean effective confining stress, σ'_m, in atmospheres; the soil plasticity index as percentage; overconsolidation ratio; loading frequency; and, number of loading cycles. For the **Zhang, Andrus & Juang** relationship you need to enter a value for mean effective confining stress in kPa, select one of the **Geologic Unit** options, and enter a value for **Plasticity Index** (PI). For each Geologic Unit option, a range of PI values is displayed on the PI label. For PI values other than those presented in Andrus et al. (2003), the coefficients will be obtained through interpolation. The effective confining stress in kN/m^2 and plasticity index values should be provided when using the **Ishibashi & Zhang** relationship.

After entering the data for the model, select the property curve, i.e. **Shear Modulus** or **Damping**, to plot and then click on the **Plot** command button to display the curve. When the graph is displayed up to 20 different values to define the curve have been selected by default. Twenty is the maximum number of points used in SHAKE to define both the shear modulus reduction and damping ratio curves. You can select different points by clicking on the point with the mouse.



Every time a symbol is chosen it changes to a light green square which is linked by a light green line to each chosen symbol. The curve represented by the green symbols and green line will be the one used by SHAKE. In the graph above, 20 points have been selected to define the curve.

To remove any point from the selected group, just click on it. The curve will be redrawn using only the remaining symbols. After selecting the points, click on the **Close** command button to return to the model form. You need to repeat the same process for the Damping ratio curve.

The mean effective confining stress, σ'_m, used in these models is computed from:

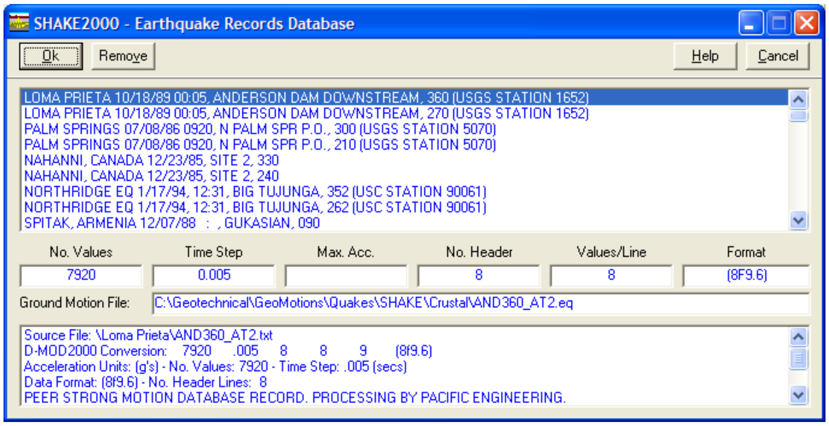
$$\sigma'_m = \sigma'_v \left(\frac{1 + 2K'_o}{3} \right)$$

Where; σ'_v = vertical effective stress
K'_o = coefficient of effective earth stress at rest

After points from both curves have been selected, i.e. the number of points for each curve is at least one, the **Ok** command button will be enabled. Click on the **Ok** command button to return to the Option 1 editor form and add the new curves to the set of material properties.

The **Mean ± Std. Dev.** options to compute the mean ± standard deviation curves are only enabled when the Darendeli, M.B. or Zhang, Andrus & Juang model is being used to obtain the curves.

Earthquake Records Database



This form is used to display a listing of earthquake records available in your system. Basic information for each record is saved in the **SHAKEY2K.EQ** database file located in the same directory where SHAKE2000 is installed. This file is an ASCII text file that can be modified either manually or through the **Edit Database of Ground Motion Files** form to include new information about new records, or to edit current information.

To select an earthquake record, click on it to highlight it, and then click on the **Choose** button. You will return to either, the Option 3 editor where the data will be displayed on the corresponding cells; or, to the **Plot Object Motion** form, where the data will be displayed on the bottom section of the form.

To add the information about a ground motion file modified with the conversion routine to the database, click on the **Add** command button.

Information related to a ground motion file can be removed from the database control file by first clicking on the record that you want to remove and then clicking on the **Remove** command button.

Please note that the **Add** command button is only enabled when this form is called from the conversion form using the **Dbase** command button. And, the **Remove** command button is only enabled when the form is called from the **Plot Object Motion** form using the **Quakes** command button.

In the SHAKEY2K.EQ data file, the name of the earthquake ground motion file is stored as shown on the data box below the **Ground Motion File** label.

The following web sites provide ground motion records for download. Please note that the following Internet addresses were valid at the time this User's Manual was written.

1. Y.K. Wen and C.L. Wu; *Generation of Ground Motions for Mid-America Cities*. University of Illinois at Urbana-Champaign.

http://mae.ce.uiuc.edu/Research/RR-1/Gmotions/Index.html

As noted in their web site: "*Simulated ground motions for three cities (Memphis, TN, Carbondale, IL and St. Louis, MO) and two soil conditions (hard rock outcrop and representative soil) are provided: 10 ground motions for each city and soil condition combination. Each filename contains 7 characters: 1st alphabetical letter indicates city location (**m** for **M**emphis, **c** for **C**arbondale, and **l** for St. **L**ouis); 2nd and 3rd numeric letters indicate exceedance probability level in 50 years; 5th and 6th numeric letters indicate sequential number in each earthquake set. The last alphabetical letter indicates soil condition (**r** for hard **r**ock, **s** for representative **s**oil). For example:*

"m10_01s" stands for m = Memphis, 10 = 10% in 50 years, 01 = sample number, s = representative soil.

In each file, the 1st line gives information used for generating ground motion, including file ID, moment magnitude, focal depth (km), epicentral distance (km), closest horizontal distance to the surface projection of rupture plane (km), epsilon (deviation from median attenuation). The 2nd line gives the headline of the ground motion data. Starting from the 3rd line is the ground motion data."

2. Woodward-Clyde Federal Services; *SAC Joint Venture Steel Project Phase 2, Develop Suites of Time Histories*. Draft Report, Project Task: 5.4.1. March 21, 1997.

http://quiver.eerc.berkeley.edu:8080/studies/summary/5-4-1.html

As noted in their web site: "*The purpose of this work is to provide response spectra and time histories for use in topical investigations, case studies, and trial applications in the SAC Phase 2 Steel Project. Ground motion estimates are provided in three locations of the United States (Boston, Seattle, and Los Angeles) corresponding to seismic zones 2, 3 and 4 respectively. Suites of time histories are provided at two probabilities of occurrence (2% in 50 years and 10% in 50 years) in each of these three locations for firm soil conditions. Time histories are also provided for 50% in 50 years for Los Angeles. Time histories for soft soil profiles are provided for 10% in 50 years in all three locations. Near fault time histories are also provided for seismic zone 4 conditions*."

3. Elgamal, A., Ashford, S., and Kramer, S., Eds.; *1st PEER Workshop on Characterization of Special Source Effects*. Workshop Report, UCSD, July 20-21, 1998, Pacific Center for Earthquake Engineering Research, UC Berkeley, 1999.

http://peer.berkeley.edu/research/motions/workshop_report1.html

As noted in their web site: "*The main objective of the 1st PEER Workshop on Characterization of Special Source Effects was to work towards development of a set of reference ground-motion time-histories for a wide range of earthquake magnitudes, site distances, and site characteristics. These ground motions are intended to provide a common basis for subsequent PEER investigations. Representatives from SCEC, USGS, and private industry as well as PEER researchers, participated in this effort. Particular attention was paid to the definition of representative ground motions for urban areas in California and the Pacific Northwest. The workshop goals included definition of an initial set of time-histories, and identification of required efforts towards the development of a more comprehensive data set. During the workshop, a set of nineteen earthquake records was selected. All selected motions will be accessible through a PEER Center web-site. The overall effort will be finalized during the next workshop to address this topic, in early 1999*."

4. PEER Strong Motion Database: This database contains over 1000 records from 140 earthquakes from tectonically active regions, processed by Dr. Walt Silva of Pacific Engineering using publicly available data from Federal, State, and private providers of strong motion data.

http://peer.berkeley.edu/smcat/search.html

http://peer.berkeley.edu/nga/search.html

5. Mid-America Earthquake Center; *Generation of Synthetic Ground Motions*.

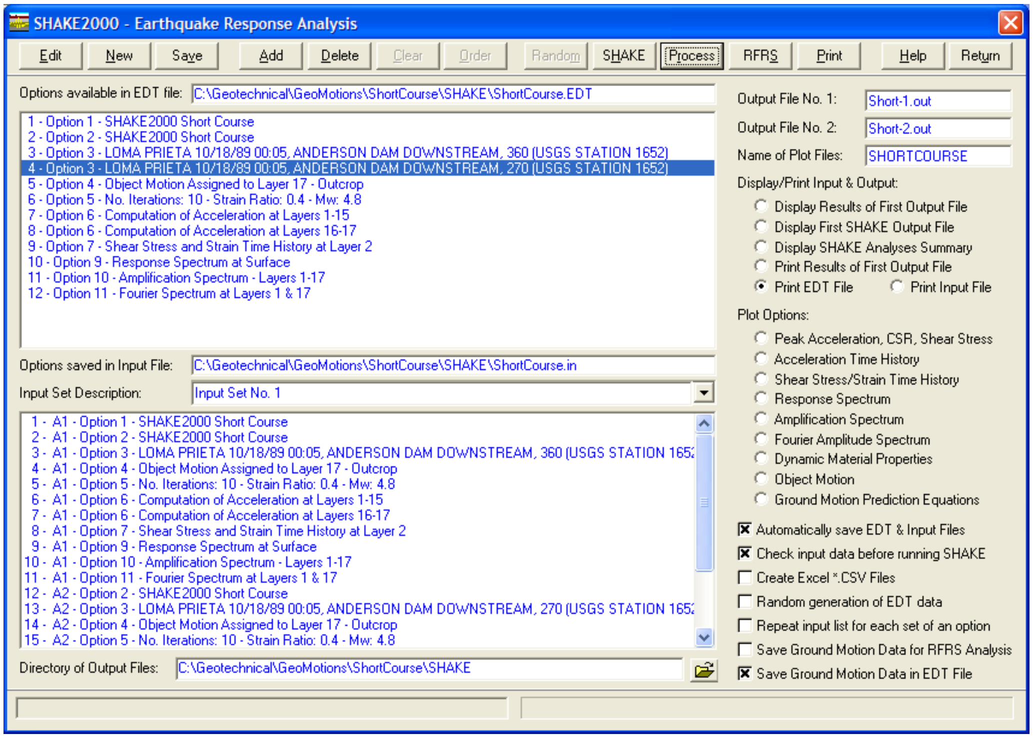
http://mae.ce.uiuc.edu/TaskStatements/RR-2.html

As noted in this web site: *"This project will investigate the generation of synthetic ground motions resulting from large New Madrid earthquakes. In this project, uncertainties in seismic and soil parameters used in* *modeling of seismic source, path attenuation, and local site condition will be quantified. Then for a specific combination of moment magnitude, epicentral distance, and site conditions, a set of synthetic ground motions will be generated."*

The ground motions available at this site are saved in a Unix formatting, thus you will need to use a text processor that can convert the file to a DOS format.

When downloading a file from an internet site, you need to save the file as a text file. Once you have an appropriate record for your analysis, you may need to transform the record to a format compatible with SHAKE2000. You can use the **Ground Motion File Utilities: Conversion & Database** option of the Main Menu to convert the file.

Earthquake Response Analysis



1. EDT File:

An *.EDT file is an ASCII file that contains data for the different options used by SHAKE2000. The data are in the format required so that the *.EDT file may be used as an input file for SHAKE2000. However, SHAKE2000 uses this file as a database to create an input file. In other words, the *.EDT file can contain several sets for each option (e.g. 6 different sets of Option 2), up to a combined total for all of the options of 32,000. Thus, when the file is saved, the options will be saved in numeric order, and all the sets for each option will be grouped together.

EDT File's Option List: When this form is displayed, the list box will show the options that are included in the *.EDT file, and the first option will be selected. This list is used to select the options that the user can edit and options to be included in the input file. The vertical scroll bars on the right side of the list box can be used to scroll between the options.

To edit an option, click on it to highlight it and then click on the **Edit** button. You can also double click on the option to edit it. If you want to remove an option from the *.EDT file, highlight it and then click on the **Delete** button. The option cannot be un-erased. To create a specific option that is not included in the *.EDT file, or to create a new set of an existent option, click on the **New** button. Click on this button to display the **SHAKE2000 – Option List** form to select new options.

To save the *.EDT and Input files, click on the **Save** button. The files can be saved automatically after you edit an option, or before you execute SHAKE, by selecting the **Automatically save EDT & Input Files** check box.

To print the EDT file, first click on the **Print EDT File** option to select it, and then click on the **Print** command button. This will display the **Print *.EDT and Input Files** form.

The **Check input data before running SHAKE** option is selected by default. When this option is selected, the data in the different options that form the input data will be checked to determine if there are any errors that may cause problems during the execution of SHAKE. For example, a value of zero for the thickness of a layer will cause

SHAKE to crash when Option 5 is started. The program tries to detect this and other errors before execution of SHAKE is started. The user will be provided with detailed information on the error. If you are sure that your data are correct and do not wish to check the data before execution of SHAKE starts, click on the check box to de-select this option.

The **Create Excel *.CSV Files** option can be used to save the output data from SHAKE as comma separated values files that can be opened with Excel. The program will use the name shown in the **Name of Plot Files** text box and add three letters to identify the data in the file. For example, SHAKEout-ACC.csv will save the acceleration time histories obtained from option 6. The files will be created in the folder shown on the **Directory of Output Files** text box.

For multiple analyses in sequence, the **Repeat input list for each set of an option** option facilitates the creation of the input file. For example in the previous form, there are 3 sets of option 3 on the EDT list (i.e. top window of options). To create an input file that includes an analysis for each of these sets, first add the list of options to the input window (i.e. bottom window of options) to define an analysis (e.g., options 1, 2, 3, 4, 5, 6, 7, 9, 10 and 11). Then, select the **Repeat input list for each set of an option** check box to select it. Next, click on any of the option 3 sets in the EDT list window and click on **Add**. You can then use this procedure to repeat the list of input options for any of the other options included in the EDT list.

When the **Automatically save EDT & Input Files** option is selected (an **x** is shown on the check box) the EDT and Input files will be automatically saved every time you return from editing an option (using the **Edit** command button), or previously to execute SHAKE (with the **SHAKE** command button).

The **Save Ground Motion Data for RFRS Analysis** option is used when the results of the SHAKE analysis will be used to conduct either a ratio of response spectra, RRS, or Fourier spectra, RFS, analysis of the ground surface motions to the input outcropping rock motions. The results of the RRS analysis can be used to obtain a design soil response spectrum by multiplying either the mean or the median curve of the RRS curves by the rock response spectrum (Dobry et al., 2000; Martirosyan et al., 2002). A likely application of this method would be to obtain a response spectrum for Site Class F soils as explained in section 3.4 of NEHRP Commentary (Building Seismic Safety Council, 2004b). For the RRS or RFS analysis using SHAKE, the input motions used in Option 3 would usually be defined as outcrop motions in Option 4. The program will save the information for the acceleration time histories at the surface, i.e. usually layer number 1, computed with Option 6. The RRS or RFS analysis is then conducted using the **Ratio of Fourier/Response Spectra** form displayed with the **RFRS** command button.

The **Random generation of EDT data** option is used to randomly generate sets of options 1, 2 and 3 based on lower bound, mean value, upper bound value and standard deviation values for modulus reduction and damping curves; thickness, G_{max} and/or shear wave velocity; and peak acceleration. When this option is selected, the current data will be deleted and a new file will be created. A message asking if this is acceptable will be displayed before the new file is created. This new file will be formed by a default set of options. The **Random** command button will be enabled. Additional information on this option is provided in the **Random Generation of EDT Data** section of this user's manual.

After randomly generating the data, the input file will be automatically created following the listing of options shown on the bottom list of the form. For this feature, only the first sets Options 1, 2, 4, and 9 will be used in the creation of the input file. If there are additional sets of these options, these will be ignored. More than one set of Option 5 can be included in the list of options save in the input file. When more than one Option 5 is found, the program will assign the first set of Option 5 to the first of Option 3, the second set of Option 5 to the second set of Option 3, etc.. If there are less Options 5 than Options 3, then the last set of Option 5 will be assigned to the remaining Options 3. Further, although more than one set of Option 3 is acceptable, only one set should be included in the list of input file options. However, if several sets of Option 3 were randomly generated, each set will be used for the creation of the input file.

For example, assume that 2 sets of Option 1, 3 sets of Option 3, and 5 sets of Option 2 were randomly generated. The program will then create SHAKE columns using the first set of Option 1, with the first set of Option 3 and each of the five sets of Option 2, i.e. a total of 5 SHAKE columns will be created. Next, the second set of Option 3 will be used together with the first set of Option 1 and each of the five sets of Option 2; i.e., and additional five SHAKE columns will be created for a partial total of 10 columns up to this point. After the third set of Option 3 is used in a similar manner (i.e. 15 columns so far), the process is repeated using the second set of Option 1 for an additional 15 SHAKE columns. At the end, 30 SHAKE columns will be generated. For each column, every other option selected (i.e. Options 4, 5, 6, 7, 9, 10 or 11) will be added to the analysis. Depending on the number of analyses conducted, the output files generated by SHAKE may be large, which may require some time to process. When plotting the results, the mean and median values for the strain-compatible damping, strain-compatible shear modulus, maximum shear strain, maximum shear stress, and peak acceleration will be computed based on a uniform layering of the data. This new layering is used because the randomly generated soil profiles will probably have different thicknesses for each layer.

2. Input File:

Input File: The top list box will show the options that are included in the *.EDT file. This list is used to select the options that will be included in the SHAKE2000 input file. To include an option in the input file, first select the option by clicking on it to highlight it, and then click on the **Add** button. The list of options shown on the input list window forms a set. More than one set of input options can be created in order to create different input files. The information about each set will be saved in the EDT file. To switch between sets, click on the down arrow next to the description text box and select a different set.

The **Order**, **Remove** and **Clear** buttons are not enabled, i.e. they are grayed out. These buttons are enabled when an option from the input file's option list is selected.

Input File's Option List: This list box will show the options that will be included in the SHAKE input file. If no options have been selected before this form is displayed, then this list box will be empty. Once you have selected the options, you can reorganize them with the **Order** button, remove any with the **Remove** button, delete all the options from this list box with the **Clear** button, and create the input file with the **Save** button.

To create an input file for SHAKE2000, select the options you want to include from the top list (i.e. EDT File's Option List) in the order they will be executed by SHAKE2000. The options selected will be shown on the bottom list box (**Input File's Option List**) with the order number next to them. Then, use the **Save** command button to store these options in the input file. A file dialog form will be displayed requesting you to enter the name for the file. Alternatively, you can select to overwrite an existing file by selecting it.

To print the input file, first click on the **Print Input File** option to select it, and then click on the **Print** command button. This will display the **Print *.EDT and Input Files** form.

A description for this set of input options is entered in the text box next to the **Input Set Description** label. To create and/or delete a set, click on any of the options on the input list window and then click on the **Clear** command button. On the message box, if you click on **Yes**, the current set will be deleted and a new set created. If you click on **No**, the current set will be kept and a new set created. When a new set is created, a default description string is entered in the description text box; and, the input list window is cleared. With each set of input options, the name and path to the input file, the output directory, the name of the two output files and the name of the plot files are also saved in the EDT file.

3. Execute SHAKE:

After you have created an input file, you will perform the earthquake response analysis using SHAKE.

Before you execute SHAKE, you need to enter the name of the two output files and select a directory path where these files will be saved. Place the cursor on the text box next to the **Output File No. 1** label and type in the name for the first output file (i.e. the file that saves information on the material properties, soil column, ground motion, peak acceleration, response spectra, etc.), followed by a period and the extension (e.g. OUT). SHAKE2000 will not add an extension to the end of the file if it is not entered. You can enter up to 32 characters. Blank spaces are not allowed. Next, place the cursor on the text box next to the **Output File No. 2** label and type in the name for the second output file (i.e. the file that saves acceleration and shear strain/stress time histories). These files will be saved to the folder shown on the text box next to the **Directory of Output Files** label. To change the location of the output directory, there is a command button located next to the text box (i.e. the button with the open folder icon). Click on this button to display the **Choose Output Directory** form, select a different folder by double clicking on it, and then click on the **Ok** button to return to this form.

Now, to execute SHAKE click on the **SHAKE** command button. The program will execute in a DOS window that automatically closes upon program termination.

After you have executed SHAKE, you need to process the two output files created. SHAKE2000 will read the output files and extract the information that is most useful to the user, and store it in a series of ASCII files that are used by the **Plot Data** options described below. The name of the output files created with the **Process** command button can be entered in the text box next to the **Name of Plot Files** label. By default, SHAKE2000 uses **Output** as the name. For example, the **Process** command button will create the following files: OUTPUT.GRF, OUTPUT.ACC and OUTPUT.STR. To change the name, place the mouse cursor in the box and delete the current contents, then type the new name. A maximum of 8 characters is allowed as input for this text box.

To process the output files, click on the **Process** command button. If there were any errors during the execution of SHAKE, then an error message will likely be displayed during the processing of the output files. In this case, it is recommended to use the **Display First SHAKE Output File** option to display the first output file and proceed to the option that may have caused the error, usually the last option saved in the output file. Then, review the information provided in the output file and review the input data for this option to determine the reason for the error.

Processing of the first output file will create files that have the name entered in **Name of Plot Files** text box, and an extension depending on the data saved in the file. The file with the extension GRF stores peak acceleration values (from Option 6), peak shear strain and shear stress, damping and shear moduli data (from Option 5); the file with the extension of SPC saves the response spectra data (from Option 9); the file with the extension AMP saves amplification spectra (from Option 10); and the file with the extension FOU saves Fourier spectrum data (from Option 11). These files can also be used by other software (e.g. Excel, etc.) to create similar graphs. Processing of the second output file creates a file with the extension of ACC that saves acceleration time histories requested in Option 6; and the file with extension STR that saves shear stress and shear strain time histories computed with Option 7.

In addition, files that can be used in a Ratio of Response Spectra or in a Newmark Displacement Analysis are created. These files are identified with the extension *.AHL (or acceleration history at layer) for those created from the same acceleration time histories requested in Option 6; and, with the extension *.HEA (or horizontal equivalent acceleration) for those created from the shear stress time histories requested in Option 7. The *.AHL files store the same data saved in the *.ACC file, for example the OUTPUT.ACC file described previously. The difference is that each AHL file only saves the acceleration time history for a layer. These files are given a name such as **L##A#D#-##-@@@@@@@@-$$$$$$$$.AHL** or **L##A#D#-##-@@@@@@@@-$$$$$$$$.HEA**, where **L** means layer and is followed by two numbers which are the layer number; **A** stands for analysis, and the number following it is the analysis number; and, **D** is for soil deposit and the number is the number of the soil deposit as defined in option 2. The numbers after the "-" show the position of this time history in the output file. For example, the very first time history in the second output file will have "-1" after the deposit number. The **@@@@@@@@** string identifies the soil profile in more detailed and it is obtained from the first 8 characters of the string entered in the **Identification for Soil Profile** text box in Option 2. Similarly, the **$$$$$$$$** string is the string of characters entered in the **Earthquake Identification** text box in Option 3.

If the incident motion is requested in Option 6, then the acceleration time history file will have a name similar to the names described above with the word "**Incident**" included. This file will have the "**ACC**" extension instead of the "AHL" extension. For more detailed information about the incident and reflected waves refer to Section 2 of this user's manual.

As recommended in Bray et al. (1995) for the seismic analysis of landfills, the HEA can be approximated from a 1-D analysis from:

$$HEA(t) = \frac{\tau_h(t)}{\rho\ z}$$

Where HEA(t) = horizontal equivalent acceleration at time *t*
$\tau_h(t)$ = horizontal shear stress at depth *z* and time *t*
ρ = mass density of material above depth *z*
z = depth to top of layer

In SHAKE2000, to create the HEA time history at the top of a specific layer of the SHAKE column based on the above equation, the shear stress time history obtained from Option 7 for that layer is used for $\tau_h(t)$; and, ρ and z are obtained from Option 2 for the corresponding SHAKE analysis.

The AHL and HEA can be plotted using the **Object Motion** of the Main Menu form.

If there were any errors during the execution of SHAKE, then an error message will be likely displayed during the processing of the output files.

4. Print & Plot Options:

After the output files are processed, you can use the **Display Results of First Output File** option to display the results stored in the *.GRF file in a spreadsheet-like form.
The **Print Results of First Output File** option is used to create a table of the main results obtained from the first output file, which can be printed. To do this, click on the option, and then on the **Print** button to display the form.

The **Display First SHAKE Output File** option is used to display the contents of the first output file created by SHAKE. To do this, select this option and then click on the **Display** command button. This is useful, for example, when trying to determine what caused SHAKE to crash. Usually when SHAKE crashes, the last option written to the output file is the one most likely to have caused the problem. By reviewing the information on the first output file, the user can determine what changes need to be made to correct the problem.

To execute a plot option click on the option to select it, and then click on the **Plot** button to plot the data saved in the file. The file for each option is formed by using the path shown in the text box next to the **Directory of Output Files** label, the file name shown in the **Name of Plot Files** text box, and the file extension for each option.

Peak Acceleration, CSR, Shear Stress: The following plots are created by choosing this option: Strain-Compatible damping vs. Depth, Strain-Compatible Shear Modulus vs. Depth, Maximum Shear Strain vs. Depth, Maximum Shear Stress vs. Depth, Peak Acceleration vs. Depth, and Cyclic Stress Ratio vs. Depth. The data for this option are saved in the *.GRF file. The maximum acceleration values are obtained from the Option 6 output section, and the other results from the Option 5 output section of the first SHAKE output file.

Acceleration time history: This option is used to plot the acceleration time history at the top of the layers specified using Option 6 of SHAKE. The data are stored in the *.ACC file.

Shear Stress/Strain time history: Use this option to plot the stress or strain time history at the top of the layers specified using Option 7 of SHAKE. The data are stored in the *.STR file.

Response Spectrum: Select this option to display plots of response spectrum for different damping ratios computed from Option 9 of SHAKE. The different response spectra plotted are: Relative Displacement (Sd), Relative Velocity (Sv), Pseudo-Relative Velocity (PSV), Absolute Acceleration (Sa), and Pseudo-Absolute Acceleration (PSA) versus Period. The data for this option are saved in the *.SPC file.

Amplification Spectrum: Select this option to plot the amplification spectrum computed from Option 10 of SHAKE. The data for this option are saved in the *.AMP file.

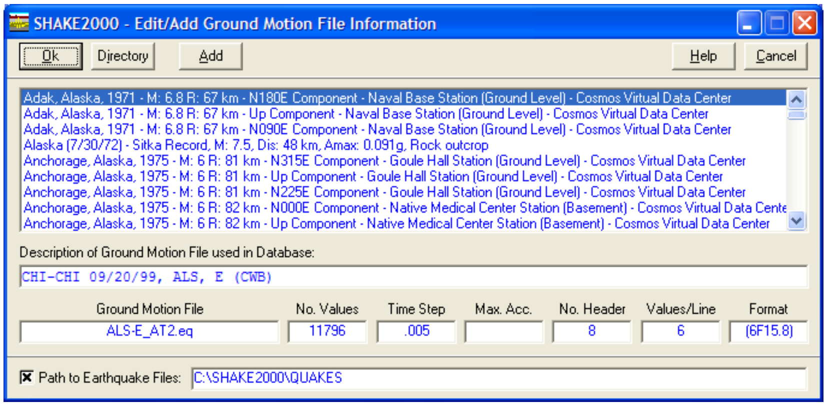
Fourier Amplitude Spectrum: Use this option to plot the Fourier amplitude spectrum computed from Option 11 of SHAKE. The data for this option are saved in the *.FOU file.

Material properties: This option is used to plot the dynamic material properties, i.e., shear modulus reduction and damping ratio curves for the different materials. The data are obtained from the *.EDT (SHAKE2000 main file) file. After selecting this option, click on the **Plot** button to display the form.

Object Motion: This option is used to plot the acceleration time history for an earthquake record. For example, you can use this option to plot the object motion that is used as input for the SHAKE analysis. The form will be displayed to allow you to select the object motion to be plotted.

Ground Motion Prediction Equations: This option is used to plot ground motion prediction equations for peak ground acceleration and peak horizontal velocity with distance, and pseudo absolute acceleration and pseudo relative velocity response spectra. Several equations are used, as described in the ground motion prediction equations section of this manual.

Edit/Add Ground Motion File Information



This form is used to edit the database of ground motion files included with SHAKE2000. The information about the files (e.g. file name, number of values, etc.) is saved in the SHAKEY2K.EQ file and can be accessed by different features of SHAKE2000 to get the information for the ground motion. For example, this database can be accessed from the Option 3 editor form to select a ground motion file used in the SHAKE analysis; or, from the response spectra form to select a ground motion for which the response spectra is computed.

The editing functions that can be performed with this form are twofold. First, you can edit the data for an existing ground motion file, or you can remove a file from the database. Second, you can add the information about a new file in the database.

Edit Information about a Ground Motion File:

To display this form, you need to first select the **Ground Motion File Utilities: Conversion & Database** option of the Main Menu form and then click on the **Ok** command button. This will display the **Conversion of Ground Motion File** form. In this second form click on the **Dbase** command button to display the editing form. Once this form is displayed, you can edit the information by entering the new values in their respective text boxes.

In the text box below the **Description of Ground Motion File used in Database** enter a string up to 128 characters long that describes the motion and that is displayed in the list box. For example, the first ground motion in the database is identified as **Alaska (7/3072) – Sitka Record, M: 7.5, Dis: 48 km, Amax: 0.091g, Rock outcrop**.

The name of the file is entered in the text box below the **Ground Motion File** text box. The information in this text box can be added to the information shown on the **Path to Earthquake Files** text box to define the path to the file. For example, when executing SHAKE2000 the path to the first ground motion will be specified as **c:\shake2000\quakes\alaska.eq** when the path option is selected. You can also enter the name and a path if you saved the files in different subdirectories. For example, you can enter **quakes\alaska.eq** if the file is saved in the **quakes** subdirectory, and then on the path option you would select the **c:\shake2000** folder as the path where the file is located. Use the **Directory** command button to choose the path to the directory where the earthquake motion files are stored. After clicking on this button, the **Path to Earthquake Files** form will be displayed. Use the mouse to select the drive and directory, and then click on the **Ok** button. The directory will be displayed on the text box next to the **Path to Earthquake Files** check box.

The total number of acceleration values that form the object motion file is entered in the text box below the **No. Values** label.

In the text box below the **Time Step** label, enter the time interval between each acceleration value.

The peak acceleration value of the ground motion can be entered in the text box below the **Max. Acc.** label. This value can be used in Option 3 of SHAKE. Entering this value is optional.

In the text box below the **No. Header** label enter the number of lines at the beginning of the file that are used to describe the object motion.

In the text box below the **Values/Line** label, enter the number of acceleration values on each line of the file. The number entered in this box is used with the information entered in the **Format** text box to determine how many values are to be read from each row of data in the file. Other examples of the information entered in this box are:

In the line below there are 4 values separated by blank spaces:

```
-.1059027E-04  -.1461820E-04  -.1690261E-04  -.1506594E-04
```

In the line below there are 8 values. Note that there are no blank spaces separating the values when a negative sign is included:

```
-0.000001-0.000001-0.000001-0.000001 0.000000 0.000000 0.000000 0.000001
```

In the line below, there are 8 values, and there are blank spaces separating the values. The last number (e.g. 1) only identifies the row number. Thus, you would enter an 8 in this cell for this specific example:

```
0.00000 -0.00434  0.00860  0.00540 -0.00565 -0.00944 -0.00369 -0.00669      1
```

The last information needed for the file is the **Format** value. The format string tells SHAKE and/or SHAKE2000 how to read the ground motion values from the file. This string is based on the syntax used in the Format statement of the FORTRAN computer language. In this statement edit descriptors specify how the values are read. The edit descriptors supported by SHAKE2000 in this feature are:

F*w.d*	Real values
E*w.d* [E*e*]	Real values with exponents
G*w.d*	Real values, extended range
D*w.d*	Double-precision real values
I*w*	Integer values

In these descriptors, the field is ***w*** characters wide, with a fractional part ***d*** decimal digits wide, and an optional exponent width of ***e***. Remember that the field ***w*** also includes any blank spaces and the sign. You can also indicate that a given data format is repeated a number of times. For example, 8F9.6 repeats a nine-character real value with six decimal digits descriptor eight times. The first character on the format field should be a "**(**" and the last character a "**)**", e.g. (8F9.6). Examples of data saved in the ground motion files included with SHAKE2000 and the format used to define them follow:

Format: (4E15.7):

```
 -.1059027E-04  -.1461820E-04  -.1690261E-04  -.1506594E-04
```

Format: (8F9.5):

```
  0.00000 -0.00434  0.00860  0.00540 -0.00565 -0.00944 -0.00369 -0.00669      1
```

Format: (8F9.6):

```
-0.000001-0.000001-0.000001-0.000001 0.000000 0.000000 0.000000 0.000001
```

From the format string, SHAKE2000 gets the number of digits that form each value, and combines this number with the value entered in the **Values/Line** box to determine the length of each value and the number of values to read from a ground motion file. For more information on format types, please refer to a FORTRAN Programming Language book.

After you have modified the information, click on the **Edit** command button to include the new information on the database file. You will be asked if you want to proceed with the changes. However, even if you accept, the information on the shakey2k.eq file will not be changed until after you leave this form using the **Ok** command button. Thus, even if you have changed the information on several of the files, but ultimately elect not to modify the information in the shakey2k.eq file, click on the **Cancel** command button to cancel all of the changes. To remove a file from the database, click on the **Delete** command button. You will be asked if you want to proceed with removal of the file's information or not.

Add Information about a New Ground Motion File:

To add information about a new file to the database of ground motion files, you first need to use the **Conversion of Ground Motion File** form to open the file and enter the information described previously. To do this, first click on the **Ground Motion File Utilities: Conversion & Database** option of the Main Menu form to select it. Then, click on the **Ok** button to display the conversion form. Next, click on the **Open** command button to display the **Open Source Ground Motion File** dialog form. Change to the folder and subdirectory where the file is located if necessary, click on the file to highlight it, and then use the **Open** button to select the file and return to the conversion form. After a few seconds, the first few lines of the file (up to 99 lines) will be shown on the top list box of the form.

Once the file is opened, you need to enter as a minimum the information requested in the **No. Values**, **Time Step**, **No. Header Lines**, **Values per Line**, **Format** and **Database Header Line** text boxes of the conversion form as discussed in the **Conversion of Ground Motion File** section of this manual. After entering this information, click on the **Dbase** command button to display the **Edit/Add Ground Motion File Information** form.

When you are adding information about a new file, the **Edit** and **Delete** command buttons are not displayed. Instead, the **Add** command button is the only button displayed. Click on this button to include the information on the database, and then on the **Ok** command button to modify the shakey2k.eq file. If you are adding data for a file converted using the **Conversion of Ground Motion File** form, then the text boxes where the information are displayed will not be enabled, i.e. you will not be able to modify the information. These boxes are enabled if you are adding information about a file that has not been converted with the conversion form.

Edit the SHAKEY2K.EQ File with a Text Processor:

The database file can be modified manually using a text processor. Please remember that the formatting in the file (i.e. the way the information is saved in columns) should not be modified. If you choose to do this, the following section explains the way the information is saved in the file which will help you edit the file manually.

Earthquake Records File - SHAKEY2K.EQ Format:

```
SHAKE2000 ".EQ" File
Earthquake Database
Number of Earthquake Records: 4

|Identification
|Path                         |No. Acc  |Time Step|Mx. Acc. |Header   |Values   |Format

Alaska (7/30/72) - Sitka Record, M: 7.5, Dis: 48 km, Amax: 0.091g, Rock outcrop
alaska.eq                      2048      0.02               3         8         (8F9.6)
Apeel 7 - crystal spr, pulgas 0 deg
pulgas0.eq                     2000      0.02               1         8         (8F9.6)
Apeel 7 - upper crystal spr. pulgas 90 deg
pulgas90.eq                    2000      0.02               1         8         (8F9.6)
ANZA 02/25/80 1047, ANZA FIRE STATION, 225 (USGS STATION 5160) - PEER Database
azf225.eq                      2058      0.0050             4         6         (6E15.7)
```

The first two lines in the file (i.e. ***SHAKE2000 ".EQ" File & Earthquake Database***) should not be modified. The third line (***Number of Earthquake Records: 2363***) is the number of records listed in the file. Every time you add or delete a record, this number should be modified accordingly. For the above example there is information listed for 4 different records. The next line is a **blank line**, followed by two lines that limit the fields for the information necessary for each record. The next line is a **blank line.** Each record is described by two lines. The first line

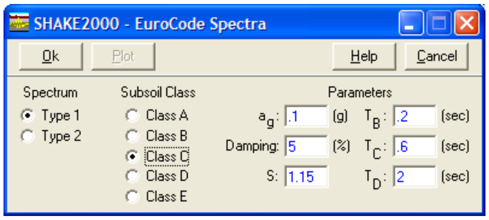
(|***Identification***) describes the record (e.g. ***Alaska (7/30/72) - Sitka Record, M: 7.5, Dis: 48 km, Amax: 0.091g, Rock outcrop***). This line can contain as many as 128 characters. The following line, i.e.:

```
|Path                              |No. Acc  |Time Step|Mx. Acc. |Header   |Values   |Format
```

gives information about the record that is used in Option 3 of SHAKE2000, and also to plot the object motion. The first field (i.e. |***Path***) is 30 characters long, from columns 1 through 30, and describes the path in your hard drive where the file is stored or the file name only. For the above example, the first record is saved as a file named ***alaska.eq*** in the ***quakes*** directory of the hard drive. You could also only include the name without the subdirectory. The |***No. Acc*** field from columns 36 through 45 is the number of acceleration values in the object motion. The time interval between acceleration values is entered in the |***Time Step*** field, from columns 46 through 55. The next field |***Mx. Acc.***, from columns 56 through 65, is used to enter the maximum acceleration value to be used. If this field is left blank, a value of zero will be assigned, and the multiplication factor for adjusting acceleration values used in Option 3 will be assigned a value of one. The number of header lines in the file containing the object motion is entered in the |***Header*** field, from columns 66 through 75. The number of acceleration values per line in the object motion file is entered in the |***Values*** field, from columns 76 through 85. The format for reading the acceleration values is entered in the |***Format*** field, from columns 86 through 95.

After modifying the file, don't forget to update the number of earthquake records in the ***Number of Earthquake Records*** line. The file should be saved as a text file, with no special formatting using a text processor.

EuroCode 8 Response Spectrum

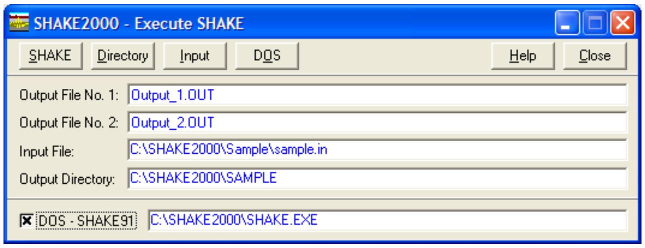


This form is used to select the options and/or enter the data necessary to plot a design response spectrum in accordance with Part 1 of the EuroCode 8 (European Committee for Standardization, 2000).

To select a spectrum, first, choose one of the **Spectrum Type** options. Then, select a subsoil class from the **Subsoil Class** options to determine the soil parameter, S. Next, enter a value for the design ground acceleration in the text box adjacent to the $\mathbf{a_g}$ label. Then, click on the **Ok** button to return to the **Response Spectrum Plot Menu** form. The value of damping shown is the first value selected in the **Response Spectrum Plot Menu** form.

The value for the soil parameter, S, can be changed to 1.4 for the special case " …*when the subsoil includes an alluvial surface layer with thickness varying between 5 and 20 m, underlain by much stiffer materials of class A"* (European Committee for Standardization, 2000). To do this, place the cursor on the text box adjacent to the **S** label and enter ***1.4***. Please note that this is only allowed when **Class B** of the **Subsoil Class** options is selected. If a different value is entered, the program will set the default value for the soil parameter based on the type of spectrum selected.

Execute SHAKE



This form provides a quick way of executing SHAKE using an input file that has been created before with the **Earthquake Response Analysis** form.

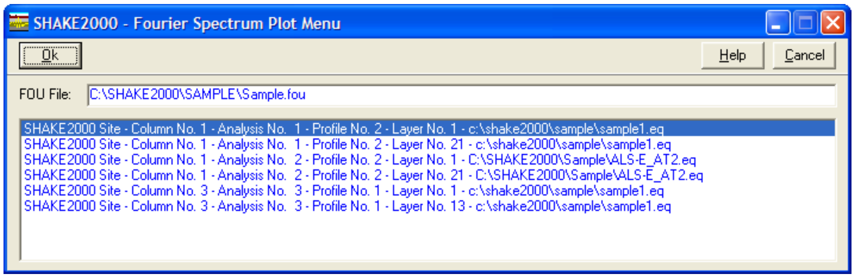
Before you execute SHAKE, you need to enter the name of the two output files and select a directory path where these files will be saved. Place the cursor on the text box next to the **Output File No. 1** label and type in the name for the first output file (i.e. the file that saves information on the material properties, soil column, ground motion, peak acceleration, response spectra, etc.), followed by a period and the extension (e.g. OUT). SHAKE2000 will not add an extension to the end of the file if it is not entered. You can enter up to 32 characters. Blank spaces are not allowed. Next, place the cursor on the text box next to the **Output File No. 2** label and type in the name for the second output file (i.e. the file that saves acceleration and shear strain/stress time histories). These files will be saved to the folder shown on the text box next to the **Directory of Output Files** label. To change the location of the output directory, click on the **Directory** button to display the **Choose Output Directory** form, select a different folder by double clicking on it, and then click on the **Ok** button to return to this form.

If you created an input file using the **Earthquake Response Analysis** form then the name and path to this file will be shown on the text box next to the **Input File** label. Otherwise, you need to select an input file by first clicking on the **Input** command button. This will display the **Open SHAKE91 Input File** dialog form. By default, files with the extension *.IN will be shown. If necessary, change folders to the location where the input file is saved. Then click on the file name to highlight it and then click on the **Open** command button to return to this form. The file name will be shown next to the **Input File** label.

Now, to execute SHAKE click on the **SHAKE** command button. A DOS window will open and then automatically close upon termination of the program.

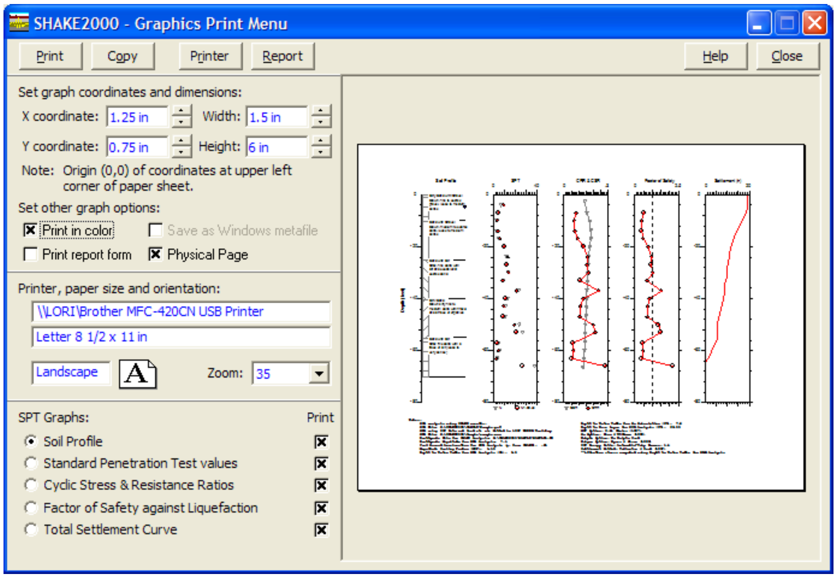
To process the output files, click on the **Close** command button to return to the main menu form. The names and paths to the output files will be shown on the text boxes next to the **Process First Output File** and **Process Second Output File** labels on the **Main Menu** form. If there were any errors during the execution of SHAKE, then an error message will likely be displayed during the processing of the output files. In this case, it is recommended to use a text editor (e.g. Wordpad) to open the output files and proceed to the option that may have caused the error. Then, review the information provided in the output file and review the input data for this option to determine the reason for the error.

Fourier Spectrum Plot Menu



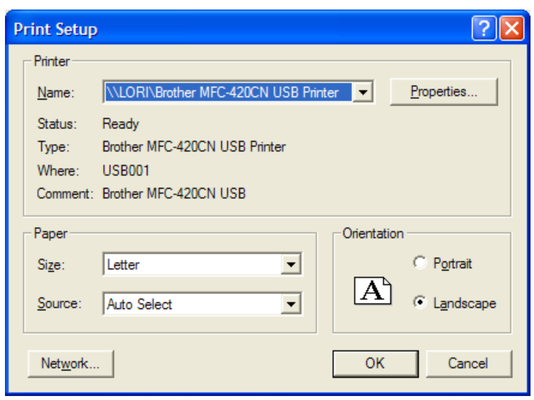
A list of the different plots is displayed on this window. To select a plot, click on it, and then click on the **Ok** button. Alternatively, you can double click on the plot. The **Cancel** button is used to return to the graph window without choosing a plot.

Graphics Print Menu



*The graph can also be printed using the **System Property Page** of the graphics server. To do so, click on the toolbar at the top of the graphics window to display the property pages. Select the **System** tab. You can also use this page to save an image of the graph to a file in either metafile or bitmap format. For further information or help, click on the question mark icon.*

SHAKE2000 uses the standard Windows printer dialog form to select a printer and/or to change the properties of the printer and paper used to print the graph. This form can be displayed by clicking on the **Printer** command button.



Every time the size or position of the graph is changed, the graph is automatically redrawn on the preview window. To zoom in on the preview graph, double-click on it with the left mouse button. To zoom out, double-click on it with the right mouse button.

Use the **Copy** command button to copy the graph to the clipboard. You can use then the **Paste** or **Paste Special** commands on other Windows applications (i.e. Microsoft Word), to insert the graph into other documents.

X coordinate: This cell is used to enter the X coordinate from the top left corner of the graph. The origin of the coordinate system is at the top left corner of the paper sheet. Use the *Tab* key to move to the other data cells, and the *Delete* key to delete the contents of a cell. Once the value of this cell is modified, the margins shown will be automatically updated.

Y coordinate: This cell is used to enter the Y coordinate from the top left corner of the graph. The origin of the coordinate system is at the top left corner of the paper sheet. Use the *Tab* key to move to the other data cells, and the *Delete* key to delete the contents of a cell. Once the value of this cell is modified, the margins shown will be automatically updated.

Graph width: Set the width of the graph using the units defined by the paper size set on the window's print setup dialog. Use the *Tab* key to move to the other data cells, and the *Delete* key to delete the contents of a cell. Once the value of this cell is modified, the margins shown will be automatically updated.

Graph height: Set the height of the graph using the units defined by the paper size set on the window's print setup dialog. Use the *Tab* key to move to the other data cells, and the *Delete* key to delete the contents of a cell. Once the value of this cell is modified, the margins shown will be automatically updated.

The paper dimensions shown in the **Width** and **Height** boxes will switch to update the paper orientation to portrait or landscape. The margins shown will also be updated. Once you have entered the dimensions and position of the graph, use the **Print** button to send a copy of the graph to the printer

To create the form that can be printed together with the graph, click on the **Report** command button to display the **Company & Project Information** form, and then on the **Form** command button to display the **Report Form Development** form.

Options:

Print in color: Select this option to print the graph in color using a color printer. By default, when the Graphics Print Menu form is displayed, the graph is drawn in black & white. When this option is selected, an **x** will appear in the check box, and the graph will be redrawn in color.

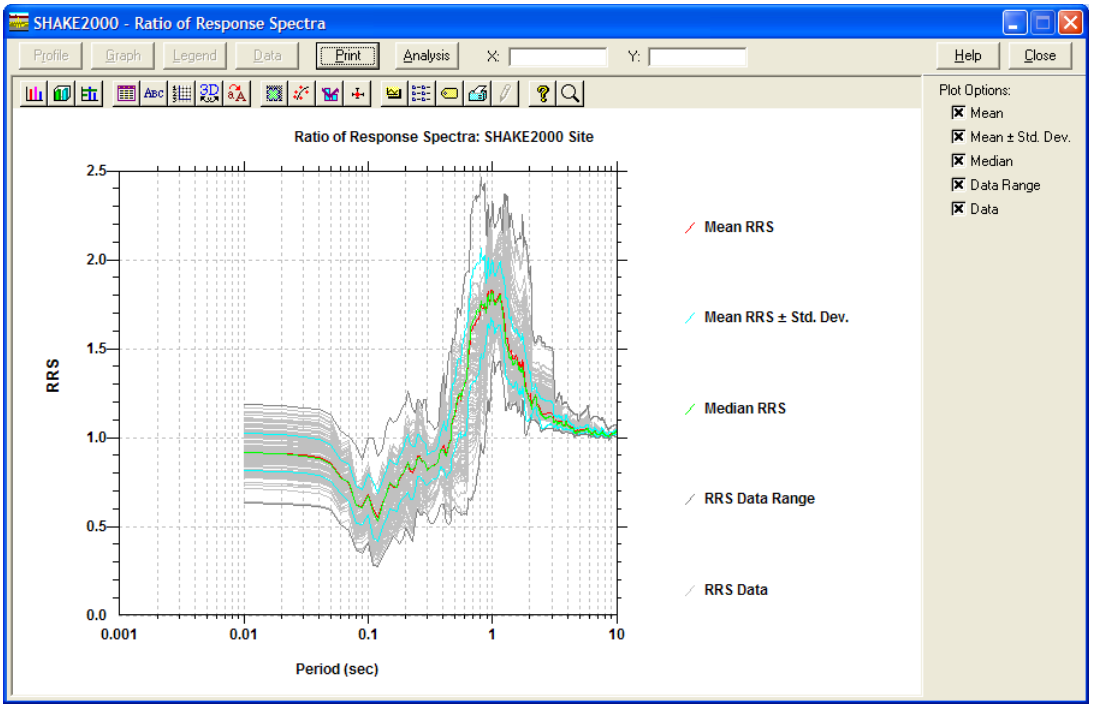
Print as a windows metafile: Select this option if you want to create a Windows metafile of the graph. Click on **Print** to display the **Windows Metafile** dialog form. Enter the name of the file, and select a directory where the file will be saved. Then click **Save**.

Print report form: Select this option to print a form on the same sheet of paper as the graph. To create the form, click on the **Report** command button to display the **Company & Project Information** form, and then on the **Form** command button to display the **Report Form Development** form.

Physical page: This option determines whether the logical page used by the printer control should correspond to the entire physical page or only to its printable area. Most printers have a “logical” paper size that corresponds to the printer's printable area, and a “physical” paper size that corresponds to the actual page size. The physical paper size is always a little larger than the logical paper size. If this option is selected (an **x** is shown on the check box), the program will print to the physical page. This option only works when the **Print report form** option is selected.

SPT, CPT or V_s Graphs: To change the position of any of the graphs on the paper, first click on the option button for the graph to select it. Then, enter the new coordinates on the coordinate text boxes, or use the up-down arrows to change the coordinates. If you don't want the graph to be printed, click on the appropriate check box of the **Print** column to deselect it (i.e. the **x** is not shown on the box). Selecting or deselecting a graph does not modify the position of the other graphs.

Graphics Window



To obtain additional help for the graphics, click on the question mark icon shown on the toolbar at the top of the graphics window. In addition, the property pages, accessed through the icons shown on the tool bar, can be used to customize the graph.

The different layers forming the soil profile can be displayed by clicking on the **Profile** command button. Click once more to remove the layers.

To display a menu of available plots, click on the **Graph** command button. A form showing the different plot options will be displayed. The form displayed depends on what option is being plotted (i.e., response spectra, time histories, etc.).

To change the number of points plotted, click on the **Data** button. This button is disabled when plotting the results from the first SHAKE output file, or when plotting more than two response spectra curves.

To change the legends of the curves, click on the **Legend** command button. This will display the **Legend Text** form.

To print a copy of the graph, or to copy the graph to the Windows Clipboard for use by other applications, click on the **Print** command button to display the **Graphics Print Menu** form.

When plotting the results from the cyclic stress ratio analysis, the **Data** command button changes to **FSL** that you can use to plot the factor of safety against liquefaction. The button changes to **CSR** that can be used to plot the cyclic stress ratio curves again.

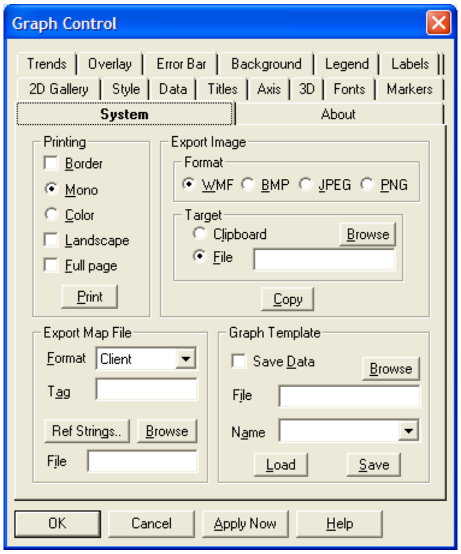
A summary of the different options that are included in the first and second output files created by SHAKE can be shown by clicking on the **Analysis** command button. This button will display the **Analysis Summary** form. This button is enabled only after executing either the **Process first output file** or **Process second output file** options of the **Main Menu** form.

Point Coordinates: To display the X and Y coordinates of a specific point on the graph, click on any of the symbols on the graph to display its coordinates in the text cells shown on the command button bar of the form.

The **CSR** button is used to redraw the CSR and CRR curves. This button changes to **FSL**, and can be used to display the curve representing the factor of safety against liquefaction. These buttons are only enabled when the cyclic stress ratio option has been selected.

The **Plot Options**, i.e. **Mean**, **Mean ± Standard Deviation**, **Median**, **Data** and **Data Range**, are only enabled when plotting results of analyses conducted using the random generation or ratio of response spectrum features. By unselecting the option, the respective curve will be removed from the graph.

The graphics routine includes a number of property pages that can be used for customization of the graph. For example, you could add a 3-D look to the graph, or change the colors. The property pages are accessed through the icons on the toolbar. Some of these icons are not enabled (i.e. they will appear grayed-out). For example, click on the **System** icon, the fourth icon from the left to display the **System** property page of the Graph Control.

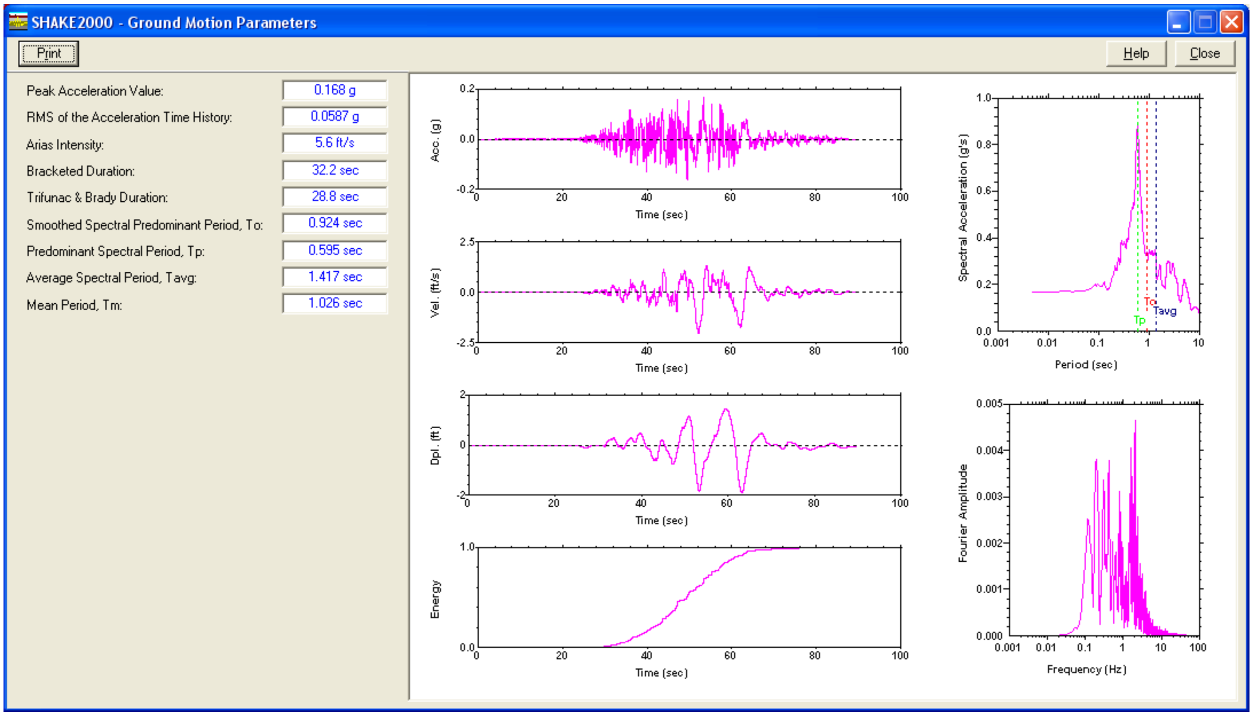


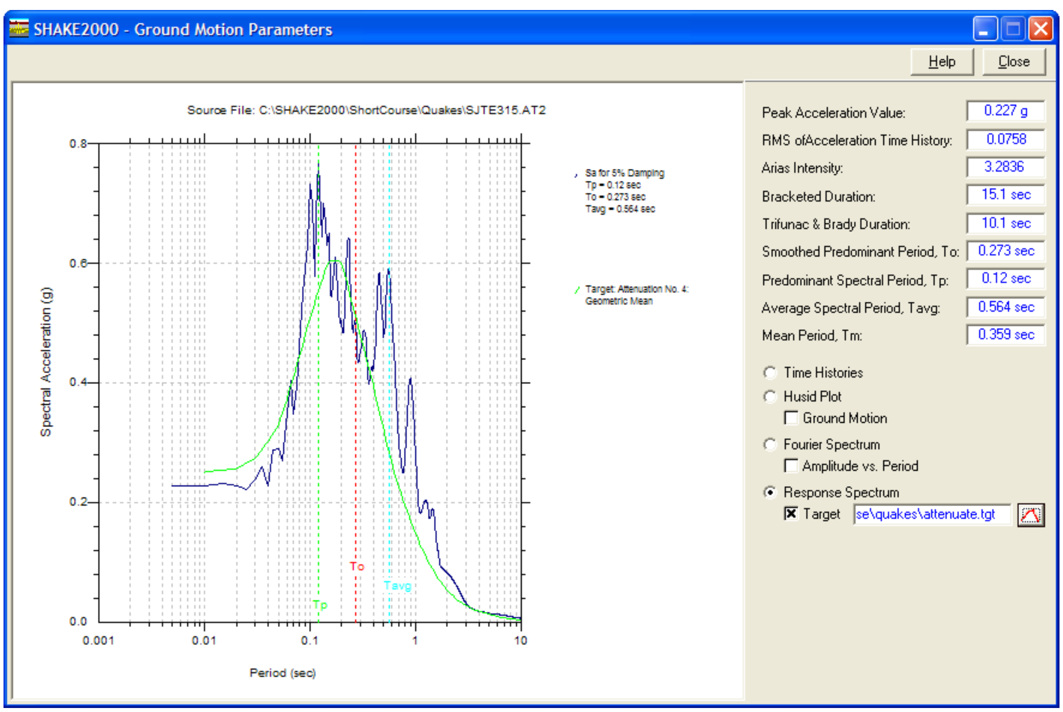
More help on these pages can be obtained by clicking on the **Help** command button of these pages.

When plotting the significant duration of earthquake ground motions using the Abrahamson & Silva (1996), Kempton & Stewart (2006) or Bommer, Stafford & Alarcon (2009) relation, the duration/distance pair for a user's record can be plotted on the same graph for comparison purposes. To do this, first enter the record's distance and duration in the respective text boxes and a label of up to 24 characters to describe this record; then, click on the **Plot user's event** option to select it.

If the incident PGA is obtained for a layer in Option 6, the word "Incident" and a green circle will be displayed at the point of the PGA vs. Depth graph where this type of motion was requested. When plotting the acceleration time history, the word "Incident" will also be displayed in the header line of the acceleration time history. For more detailed information about the incident and reflected waves, please refer to Section 2 of this user's manual.

Ground Motion Parameters





This form presents various parameters used to characterize a ground motion, which can then be used to select a representative time history for site specific response analyses.

These parameters include peak ground acceleration, Arias Intensity, Root-Mean-Square of the acceleration time history (RMSA), bracketed duration, Trifunac & Brady duration, and predominant period (Hu et al., 1996; Kavazanjian et al., 1997; Kramer, 1996). In addition, you can plot a graph of the Normalized Arias Intensity, or Husid Plot, together with the ground motion; and the computed and smoothed Fourier Amplitude Spectra.

The upper most version of the form is displayed when calling this form from the **Plot Object Motion** form; and, the lower version of the form displayed when the form is called from the **Conversion of Ground Motion File** form.

The Peak Acceleration Value is the maximum, absolute acceleration value of the time history.

The energy content of the acceleration time history provides another means of characterizing strong ground motions. A measure of the total energy content of a ground motion is given by the Arias Intensity, which is defined by the following relation:

$$I_A = \frac{\pi}{2g}\int_0^{t_f}[a(t)]^2 dt$$

Where t_f is the duration of ground shaking, $a(t)$ the ground acceleration, and g is the acceleration of gravity. A plot of the increase of the energy content as a ratio of the total energy versus time is known as a Normalized Husid Plot.

The root-mean-square of the acceleration time history, or RMSA, is also used as a measure of the energy content. The RMSA is defined by the following relation:

$$RMSA = \sqrt{\frac{1}{t_f}\int_0^{t_f}[a(t)]^2 dt}$$

In SHAKE2000, the time interval between 5 and 95 percent of the total Arias Intensity is used to compute the RMSA.

The *Bracketed Duration* of strong motion is the time interval between the first and last acceleration peaks greater than a specified acceleration value, or threshold acceleration. The value shown in the above form is for a threshold acceleration of ±0.05 g. Based on the Normalized Husid Plot, the *Trifunac & Brady Duration* is the time interval between 5 and 95 percent of the total Arias Intensity.

Other parameters commonly used to evaluate the frequency content of a ground motion are the predominant spectral period, T_p, or commonly defined as the "… *period of the maximum spectral acceleration."* (Rathje et al., 2004); the smoothed spectral predominant period, T_o, which "….*attempts to define the peak in the response spectrum by smoothing the spectral accelerations over the range where S_a is greater than 1.2 * PGA"* (Rathje et al., 2004); and, the average spectral period, T_{avg}, defined as an average period (over a specified frequency range) weighted by the spectral accelerations (Rathje et al., 2004). To compute these periods, the response spectrum for 5% damping is first computed using equally spaced periods on a log axis to obtain T_o, and then the spectrum is computed a second time using equally spaced periods on an arithmetic axis to obtain T_{avg}.

Another indicator of frequency content of accelerograms is the Mean Period, T_m, defined as (Rathje et al., 1998; Stewart et al., 2001):

$$T_m = \frac{\sum_i C_i^2 \left(\frac{1}{f_i}\right)}{\sum_i C_i^2}$$

Where: C_i = Fourier amplitudes of the entire accelerogram

f_i = Discrete Fourier transform frequencies between 0.25 and 20 Hz.

The value for T_m is shown on the text box next to the **Mean Period, T_m** label.

On the bottom section of the form there are two plotting options. The **Husid Plot** option will display a graph of the Normalized Husid Plot.

If you select the **Plot Ground Motion** option, then the acceleration time history will be plotted on the same graph with the Husid Plot. In the plot, the section of the Husid Plot for the Trifunac & Brady duration is shown as a red curve.

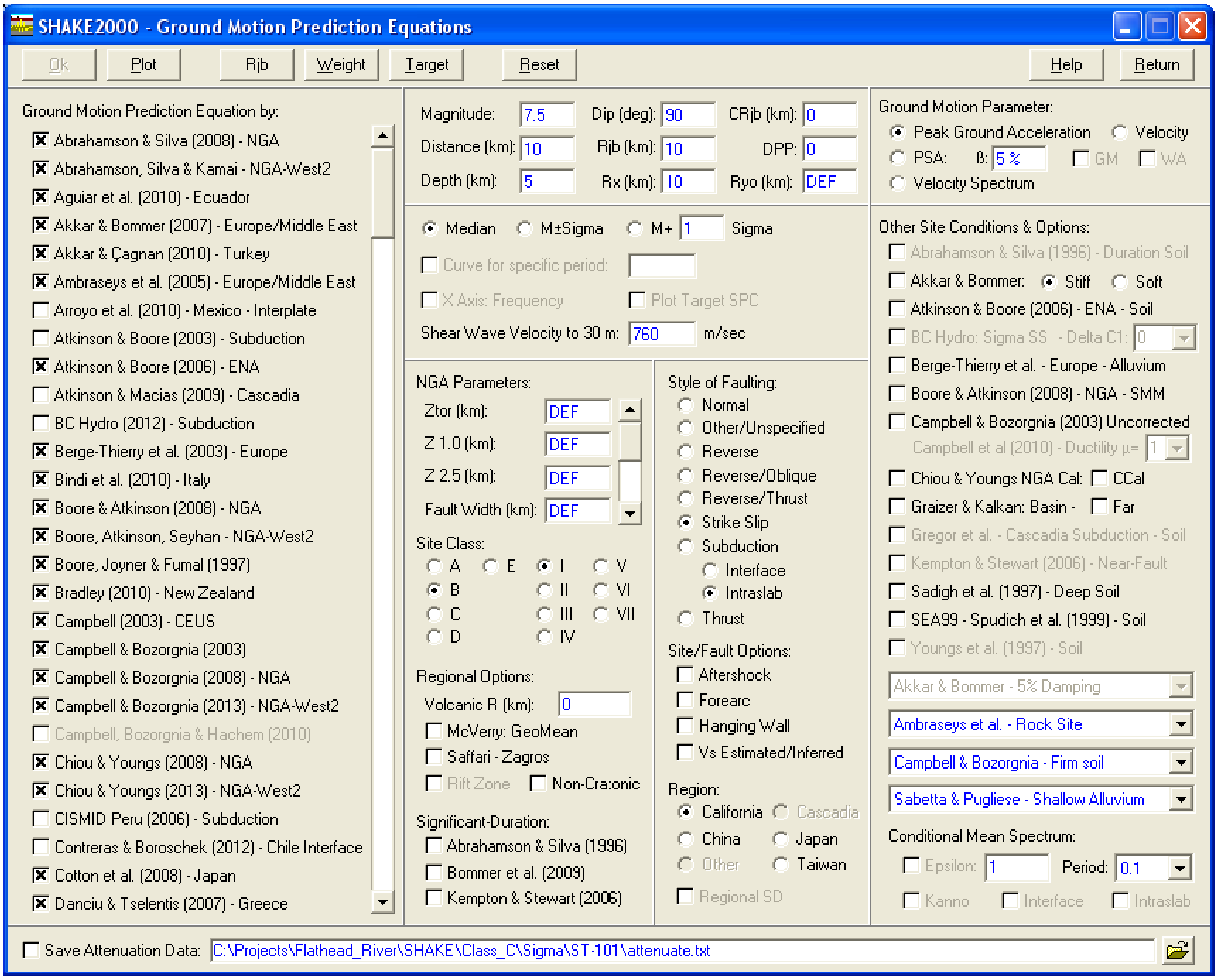
The **Fourier Spectrum** option will plot the Fourier amplitude spectrum. By default, the Fourier response spectrum is plotted using frequency values in the X-axis. Alternatively, to plot the Fourier amplitudes vs. period click on the **Amplitude vs. Period** check box to select it.

After selecting one of the plotting options, click on the **Plot** command button to display the graphs. When plotting the response and the Fourier spectra, T_p, T_o, T_{avg} and T_m will be shown on the graphs.

You can print the results by using the **Print** command button.

To plot a target response spectrum, click on the spectrum icon to display the file dialog form, and then select a target spectrum file (i.e., *.TGT file). After reading the contents of the file, click on the **Target** check box to display the spectra.

Ground Motion Prediction Equations



This section presents a number of ground motion ground motion prediction equations that can be used to estimate the peak ground acceleration or velocity with distance, and the pseudo-absolute acceleration or pseudo-relative velocity response spectra. The reference for each attenuation relation is given, and the user is solely responsible for verifying that the ground motion prediction equations are appropriate for his/her particular problem, and that the data required for each attenuation relation are entered in the appropriate units. It is recommended to review the references listed in this section to obtain more detailed information about these ground motion prediction equations and their uses.

The ground motion prediction equations available in SHAKE2000 include:

1. Abrahamson & Silva (2008) – NGA. Reference: Abrahamson, N.A. and Silva, W. (2008).
2. Aguiar et al. (2010) – Ecuador. Reference: Aguiar, R., et al. (2010).
3. Akkar & Bommer (2007) – Europe/Middle East. Reference: Akkar, S. and Bommer, J. (2007a, 2007b).
4. Akkar & Çağnan (2010) – Turkey. Reference: Akkar S. and Çağnan, Z. (2010)
5. Ambraseys et al. (2005) – Europe/Middle East. Reference: Abramseys, N.N., Simpson, K.A., and Bommer, J.J. (1996); and, Ambraseys et al. (2005a, 2005b).
6. Arroyo et al. (2010) – Mexico. Reference: Arroyo et al. (2010).
7. Atkinson & Boore (2003) - Subduction. Reference: Atkinson, G.M. and Boore, D.M. (1997a); Atkinson, G.M. and Boore, D.M. (2003, 2008).

8. Atkinson & Boore (2006) - ENA. Reference: Atkinson, G.M. and Boore, D.M. (2006).
9. Atkinson & Macias (2009) – Cascadia. Reference: Atkinson, G.M. and Macias, M. (2009).
10. BC Hdyro (2012) – Subduction. Reference: Abrahamson et al. (2012).
11. Berge-Thierry et al. (2003) - Europe. Reference: Berge-Thierry, C., Cotton, F. and Scotti, O. (2003).
12. Bindi et al. (2010) – Italy. Reference: Bindi, D., et al. (2010).
13. Boore & Atkinson (2008) – NGA. Reference: Boore, David and Atkinson, Gail (2008); Atkinson & Boore (2011).
14. Boore, Joyner & Fumal (1997). Reference: Joyner, W.B., Boore, D.M. and Fumal, T.E. (1997).
15. Bradley (2010) – New Zealand. Reference: Bradley (2010).
16. Campbell (2003) - CEUS. Reference: Campbell, K.W. (2002; 2003, personal communication; 2004).
17. Campbell & Bozorgnia (2003). References: Campbell, K.W. and Bozorgnia, Y. (2003a, 2003b, 2003c, 2004); Campbell, K.W. (2003).
18. Campbell & Bozorgnia (2008) - NGA. Reference: Campbell, K.W. and Bozorgnia, Y. (2008).
19. Campbell, Bozorgnia & Hachem (2010) – Relation for ***Inelastic*** response spectra. Reference: Bozorgnia et al. (2010).
20. Chiou, B. & Youngs, R. (2008) – NGA. Reference: Chiou, Brian S. and Youngs, Robert R. (2008); Chiou et al. (2010).
21. CISMID Peru (2006) – Subduction. Reference: Chavez (2006).
22. Contreras & Boroschek (2012) – Chile Interface. Reference: Contreras and Boroschek (2012).
23. Cotton et al. (2008) – Japan. (Surface Site Conditions). Reference: Cotton et al. (2008).
24. Danciu & Tselentis (2007) – Greece. Reference: Danciu, L. and G-Akis Tselentis (2007).
25. Di Alessandro et al. (2012) – Italy. Reference: Di Alessandro, C. et al. (2012).
26. Douglas et al. (2006) – Southern Norway. Reference: Douglas et al. (2006).
27. Douglas et al. (2006) – Southen Spain. Reference: Douglas et al. (2006).
28. García et al. (2005) – Mexico. Reference: Garcia, D., et al. (2005).
29. Graizer & Kalkan (2007, 2009). Reference: Graizer, V and Kalkan, E. (2007, 2009).
30. Gregor et al. (2002) - Cascadia Subduction. Reference: Gregor et al. (2002).
31. Idriss, I.M. (2008) – NGA. Reference: Idriss, I.M. (2008).
32. Kalkan & Gülkan (2004) – Turkey. Reference: Kalkan, E. and Gulkan, P. (2004).
33. Kanno et al. (2006) – Japan. Reference: Kanno et al. (2006).
34. Lin et al. (2011) – Crustal – Taiwan. Reference: Lin, P. et al. (2011).
35. Lin & Lee (2008) – Subduction – Taiwan. Reference: Lin, P. and Lee, C. (2008).
36. Margaris et al. (2002) – Greece. Reference: Margaris, B.N. et al. (2002).
37. Massa et al. (2008) – Northern Italy. Reference: Massa et al. (2008).
38. McVerry et al. (2006) – New Zealand. Reference: McVerry et al. (2006).
39. Megawati et al. (2005) – Sumatran-Subduction. Reference: Megawati, K. et al (2005).
40. Mezcua et al. (2008) – Spain. Reference: Mezcua, J. et al. (2008).
41. Pezeshk et al. (2011) – ENA. Reference: Pezeshk, S. et al (2011).
42. Ruiz & Saragoni (2005) – Chile. Reference: Ruiz, S. and Saragoni, G.R. (2005).
43. Sabetta & Pugliese (2009) - Italy. References: Sabetta, F. and Pugliese, A. (1987, 1996); Bindi et al. (2009).
44. Sadigh et al. (1997). Reference: Sadigh et al. (1997).
45. Saffari et al. (2012) – Iran. Reference: Saffari, H. et al. (2012).
46. SEA99 - Spudich et al. (1999). Reference: Spudich, P. et al. (1996); Spudich, P. et al. (1999); and, Pankow & Pechmann (2004).
47. Silva et al. (2002) – CEUS. (Single corner model with constant stress drop and saturation). Reference: Silva, W. et al. (2002).
48. Somerville et al. (2001) – CEUS. Reference: Somerville, P., et al. (2001).
49. Somerville et al. (2009) – Australia. Reference: Somerville, P. et al. (2009).
50. Tavakoli & Pezeshk (2005) – ENA. Reference: Tavakoli & Pezeshk (2003).
51. Toro & Silva (2001) – CEUS – Double Corner. Reference: Toro, G.R. and Silva, W.J. (2001).
52. Toro & Silva (2001) – CEUS – Single Corner. Reference: Toro, G.R. and Silva, W.J. (2001).
53. Toro et al. (1997) - CEUS - Gulf. References: Toro, G.R., Abrahamson, N.A. and Schneider, J.F (1997); Silva, W., Pyke, R., Youngs, R., and Idriss, I.M. (1996); Electric Power Research Institute (EPRI) (1993); and, Toro, Gabriel R. (2002).

54. Toro et al. (1997) - CEUS - Midcontinent. References: Toro, G.R., Abrahamson, N.A. and Schneider, J.F (1997); Silva, W., Pyke, R., Youngs, R., and Idriss, I.M. (1996); Electric Power Research Institute (EPRI) (1993); and, Toro, Gabriel R. (2002).
55. Youngs, Chiou, Silva & Humphrey (1997). Reference: Youngs, R.R., Chiou, S.J., Silva, W.J. and Humphrey, J.R. (1997).
56. Zhao et al. (2006) – Japan. Reference: John X. Zhao et al. (2006).

Three equations for prediction of significant-duration are also provided:

57. A&S 1996 (Abrahamson & Silva, 1996). Reference: Abrahamson and Silva (1996).
58. BSA 2009 (Bommer, Stafford & Alarcon, 2009). Reference: Bommer et al. (2009).
59. K&S 2006 (Kempton & Stewart, 2006). Reference: Kempton and Stewart (2006).

Please refer to the above references for detailed information on the use and application of these ground motion prediction equations. Two excellent references that provide detailed information on the parameters used by each relation are Douglas (2011) and Douglas et al. (2010).

To plot an attenuation relation, first select what type of plot you would like to use by choosing one of the four options on the top right section of the form. There are four options: **Peak Ground Acceleration, Peak Ground Velocity, Acceleration Spectrum,** and **Velocity Spectrum**. Depending on what type of ground motion parameter you choose, different relations will be available. For example, by default, when the **Peak Ground Acceleration** option is chosen, most of the equations are enabled (i.e., they are not grayed out). If you choose the **Peak Ground Velocity** option, then only the Atkinson & Boore (1997) - Cascadia; Atkinson & Boore (2006) ENA; Atkinson & Silva (2000) – California; Campbell, K.W. (1997); Sabetta & Pugliese (1996); and, SEA99, Spudich et al. relations will be enabled and the others will be disabled (i.e. shown as grayed out options).

Next, select which ground motion prediction equations you want to use by clicking on the check box next to each. An **x** appears in the box when an attenuation relation is selected. Use the *Tab* key or the mouse to place the cursor on the **Magnitude** text box, and enter the earthquake magnitude. Enter the distance and depth in the **Distance** and **Depth** text boxes, respectively. Select other options as explained below, depending on the relations chosen. The **Plot** command button is enabled when at least one attenuation relation is selected. Click on the **Plot** button to display the curve. Please note that the depth value used in the Campbell (1997) equation is the depth to basement rock.

When computing response spectrum, the default damping value is 5%. To obtain the spectrum for a different value of damping enter the damping value in percentage (e.g. 5), the program will use then the damping scaling factors provided by Rezaeian et al (2012) to obtain the spectrum for the different damping ratio.

The program will include a short label for the distance and magnitude scale used in the attenuation relation. For more detailed information about each distance definition, please refer to the appropriate reference. These labels include: Rrup (closest distance to the rupture plane); Repic (epicentral distance); Rhyp (hypocentral distance); Rjb (horizontal distance to the surface projection of the rupture, Joyner-Boore distance); Rseis (distance to seismogenic rupture); Rcd (closest distance to the fault rupture; closest distance to fault surface; closest distance to the fault); and, Rsrc (shortest distance to the seismic fault plane; shortest distance to the fault rupture plane; shortest distance to the rupture zone; source-to-station distance). For magnitude: Mw (moment magnitude); Ml (local magnitude); and, Ms (surface-wave magnitude).

The **Return** button is used to return to the Main Menu form, or to return to the Response Spectrum Plot Menu form.

The **Curve for specific period** option allows you to plot the spectral acceleration or velocity attenuation curve (i.e., acceleration or velocity vs. Distance) for specific periods. When selecting more than one attenuation relation, the attenuation curve will be displayed only for those equations that have coefficients for that specific period. Check the **Period** column for each attenuation relation’s coefficients to determine if a period value is acceptable. Enter the value for the period in the text box next to the label.

Depending on the attenuation relation selected, there are other options that can be used. Some relations classify the faulting mechanism of an earthquake into one of a number of categories. The different categories are shown in the

Style of Faulting section of the form. By default, the **Strike Slip** type is chosen. You can select other types by clicking on any of the options shown. The type selected will be used for all of the relations that it applies to when those relations are selected. Note that an attenuation relation will not be selected (i.e. an **x** is shown on the check box) if the **Style of Faulting** option selected does not apply to this relation. The **Subduction** option in the **Style of Faulting** list only applies to the Zhao et al. (2006) relation.

The **Intraslab** and **Interface** options apply to the Youngs, Chiou, Silva & Humphrey (1997); Atkinson & Boore (2003); and Zhao et al. (2006) relations. By default, the **Intraslab** option is selected, thus the attenuation relation for intraslab events will be used. To use the attenuation relation for interface events, click on the **Interface** option.

The **M ± Sigma** option is used to plot the median attenuation curve, and the curves that represent the median plus and the median minus sigma. When this option is selected, only one of the ground motion prediction equations will be used, i.e. the top attenuation relation selected will be the one used.

The **Plot Spectra vs. Frequency (Hz)** option is used to change the X-axis to the frequency scale. When this option is selected, an **x** appears in the check box. To deselect this option, click on the check box, this will switch to the period scale in the X-axis.

A value for the shear wave velocity (V_s) to a depth of 30 meters can be entered in the **Shear Wave Velocity to 30 m** label, in m/sec.

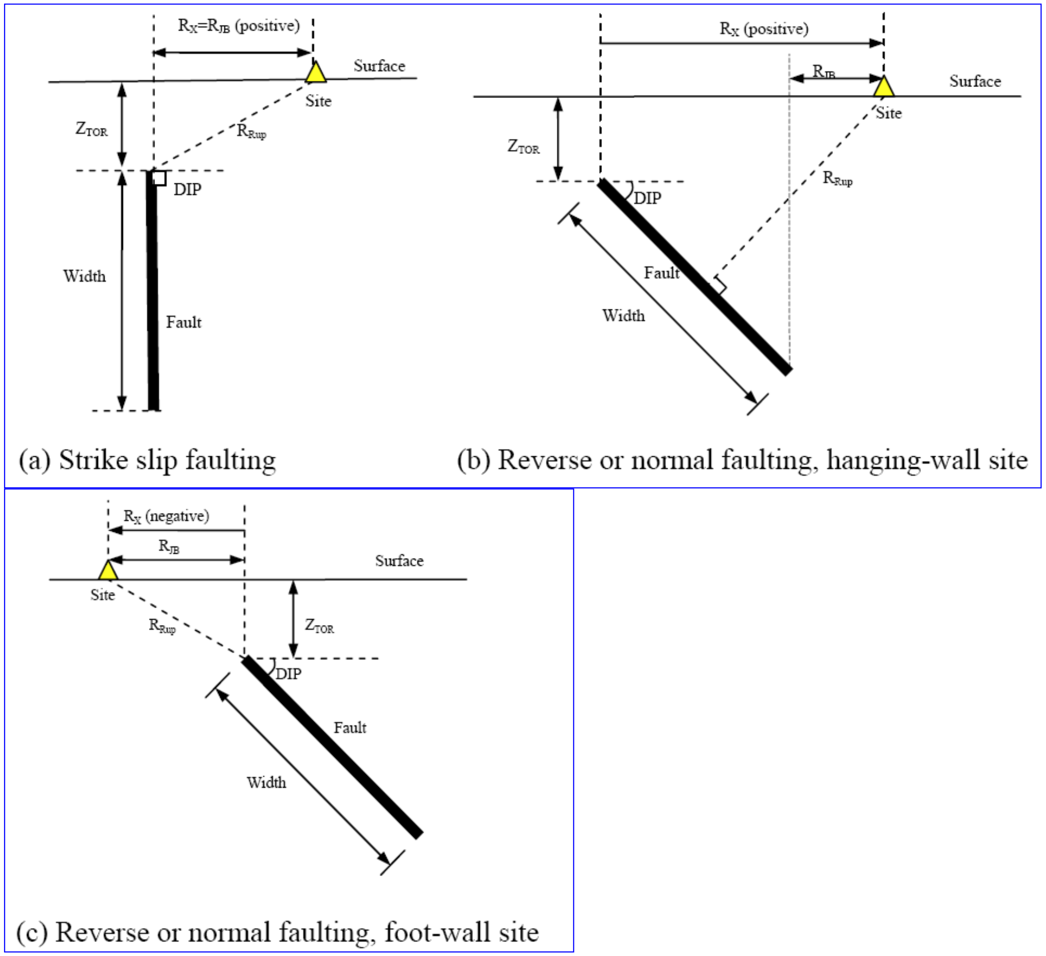
When using the **Vertical** component option, the ground motion prediction equations and/or coefficients for the vertical component of PGA, PGV and PSA will be used.

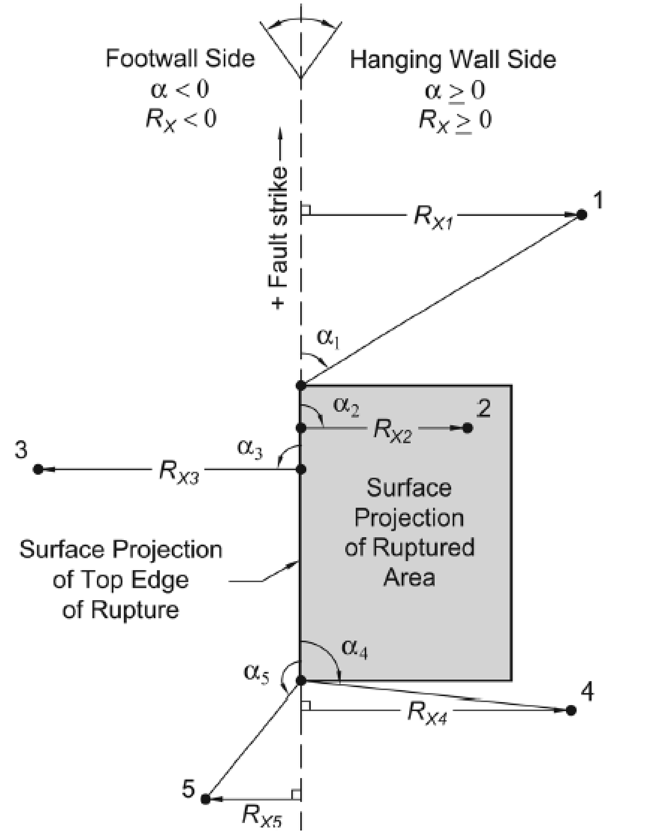
The **Site Class** options are used with the Atkinson & Boore (2003), Bindi et al. (2010), Danciu & Tselentis (2007), Lin & Lee (2008), Margaris et al. (2002), Ruiz & Saragoni (2005), and Zhao et al. (2006) ground motion prediction equations. By default, the attenuation relation for **Site Class B** is selected. A different site class can be chosen by clicking on the respective option. The site classes represent the NEHRP classes (see Table 2 of Zhao et al. (2006) for equivalent site class definitions). Further, for the Atkinson & Boore (2003) relation, classes A and B represent rock. In addition, the user can select a region for the Atkinson & Boore relation by selecting the **Cascade**, **Japan**, or **Other** option; and, the **Regional SD** option for region specific error terms.

For the Toro et al. (1997) ground motion prediction equations, the equations used are those for **Moment Magnitude**.

For Bozorgnia & Campbell (2003), when considering the effect of the hanging wall, it is necessary to enter r_{jb}, or the closest distance to the surface projection of fault rupture (Campbell, K.W. and Bozorgnia, Y., 2003a; Boore et al., 1997). Alternatively, the fault dip angle, δ, can be used instead. To enter r_{jb}, click on the **Rjb** command button to display the **R_{jb} and R_x Distance** form. On this form, enter the r_{jb} distance for each value of r_{seis}. If you need more information about this distance, please refer to Cambpell, K.W. and Bozorgnia, Y. (2003a) and Abrahamson, N.A. and Shedlock, K.M. (1997). The dip angle value can be entered in the **dip (deg)** text box. By default, the peak ground acceleration is estimated using the attenuation relation for uncorrected PGA. To use the corrected PGA attenuation relation, click on the **Corrected** option of the **Bozorgnia (PGA)** options. Please note that the value of PGA used in the computation of the standard deviation, σ_{lnY}, is determined based on the choice of the **Bozorgnia (PGA)** options.

The R_{jb} and R_x distances are also required when using the Campbell & Bozorgnia (2003); Abrahamson & Silva (2008) – NGA; Akkar & Bommer (2008); Boore, D. & Atkinson, G. (2008) – NGA; Campbell & Bozorgnia (2008) – NGA; Chiou, B. & Youngs, R. (2008) – NGA; and, Campbell, Bozorgnia & Hachem (2010) relations. To enter R_{jb} and R_x, click on the **Rjb** command button to display the **R_{jb} and R_x Distance** form. Note that the program will plot the PHA vs. Distance, where for the NGA equations the distance is R_{rup} and for the Campbell & Bozorgnia (2003) it is R_{seis}. Accordingly, when R_{jb} and/or R_x are needed, these should be computed and entered in the respective columns of the **R_{jb} and R_x Distance** form. Similarly, for the Boore & Atkinson NGA and the Akkar & Bommer relations, the program will also plot the PHA vs. Distance wherein distance is assumed to be R_{rup}, but the program will use R_{jb} entered in the respective column of the **R_{jb} and R_x Distance** form for the computations.





Distance Definitions in PEER NGA Excel Spreadsheet

Definition of source-to-site-azimuth and site coordinates when using Kaklamanos et al. (2010) equations (figure extracted from Kaklamanos et al. (2010).

The single value of R_{jb} or R_x distance used for computation of response spectra can be entered in the **r_{jb} (km)** or **R_x** text box, respectively. For the Boore & Atkinson NGA, the value of distance entered in the **r_{jb} (km)** text box is used instead of the value entered in the **Distance** text box. The following figures included in the PEER NGA Excel spreadsheet and in Kaklamos et al. (2010) will help you understand the distance definition in a more clear way.

For a definition of the parameters in the **NGA Parameters** section of the form, please refer to references for the NGA ground motion prediction equations. The user can manually enter a value for each parameter, or enter the "DEF" string to use the default values. For the Z_1 and $Z_{2.5}$ parameters, the default values are based on relationships provided in Abrahamson & Silva (2008), Campbell & Bozorgnia (2008) and Chiou & Youngs (2008), based on the $V_{S,30}$. For the Z_{tor} and Width values, the program will use the relations presented in Kaklamos et al. (2011).

In the Sabetta & Pugliese (2009) relation, the data for the Joyner-Boore distance are used. Further, when computing response spectra, the program will use the distance entered in the **r_{jb}** text box.

The ground motion parameters recommended by Stewart, Liu & Choi (2003) are taken as the product of their amplification factors and the median attenuation values for rock obtained from the Abrahamson & Silva (1997) relation. For this relation, a classification category can be selected from the **Stewart** combo list in the **Other Site Conditions & Options** section of the form. In addition, the effect of the hanging wall can be accounted for by selecting the **Stewart** option of the **Hanging Wall** options.

When an attenuation relation can be applied to more than one site condition (e.g. rock and deep soil), SHAKE2000 will by default use the attenuation relation for rock when plotting the ground motion parameters. To plot these parameters for other site conditions, select the appropriate option for each attenuation relation from the **Other Site Conditions & Options**. Some specific information about these options is:

- In the Campbell (1997) attenuation relation, the coefficients for local site conditions are defined by selecting one of five options: Alluvium/firm soil, soft rock, hard rock, generic soil, or generic rock. By default, the option for hard rock is selected. For the generic options, default values of depth to basement rock of 1 and 5 km for rock and soil respectively, are used in the attenuation relation.
- For the Abrahamson & Silva (1997, 2008 NGA), Bozorgnia & Campbell (2003), Chiou & Youngs (2008 NGA) or Stewart et al. (2003) ground motion prediction equations, select the corresponding option of the **Hanging Wall** options to use the factor to distinguish between ground motions on the hanging wall and footwall of dipping faults.

The **Boore & Atkinson (2008) – NGA – SMM** option can be selected to modify the values for western events with magnitudes less than 5.75 as recommended in Atkinson & Boore (2011).

The **Chiou & Youngs NGA Cal** option can be used to modify the Chiou et al. NGA attenuation results based on the information presented in Chiou et al. (2010) based on data from the California ShakeMap systems for events ≤ 5.5 up to distances of 200 km. By default, the parameters for central California will be used. To use the parameters for southern California, select the **CCal** option.

The **AB & CB** option of the Hanging Wall section, applies only to the Boore & Atkinson (2008) and Campbell and Bozorgnia (2003) relationships, and it is intended only to be used for computing R_{jb}, i.e., these equations do not have a hanging wall component but use R_{jb} on the computation.

When using the ground-motion prediction equations for significant-duration by Abrahamson & Silva (i.e. **A&S 1996**), Bommer, Stafford & Alarcon (**BSA 2009**) or Kempton & Stewart (i.e. **K&S 2006**), the magnitude value is entered in the **Magnitude** text box. For Kempton & Stewart and Bommer, Stafford & Alarcon, the value for $V_{s\text{-}30}$ is entered in the **Shear Wave Velocity to 30 m** text box; and, the value of Z_{tor} entered in the **Ztor** text box for the BSA. The **Mediand±Sigma** options also apply to these equations. By default, for Abrahamson and Silva, the equation for rock is used. If you wish to use the equation for soil, click on the **Abrahamson & Silva (1996) – Duration Soil** option to select it. The base model by Kempton and Stewart can be corrected for near-fault conditions by selecting the **Kempton &Stewart (2006) – Near-Fault** option. The result plotted will be the $D_{a5\text{-}95}$ value, i.e. the time interval between 5-95% of the Arias Intensity as a function of the acceleration record.

When an attenuation relation can be applied to more than one site condition (e.g. rock and deep soil), SHAKE2000 will by default use the attenuation relation for rock when plotting the ground motion parameters. To plot these parameters for other site conditions, select the appropriate option for each attenuation relation from the **Other Site Conditions & Options**. Some specific information about these options is:

- In the Campbell (1997) attenuation relation, the coefficients for local site conditions are defined by selecting one of five options: Alluvium/firm soil, soft rock, hard rock, generic soil, or generic rock. By default, the option for hard rock is selected. For the generic options, default values of depth to basement rock of 1 and 5 km for rock and soil respectively, are used in the attenuation relation.
- For the Abrahamson & Silva (1997, 2008 NGA), Bozorgnia & Campbell (2003), Chiou & Youngs (2008 NGA) or Stewart et al. (2003) ground motion prediction equations, select the corresponding option of the **Hanging Wall** options to use the factor to distinguish between ground motions on the hanging wall and footwall of dipping faults.

For the Contreras & Boroschek (2012), select the *Site Class A or B* option to obtain the results for rock (which is defined as rock with $V_S \geq 900$ m/sec as per the Chilean code soil classification); and, select any other *Site Class* option (i.e., C, D, or E) for soil. However, this does not mean that the results are for site class C or D or E, i.e., the results for soil will be the same; this is just a convenient way of doing it in the program.

For the Bradley (2010) and McVerry (2006) equations, the volcanic distance can be entered in the **Volcanic R (km)** text box.

When using the ground-motion prediction equations for significant-duration by Abrahamson & Silva (i.e. **A&S 1996**), Bommer, Stafford & Alarcon (**BSA 2009**) or Kempton & Stewart (i.e. **K&S 2006**), the magnitude value is entered in the **Magnitude** text box. For Kempton & Stewart and Bommer, Stafford & Alarcon, the value for $V_{s\text{-}30}$ is entered in the **Shear Wave Velocity to 30 m** text box; and, the value of Z_{tor} entered in the **Ztor** text box for the BSA. The Mediand±Sigma options also apply to these equations. By default, for Abrahamson and Silva, the equation for rock is used. If you wish to use the equation for soil, click on the **Abrahamson & Silva (1996) – Duration Soil** option to select it. The base model by Kempton and Stewart can be corrected for near-fault conditions by selecting the **Kempton &Stewart (2006) – Near-Fault** option. The result plotted will be the $D_{a5\text{-}95}$ value, i.e. the time interval between 5-95% of the Arias Intensity as a function of the acceleration record.
For those ground motion prediction equations that yield pseudo velocity (PRV), the Pseudo Absolute Acceleration (PAA) is obtained using the following equation:

$$PAA = \frac{2\pi\left(PRV\right)}{\left(981\right)T}$$

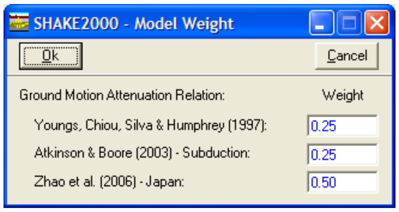
In addition, for those ground motion prediction equations that yield pseudo absolute acceleration, the Pseudo Relative Velocity is obtained using the following equation:

$$PRV = \frac{\left(981\right)T\left(PAA\right)}{2\pi}$$

In which T is period in seconds.

The attenuation data can be saved to a text file by selecting the **Save Attenuation Data** option. This text file can then be open with other applications, e.g. Excel, for further use. The path and name of the text file can be changed by clicking on the command button with the folder icon next to the text box. When plotting acceleration response spectra, a CSV (comma separated values) file will also be created in the same path using the same name but with the extension ".csv". This file can be opened with Excel for further processing. The CSV file will only save the data for one response spectrum.

When obtaining response spectra, the **GM** option will compute the geometric mean spectrum for the set of relations selected for the common range of periods. The **WA** option is used to obtain a "weighted" spectrum, i.e., different weights summing up to 1.0 can be assigned to the relations selected to compute a weighted spectrum. To enter the weights, first select between 2 and 10 relations and then click on the **Weight** command button to display the **Model Weight** form.



In this form, enter the weights for each relation in their respective text boxes. The weights should add up to 1.0 and each weight should be greater than 0.0. Also, when obtaining target response spectrum, the geometric mean or the weighted spectrum will be used as the target.

With the **LIQ** option, the model of Gingery et al. (2014) can be used to adjust acceleration response spectra computed with the 2008 NGA GMPEs to account for the effects of liquefaction on ground shaking.

To enter the data for a target response spectrum that can be plotted with the other spectra, click on the **Target** button to display the **Target Response Spectrum** form. In this form, you can enter values of period and spectra for a target response spectrum. To plot the target spectrum, select the **Plot Target SPC** option.

Peak Ground Acceleration value for Simplified CSR: The value for peak ground acceleration can be estimated using the ground motion prediction equations included with SHAKE2000. To do this, select an attenuation relation, enter the values for magnitude and depth, then select the other options for the attenuation relation. Click on the **Plot** command button to display the acceleration attenuation curve. Once the curve is plotted, click on the symbol for the distance of interest (or the closest distance value) to display the values in the X Y cells of the graphics window. Then click on the **Close** command button to return to this form and then click on **Ok** to return to the **Simplified CSR** form.

Conditional Mean Spectrum: This option is provided to compute the conditional mean spectrum as defined by Baker (2009) and further explained in Baker & Cornell (2005a, 2005b, 2006a, 2006b, 2008) and Baker & Jayaram (2008). An example of the applicability of this spectrum in the selection of ground motions for analysis is provided by PEER Ground Motion Selection and Modification Working Group (2009). This option only works with a few selected ground motion relations.

To plot a conditional mean spectrum, click on the **Epsilon** check box, then enter a value for epsilon in the text box. Based on the ground motion relation selected, a list of periods will be displayed when clicking on the down-arrow for the **Period** list. Click on the down-arrow to display the list and then click on the period that you would like to use for computation of the conditional mean spectrum. To plot the results, click on the **Plot** command button. Both the ground motion spectrum and the conditional mean spectrum will be displayed. When obtaining target response spectrum, only the conditional mean spectrum will be plotted.

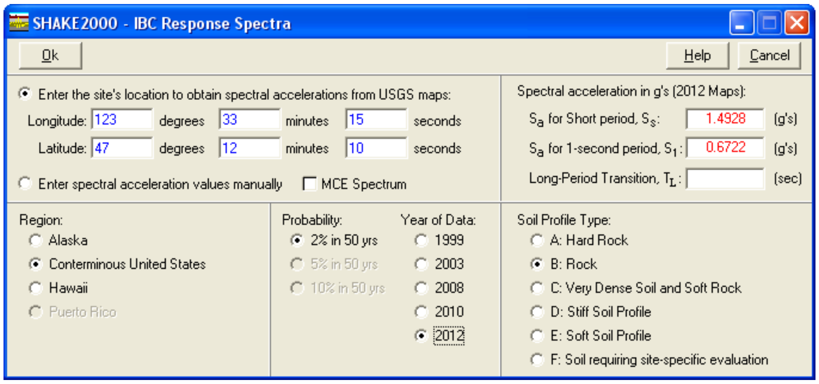
The **Kanno (2006)**, **Interface** and **Intraslab** options provide correlation values based on Japanese earthquake ground motion data (Jayaram et al., 2011). These options can be used instead of the values computed with the Baker and Jayaram relationship. The **Kanno (2006)** applies to the Kanno et al. (2006) attenuation relation; and, the **Interface** and **Intraslab** options apply to the Atkinson & Boore (2003) – Suduction, Gregor et al. (2002) – Cascadia Subduction, Youngs, Chiou, Silva & Humphrey (1997) and Zhao et al. (2006) – Japan relationships.

To plot a conditional mean spectrum, click on the **Epsilon** check box, then enter a value for epsilon in the text box. Based on the ground motion relation selected, a list of periods will be displayed when clicking on the down-arrow for the **Period** list. Click on the down-arrow to display the list and then click on the period that you would like to use for computation of the conditional mean spectrum.

To plot the results, click on the **Plot** command button. Both the ground motion spectrum and the conditional mean spectrum will be displayed. When obtaining target response spectrum, only the conditional mean spectrum will be plotted.
For the NGA-West2 GMPEs:

- Using **DEF** when the value is not known is similar to using **Unknown** in the PEER Excel file.
- The value of DPP centered on the earthquake-specific average DPP used in Chiou & Youngs, is entered in the **DPP** text box. This value is only used when computing the response spectrum. Further, DPP is zero when computing the median value.
- For the Abrahamson, Silva & Kamai GMPE, the value of centroid R_{jb} is entered in the **CRjb** text box. The R_{y0} distance is estimated based on R_{jb} if **DEF** is entered in the **CRjb** text box.
- For the Campbell & Bozorgnia GMPE, enter the value for Z_{HYP} in the **Z hyp** text box. Use the scroll bar to display this text box.
- If the distance to the bottom of the rupture zone is know, then enter it in the **Z Bot** text box.
- The different "region" options can be set by selecting the appropriate option in **Region**. Please note that if a region does not apply to the GMPE, then the base region will be used. Also, **California** identifies the base region.

IBC Response Spectra



This form is used to select the options and/or enter the data necessary to plot a MCE or a design response spectrum in accordance with the IBC (International Code Council, 2003, 2012; ASCE, 2006, 2010).

The procedure followed to obtain the spectrum starts by first selecting spectral accelerations at short period, S_s, and at 1-second period, S_1, from the Maximum Considered Earthquake (MCE) Ground Motion Maps provided in the IBC code.

The MCE maps were based on the U.S. Geological Survey (USGS) probabilistic hazard maps (Leyendecker et al., 2000; Frankel et al., 1996; Frankel et al., 2002; USGS, 2008, 2010); however, for some selected areas, the USGS maps were modified to incorporate deterministic ground motions and to apply engineering judgment.

In SHAKE2000, either the S_s or S_1 values can be entered manually or they can be automatically obtained from the files of gridded points used to create the USGS hazard maps. However, as previously noted, the maps included in the IBC are not “exactly the same” as the USGS maps for selected areas. Accordingly, the second option in SHAKE2000 should only be used for those regions for which the USGS maps were not modified. Leyendecker et al. (2000) briefly explain where the probabilistic USGS maps are and/or are not applicable. We recommend that you review the article by Leyendecker et al. (2000) for more information about the creation of the Maximum Considered Earthquake Ground Motion Maps. Also, before using the automatic option, check that your site is located in a region where the USGS maps are applicable; or, use this option to obtain “approximate” values of S_s and S_1 that are to be compared to the values on the IBC maps.

In accordance with the IBC, the maps used in SHAKE2000 are for 0.2 and 1.0 second spectral response acceleration with 2% probability of exceedance in 50 years for the Conterminous United States, Alaska, Hawaii and Puerto Rico. For the other maps included in the IBC (i.e. Culebra, Vieques, St. Thomas, St. John, St. Croix, Guam and Tutuilla), the user needs to enter the values for S_s and S_1 manually.

Please note that the program uses two sets of maps for the **Conterminous United States** region, i.e. the data maps generated in 2003 and 2008 updates of the National Seismic Hazard Maps (Frankel et al., 2002; U.S. Geological Survey, 2003a, 2003b, 2008, 2010).

For Alaska, the program uses the maps developed in either 1999 or 2007; for Hawaii the maps developed in 1999; and, for Puerto Rico the 2003 maps. The 2008 and 2010 updates of the maps were recently released by the USGS (2008, 2010). Although these latest updates have not been adopted for use in the IBC code, these maps are included with the program for comparison purposes only; i.e., at this moment they should not be used for any other purpose other than to compare the values. To use a specific year, click on the year’s option to select it.

The issue year for the maps used is shown on the **Spectral acceleration in g’s** label.

For the **2012** option, the program can use the data provided by the USGS website at:

http://earthquake.usgs.gov/hazards/designmaps/usdesign.php

For this option, you can obtain the most-up-to-date parameters using the on-line application at:

http://earthquake.usgs.gov/designmaps/us/application.php

If you want to use the maps to obtain the spectral accelerations S_s and S_1, first click on the **Enter the site's location to obtain spectral accelerations from USGS maps** option to select it, and then enter the latitude and longitude of your site in degrees, minutes and seconds. There is no need to enter a negative sign for the longitude value as required by the online NEHRP website. Next, select one of the **Region** options and the site class by selecting one of the **Soil Profile Type** options. The spectral values for the four grid points that surround your site are retrieved from the files, and if necessary, the values interpolated between the four grid points. The S_s and S_1 values are displayed in their corresponding text boxes on the upper right corner of the form.

To enter the values of S_s and S_1 manually, first click on the **Enter values of spectral acceleration manually** option to select it. Then, enter the value for S_s on the text box next to the **S_a for Short period, S_s** label; and, the value for S_1 on the text box next to the **S_a for 1-second period, S_1** label. In this option, you also need to select one of the **Soil Profile Type** options. The long-period transition period, T_L, needs to be entered in the **Long-Period Transition, T_L** text box.

By default the program will compute the design spectrum. If you need to use the MCE spectrum, click on the **MCE Spectrum** option to select it. When the spectrum is plotted, either the **Design** or **MCE** word will be shown on the plot label to indicate which spectrum is being used. When this form is called from the RRS form, the default spectrum will be the MCE.

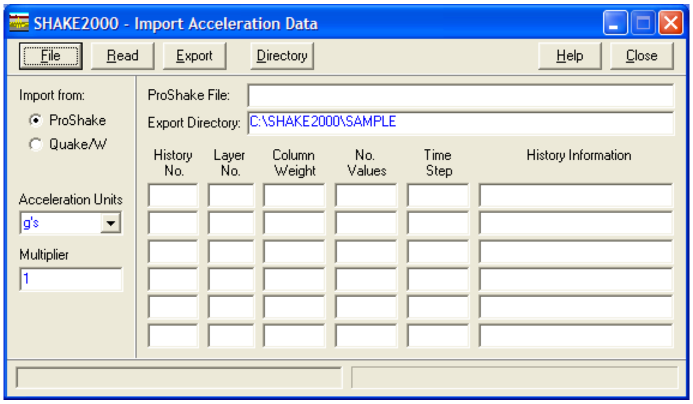
If you would like to manually enter the values for period and spectral acceleration, select the **User** option. The **User** command button will be enabled when this option is selected. This option will display the **User Defined Response Spectrum** form.

In this form, you can enter values of period and spectra for a user defined response spectrum that will be used to compute the modified spectrum using the results of the RRS analysis. In this way, you can enter a user-defined spectrum and select the IBC 80%-design spectrum to be plotted on the same graph with the modified spectrum.

After you have entered the above input information, click on the **Ok** button to compute the spectrum and to return to the previous form. If you click on the **Cancel** button, you will return to the previous form without modifying the input information if any had been selected previously.

If any of the options is disabled or results for any of the parameters are not shown on the respective text box, this is due to the maps for this option or for these parameters not being available from the USGS.

Import Acceleration Data



This form is used to import acceleration files for use in the Newmark Method for displacement analysis included with SHAKE2000. The applications supported by SHAKE2000 are ProShake and Quake/W.

In short, first, you will select an output file created by another application, e.g. ProShake; then, read that output file to determine if there are any acceleration time histories and how many there are (SHAKE2000 will only read the first 6 acceleration time histories found in the file); and finally, create a series of output files, i.e. one per acceleration time history, in the format used by SHAKE2000 to perform the displacement analysis with the Newmark Method.

Before using any of the files created with this form, we highly recommend that you compare the contents of each file with the data in the original output file to determine if the data were read correctly. You can use a text processor to open the files.

For ProShake, SHAKE2000 supports two types of output files: 1) files with the extension *.RAW; and, 2) files with the extension *.LYR. For Quake/W, SHAKE2000 uses the History Node file, i.e. files whose extension starts with the letter "O".

To select an output file, first select one of the software applications, and then click on the **File** command button to display the **Open Output File** dialog form. By default, for ProShake a listing of the files with the extension *.LYR will be automatically displayed. To select files with the extension of *.RAW, click on the down-arrow for the list box next to the **Files of type** label and then select the ProShake *.RAW option. For Quake/W, a listing of files whose extension starts with the letter "O" will be displayed. Double-click on the file to select it and return to SHAKE2000. The file name and its path will be shown on the text box next to the **ProShake** or **Quake/W File** label. The next step is to read the contents of the output file to extract the information necessary to create the acceleration time history file. In ProShake, SHAKE2000 will only read the first 6 acceleration time histories in the file.

Click on the **Read** command button to start reading the output file. After a few seconds, some information for the acceleration time histories will be displayed in the text boxes on the form. The number shown on the **History No.** column indicates the position of this time history in the output file. In ProShake, the number of the soil layer for which the acceleration time history was computed is shown on the **Layer No.** column. For Quake/W, the number of the node will be shown in the **Node No.** column. As noted in the **Newmark Method - Accelerogram File** section of this document, a weighted-average file created from a series of files can be used in the Newmark Method included with SHAKE2000. To create this average file, you need to know the weight of the soil column above the layer. However, this value is not read from the ProShake or Quake/W output file, thus, a number is not shown on the **Column Weight** column for the time history. If you know this value, you can enter it in the specific text box for each time history, otherwise, a value of 0.00 (zero) will be saved in the new time history file. The number of values for each time history is shown in the **No. Values** column, and the time step for the acceleration time history in the **Time Step** column. A description for each history found in the output file is shown on the **History**

Information column. For ProShake, if a file of type *.RAW is read, this description is usually a number that identifies the ground motion used (e.g. 1, 2, etc.). For files of type *.LYR, this description will be the path to the ground motion file used in the analysis (e.g. C:\PROSHAKE\YERBA.EQ), and other information such as number of values, period, etc.. For Quake/W, the information on this text box will be the information shown in the second line of the history node file. You can modify the description for the history by entering up to 128 characters in this text box.

To create the acceleration time history files compatible with SHAKE2000, click on the **Export** command button. An individual file will be created for each time history displayed in this form. For ProShake, each file will have a name such as **PrSk#L##.AHL**, wherein the number before the **L** is the number on the **History No.** column, and the number after the **L** is the number shown on the **Layer No.** column. The files will be written to the directory shown on the **Export Directory** box. For Quake/W, each acceleration file will have a name that starts with the string **QkeW** followed by the number in the **Node No.** column, and will have an extension of AHL. For example, **QkeW79.AHL** is the acceleration time history for node 79, extracted from a Quake/W history node file.

The output files created have the following format:

```
        0       2048     0.0200   3    8    9
ProShake Output File: C:\ProShake\Output\Shake.lyr
Acceleration Time History],17, 0, 1,C:\Download\EduShake\TREAS.EQ, 2048, .0200
 -.000408 -.002954 -.002443 -.000820 -.000282  .000451  .000215 -.000442
```

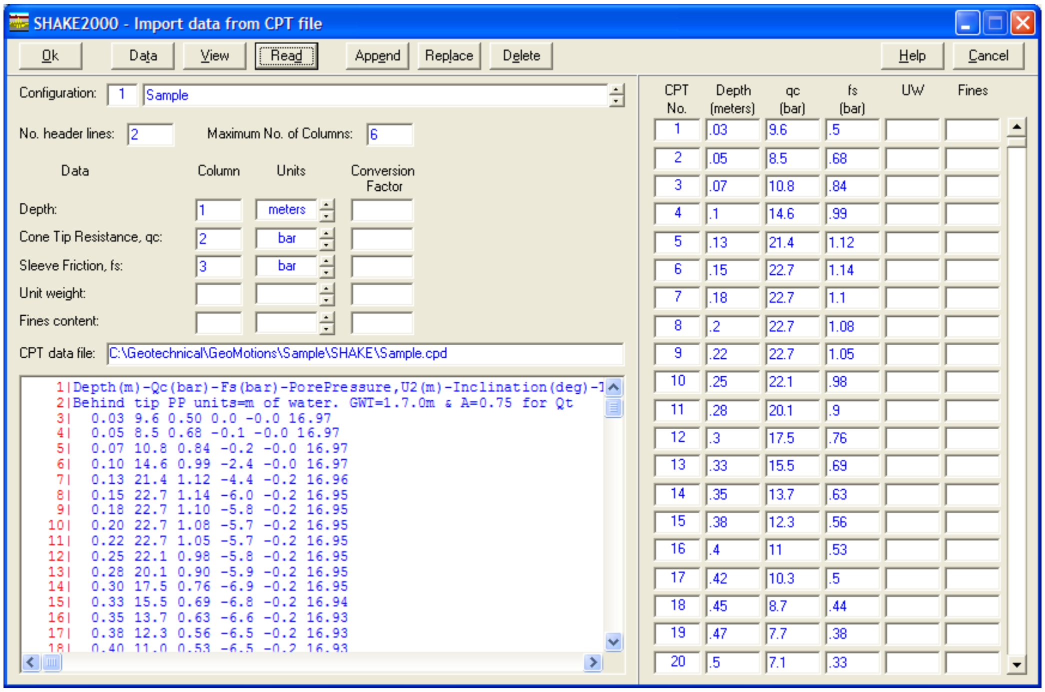
The values shown on the first line are: the weight of the soil column above the layer (e.g. 0); the number of values in the acceleration time history (e.g. 2048); the time step for the acceleration time history (e.g. 0.02 seconds); the number of header lines in this file (e.g. 3 header lines); the number of data columns used to write the acceleration values (e.g. 8 columns are used, see line four); and, the number of digits that form each data column (e.g. 9 digits per column, see line four).

The second line describes the type of output file used to create this file and its path (e.g. a ProShake output file named Shake.lyr located in the C:\ProShake\Output directory). The third line shows the header line found in the original ProShake output file for this specific acceleration time history. The fourth and subsequent lines are the values of acceleration for the time history saved in the file. This file can now be used in SHAKE2000 to perform the Newmark Displacement Analysis as explained in the **Newmark Displacement Analysis** section of this document.

If the acceleration values in the source file are in units other than g's then you need to select a factor to convert the values to units compatible with SHAKE2000, i.e. fractions of acceleration of gravity (g's), if necessary. Some files provide motion data in different units, for example cm/sec^2, ft/sec^2, etc.. To convert the units, select a factor that represents the units of the acceleration data in the source file from the list of options shown on the **Acceleration Units** list box. Remember that these are the units of the source or original data. Click on the down arrow of the list and select an option. After selecting a unit, a multiplication factor value will be displayed on the **Multiplier** box. This is the multiplication factor that will be used to convert the values. For example, to convert values of acceleration from cm/sec^2 to g's, you need to divide each value by 980.665 cm/sec^2; which is equivalent to multiply each value by 1/980.665 = 1.0191716E-03. If the accelerations in the source file are in units that are not shown in the list, select the **Other** option, and then enter the correct multiplication factor in the **Multiplier** text box.

The **Directory** command button can be used to to select the directory where the acceleration files generated will be stored. This button will display the **Choose Output Directory** form.

Import Data from CPT File



Cone Penetration Test data are typically recorded and stored as text files for further processing. However, the format of the data and the units may not be standard, i.e. it may be different from one CPT recorder to another. Thus, in order to provide the user with as much flexibility as possible when working with CPT data files, this form is used to define how the file is to be read.

In short, the user needs to define how the data are organized in the file by entering the number of header lines, the maximum number of data columns on the file, and the position (i.e. column number) in the file for at least the depth, cone tip resistance (q_c), and sleeve friction (f_s). In addition, data for unit weight, and fines content can also be read. This description, herein called a *configuration*, can be saved for future use, and other configurations created and saved to be used with different types of CPT data files.

We will use the section of CPT file shown below to better explain the use of this form.

```
CPT-15111-2551 12:24 p.m. XXXXXXXX Inc.        English
CPT-B1           111              547889-36
  0.05     6.22  0.0854     0.16     1.21
  0.10     4.54  0.7546     0.11     0.89
  0.15   169.22  0.8964     0.12     1.20
  0.20   275.64  1.4185     0.24     1.19
  0.25   228.11  1.8954     0.15     1.13
  0.30   189.85  2.1345    -0.04     0.99
  0.35   139.64  1.5945     0.01     0.99
```

For this example, the order and units of the data shown above are as follows:

Depth	q_c	f_s	U_2	Inclination
(meters)	(tsf)	(tsf)	(psi)	(°)

First, use the **Data** command button to display the **Open CPT Data File** dialog form, change to a different folder and/or subdirectory if necessary, and click on the file that stores the CPT data to select it. This file needs to be a text or ASCII file. Then click on the **Open** command button of the dialog form to open it. After a few seconds, the first few lines of the file (up to 99 lines) will be displayed on the bottom list box of the form.

The first four characters displayed in red are the numbers of each row of data in the file followed by a "|". These characters are not part of the source file and are only shown to number the rows. After the row numbers, the alphanumeric characters that constitute the information saved in the file for each row are shown. Note that the characters are displayed as blue on a white background, and that every tenth character is displayed in red. However, if the tenth character is a "blank space" then the character is not shown. If the data are shown in columns aligned vertically, then probably the only separators used between columns are tabs. On the other hand, if the data do not appear to be vertically aligned then the columns may be separated by blank spaces.

To create a configuration, first enter a description for it in the text box next to the **Configuration** label. Note that a number is automatically assigned to this configuration. You can scroll between the different configurations by using the up-down arrows next to the text box. For the example above, enter *Standard CPT File.*

The next step is to enter the number of header lines in the file. These are usually lines at the very top of the file used to provide some general information of interest to the user and are read before the CPT data. This number is entered in the text box next to the **No. header lines** label. For our example, the first two lines are only given for information. Thus, enter a **2** in the text box. The next number needed to define this file is the maximum number of data columns in the file. Note that in the file there may be more columns than data needed for the CPT analysis. SHAKE2000 needs, as a minimum, information on depth, q_c and f_s. However, some files also provide columns for U_2, U_3, inclination, temperature, etc.; or, the user can add a column of values for unit weight and/or fines content that can also be read as noted below. Accordingly, there can be 5, 6, or more columns in the file. For the above example file, enter a **5** in the text box next to the **Maximum No. of Columns** label.

The order and units of the data columns is defined next. Enter here the numeric order of the column for each of the data that will be read from the file. For our example above, the first column of data corresponds to depth, the second to the cone tip resistance, q_c, etc. In the text box below the **Column** label and next to the **Depth** label, enter a **1**.

Next, you need to select the units for the data in the file. Although you can select different units, SHAKE2000 works with a consistent set of units. Accordingly, SHAKE2000 transforms the units for depth to *feet* when working with English units or to *meters* when working with SI units. Similarly, the units for q_c and f_s will be converted to *kPa* for either the English or SI systems. The units of unit weight are converted to lb/ft^3 in the English system, or to kN/m^3 in the SI system; and the fines content to percentage (%) for both systems. Use the up-down arrows next to the text box below the **Units** label to select the units for each data column. For our example, the depth data are given in meters. Thus, click on the up-down arrows until **meters** is shown in the text box.

If the data in the file are in units that are not shown on the list, select the **Other** option, and then enter a multiplication factor in the text box at the **Conversion Factor** column. This factor, when multiplied by the original data, should convert the value to the appropriate units used by SHAKE2000. For example, if the depth data were given in inches, you will need to enter **0.08333** or **1/12** to convert them to feet. Accordingly, for q_c or f_s you will need to enter a multiplier to convert the tip values to *kPa*. For unit weight, you would need to enter a multiplier to convert the data to *pcf* (i.e. lb/ft^3) when using the English system; or, to kN/m^3 when using SI units.

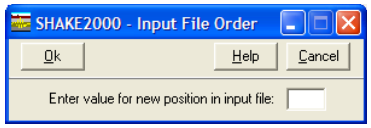
By default, SHAKE2000 estimates the unit weight of the CPT column based on soil classification using cone tip resistance (q_c) and friction ratio (R_f), as recommended by Robertson and Cabal (2010), or from the CSR analysis or SHAKE column when applicable. However, the data can also be read from the CPT data file by defining the column number.

To read the data from the file, click on the **Read** command button. After a few seconds, the data will be displayed on the data text boxes on the right side of the form. The data read from the file can also be edited manually. To do this, first click on the **View/Edit CPT file data** option to select it. Then, place the cursor on any of the data-text boxes and enter the new value.

After you have created the configuration used to read the CPT file, click on the **Append** command button to add it to the configuration file. The different configurations created are saved in this file and read every time this form is loaded. If you have made some changes to an existing configuration and would like to use the new changes instead of the current ones, click on the **Replace** button. The new configuration will overwrite the current configuration data. The **Delete** command button can be used to erase a configuration from the configuration file.

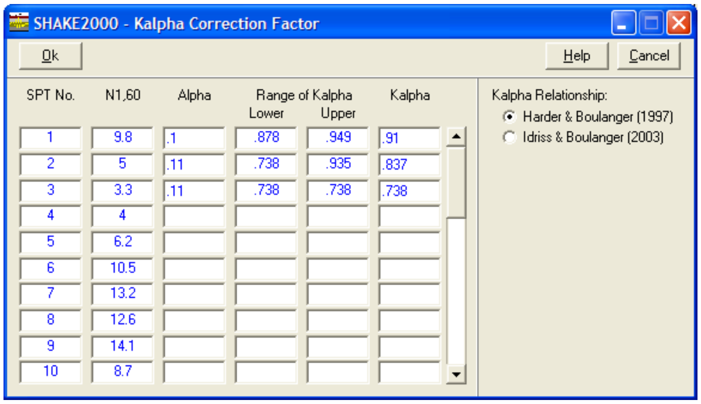
Once you have created the configuration and selected a data file, you can return to the **Cyclic Resistance Ratio using CPT** form by clicking on the **Ok** command button.

Input File Order



Enter value for new position in input file: Enter the value for the new position of an option in the input file. For example, if you set **Option 6 - Compute Accelerations for Layers 1 to 15** in position 5 and **Option 5 - Obtain strain compatible soil properties** in position 6, you will need to reorganize your input file so that SHAKE2000 executes Option 5 before Option 6. To do this, click on Option 5 on input file option's list of the **Earthquake Response Analysis** form, and then click the **Order** button. Then, enter 5 on the data cell and click on the **Ok** button. Control will be returned to the **Earthquake Response Analysis** form, and the options will be reorganized automatically. To cancel this action without modifying the order, click on the **Cancel** button.

K_{alpha} Correction Factor



This form is used to enter the correction factor for static “driving” shear stresses, or K_α, using the curves recommended by Harder & Boulanger (Youd and Idriss, 1997), or the relationship proposed by Idriss & Boulanger (Idriss and Boulanger, 2003a,b; Boulanger, R.W., 2003).

When using the Harder & Boulanger graph, the curves are for specific ranges of $N_{1,\,60}$ values. For the user's convenience and for other values of $N_{1,\,60}$, the following approximations are performed by SHAKE2000: 1) for values of $N_{1,\,60}$ less than 4, the lower bound curve for $N_{1,\,60}$ of 4-6 is used; 2) for values of $N_{1,\,60}$ greater than 6 but less than 8, SHAKE2000 uses the upper bound curve for $N_{1,\,60}$ of 4-6 and the lower bound curve for $N_{1,\,60}$ of 8-12; 3) for values of $N_{1,\,60}$ greater than 12 but less than 14 the upper bound curve for $N_{1,\,60}$ of 8-12 and the lower bound curve for $N_{1,\,60}$ of 14-22 are used; and, 4) the upper bound curve for $N_{1,60}$ of 14-22 is used for $N_{1,60}$ values greater than 22. If you disagree with this approach, you can enter the values for K_α manually. Futher, for the Harder & Boulanger graph, acceptable values for α are $0 <= \alpha <= 0.30$. If you enter any other value for α, SHAKE2000 will not use the curves to obtain K_α. The chart used is based on data for conditions where initial effective overburden stress is less than 3 tsf (or 287 kN/m^2). When the effective stress is greater than 3 tsf (or 287 kN/m^2), SHAKE2000 will not use the curves to obtain K_α. If you don't wish to use the chart, values for K_α can be manually entered without having to enter values for α.

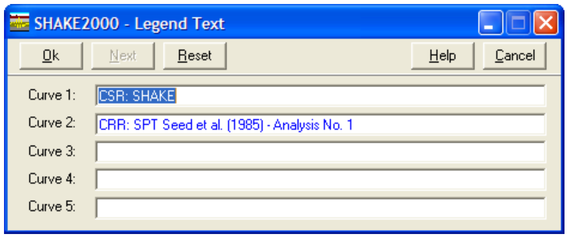
For the Idriss & Boulanger relationship, the values of α and ξ_R are constrained to $\alpha \le 0.35$ and $-0.6 \le \xi_R \le 0.1$, respectively (Boulanger, R.W., 2003).

To estimate K_α, place the cursor on the **Alpha** column. Enter a value for α, or “*… the ratio of static driving shear stress on a horizontal plane to the initial effective overburden stress”* (Youd and Idriss, 1997). Press the *Tab* key to move the cursor. For the Harder & Boulanger option, a series of values will be automatically displayed in the **Lower** and **Upper** columns. These values correspond to the K_α values for the lower curve and the upper curve that bound the range of K_α values for the corresponding $N_{1,\,60}$ value. The value for K_α is displayed in the **Kalpha** column. This value is obtained by interpolating between the upper and lower values. For the **Idriss & Boulanger (2003)** option, the $N_{1,60,cs}$ values used are displayed in the **N1,60** column, the value of the State Parameter Index, ξ_R, will be shown in the **Er** column, and the computed value of K_α will be displayed in the **Kalpha** column. ξ_R is computed assuming a value of 10 for Q and a value of 0.45 for K_o.

To estimate the K_α value for other points, repeat the above procedure. Once you have entered all of the data, click on the **Ok** button to return to the **Cyclic Resistance Ratio** form.

Please note that Youd and Idriss (1997) and Youd et al. (2001) recommend that K_α should not be used in routine engineering practice.

Legend Text

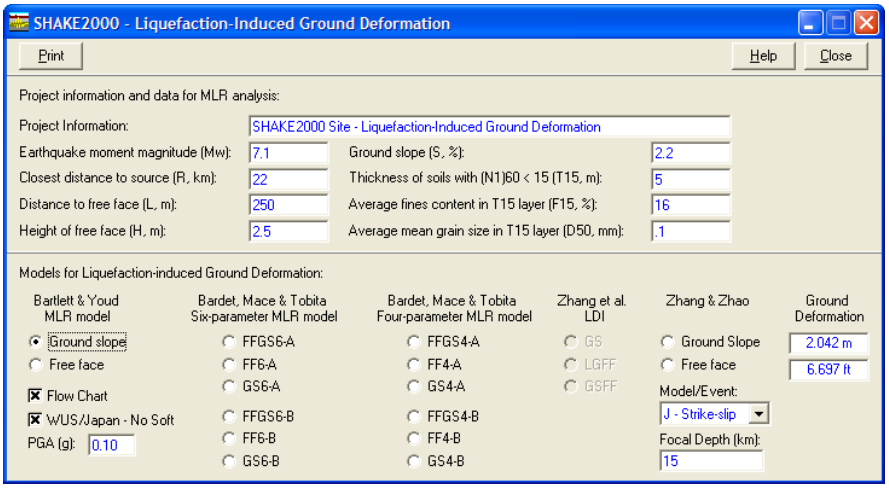


This form is displayed by clicking on the **Legends** command button on the graphics window. When the form is displayed, the legends for the first five curves are shown in the text boxes. To edit the legend, place the cursor on the text box and enter the new legend. Each legend has a maximum length of 80 characters.

To display the legends for the following set of five curves, click on the **Next** button. Click on the **Ok** button to return to the graphics window. If you don't want to modify the legends, click on the **Cancel** button.

The **Reset** command button is used to restore the original legends for the curves.

Liquefaction-Induced Ground Deformation



Use this form to estimate the liquefaction induced ground deformation with any of the Multiple Linear Regression models shown. The models included are those developed by Bartlett and Youd (1992, 1995; Youd, 2002; Youd et al., 2002); Bardet, Mace and Tobita (1999; Bardet et al., 2002); Zhang, Robertson and Brachman (Zhang et al., 2004); and, Zhang and Zhao (2005; Zhang, 2005).

The coefficients used in the different models are saved in the SHAKEY2K.CSR file in the SHAKE2000 directory.

For proper use of these models, the user should refer to the information provided in the above references. These authors provide guidance on the use of the models, and more important, the range of acceptable input data.

For the Bartlett & Youd models, the default option in SHAKE2000 is to follow the procedure recommended by the authors, as shown in Figure 9 of Youd et al. (2002). If the **Flow Chart** option is not selected, then the procedure is not followed, however, the models are still enabled but the results may not be reliable. When the procedure in the flow chart is followed, the user has the option of specifying if the site is located in the western USA or Japan, and the soils are not soft. This is set by selecting the **WUS/Japan – No Soft** option. If this option is not selected, then the equivalent source distance, R_{eq}, will be obtained from Figure 10 of Youd et al. (2002) and used in the models. To this end, the user needs to enter a value for peak horizontal ground acceleration in g's, in the text box next to the **PGA (g)** label.

The Zhang, Robertson and Brachman method is only enabled when this form is called from the **Cyclic Resistance Ratio using CPT** or **Cyclic Resistance Ratio using SPT** forms. A liquefaction analysis using CPT data and the Robertson and Wride method; or, a liquefaction analysis using SPT data and following the recommendations of the 1996 NCEER and 1998 NCEER/NSF Workshops (Youd et al., 2001), should be conducted prior to calculating the liquefaction-induced lateral displacement.

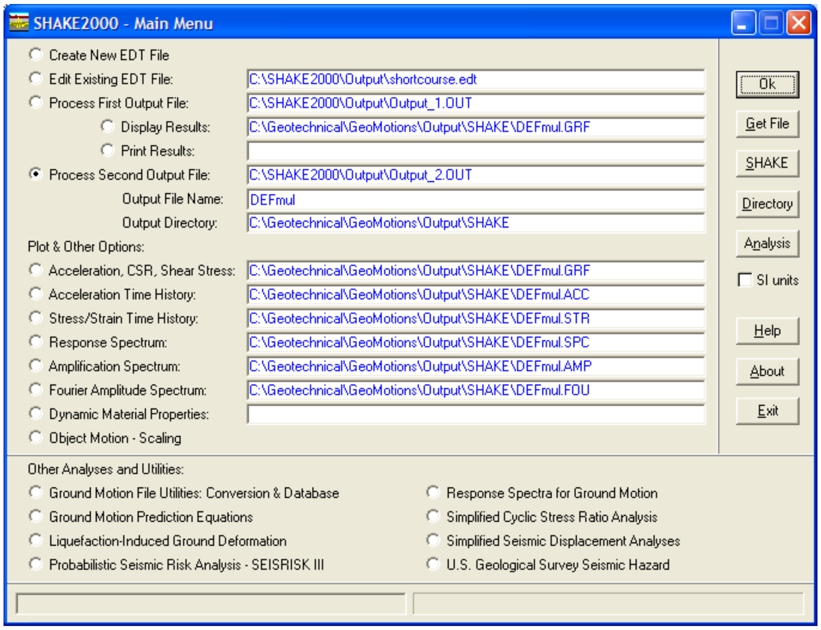
For the Zhang & Zhao method, a type of seismic event and faulting mechanism can be selected from the list of options listed on the **Model/Event** list. In this list, options starting with a "**J**" apply to the models developed using Japanese spectral attenuation models; and, options starting with "**SY**" apply to the models developed using the Sadigh et al. (1997) and Youngs et al. (1997) attenuation models.

When this form is loaded, the cursor is located on the text box next to the **Project information** label. In this box, you can enter a description for this analysis, up to 80 characters. This information is included in the print out of the results. Next, click the *Tab* key to move the cursor to the text box next to the **Earthquake moment magnitude (Mw)** label. Enter the earthquake magnitude used in the analysis. Then, follow the same procedure to enter the other data needed for the MLR model you are using for the analysis. The ground deformation calculated will be shown on the text box below the **Ground Deformation** label.

A different MLR model can be selected by clicking on the option button for the model. The ground deformation value will be re-calculated and shown on the text box. Please note that some of the MLR models require more input data than others. For example, for the FF6 model you need to enter values for F_{15} and $D50_{15}$, which are not required for the FF4 model. Accordingly, the ground deformation will only be calculated and shown on the text box, if all of the input data required for the model have been entered.

You can print the results by using the **Print** command button. This button will display the **Print Menu** form.

Main Menu



This is the main form of SHAKE2000, and the form that is first displayed when the program is launched. This form is organized into three sections. The **Editing and Processing** section includes options that can be used to create and edit input files for SHAKE, and to process the results so that the data are presented graphically. In the **Plot Options** section a series of options used to graphically present the input data and the results are provided. Additional analyses of common use in Geotechnical Earthquake Engineering are included in the third section, **Other Analyses**.

Editing and Processing Options:

SI units: By default, SHAKE2000 will use English units for most of the data used in the program. If you wish to use SI units, select this option by clicking on the check box. Please note that the original source code for SHAKE has not been revised to determine if SI units are compatible with SHAKE. Accordingly, when working with SI units, the input data for SHAKE are transformed to English units before executing SHAKE. This transformation only takes place for the data saved in the input file, and does not affect the data shown on the different SHAKE2000 forms.

Similarly, the output data provided by SHAKE are in English units. When working with SI units, these data are converted to SI units during processing of the data. More information on the different data used in a SHAKE analysis is provided in the **SHAKE** and **Earthquake Response Analysis** sections of this manual.

A few of the features included in SHAKE2000 are available only on SI units, for example, the ground motion prediction equations and liquefaction-induced ground deformation. This is the case when the feature has been originally developed using the SI units, and to support the worldwide move towards a common system based on the SI units. Similarly, the basic parameters for the Cone Penetration Test are presented in SI units (MPa and kPa), but the data for the depth and unit weights will depend on the system of units selected by the user (i.e. ft and lb/ft^3 for English units; and, meters and kN/m^3 for SI units). For most data used in SHAKE2000, the units for each value are shown on each form. Files created with previous versions of SHAKE2000 will be converted automatically to SI units when the **SI units** option is selected.

Create New EDT file: This is the default option when SHAKE2000 is launched. Use this option to create a new EDT file that will contain default values for the different options of SHAKE. By clicking on the **Ok** button, the

Earthquake Response Analysis form is displayed. An EDT file is an ASCII file that contains data for the different options used by SHAKE2000. The data are in the format required so that the *.EDT file may be used as an input file for SHAKE2000. However, SHAKE2000 uses this file as a database to create an input file. The *.EDT file can contain several sets sets for each option (e.g. 6 different sets of Option 2), up to 32,000 for all of the options combined. By choosing the **Edit Existing EDT file** option you can select which options to use, and in which order those options will be organized in the input file for SHAKE2000.

Edit Existing EDT file: Use this option to load and edit an existing *.EDT file. Click on the option, and then on the **Get File** command button to select the *.EDT file. Then, click on the **Ok** button to display the **Earthquake Response Analysis** form. A backup copy of the EDT file will be automatically created in the Backup\SHAKE folder. This backup copy can be used to restore your original file, and it can also be used to restore some of the other working files as explained in the following sections.

Process first output file: Select this option to process the first output file created by SHAKE. After selecting the option, click on the **Get File** button to select the output file, and then click on the **Ok** button to process the file. SHAKE2000 will read the file and extract the information that is most useful to the user, and store it in a series of ASCII files that are used by the **Plot Data** options described below. This option will create the *.GRF, *.SPC, *.AMP and *.FOU files. These files can also be used by other software (e.g. Excel, etc.) to create similar graphs. The **Analysis** command button is enabled after the files are processed. This button will display a summary list of the different options that form each analysis group. The results contained in the first and second output files generated from the execution of SHAKE are grouped in sets, or analysis, depending on the order of the different options.

Display Results: After the first output file is processed, you can use this option to display the results stored in the *.GRF file in a spreadsheet-like form. To do this, click on the option, and then on the **Get File** command button to select the *.GRF file. Click on the **Ok** button to display the **Summary of Results of First Output File** form.

Print Results: This option is used to create a table of the main results obtained from the first output file, which can be printed. To do this, click on the option, and then on the **Get File** command button to select the *.GRF file. Click on the **Ok** button to display the **Print Results of First SHAKE Output File** form.

Process second output file: Select this option to process the second output file created by SHAKE. After selecting the option, click on the **Get File** button to select the output file, and then click on the **Ok** button to process the file. SHAKE2000 will read the file and extract the acceleration and stress/strain values, and create the *.ACC and *.STR files used in the **Plot Data** options described below.

Other files that save the individual time histories for each layer are also created. These files are identified with the extension *.AHL (or acceleration history at layer) for those created from the **Outcrop** or **Within** acceleration time histories requested in Option 6; *.ACC for the **Incident** acceleration time history requested in Option 6; and, with the extension *.HEA (or horizontal equivalent acceleration) for those created from the shear stress time histories requested in Option 7. For more detailed information about these files, please refer to the **Earthquake Response Analysis** section of this user's manual.

Output file name: The name of the output files created with the **Process first output file** and **Process second output file** can be entered in this text box. By default, SHAKE2000 uses **Output** as the name. For example, the **Process Second Output File** option would create the following files: OUTPUT.ACC and OUTPUT.STR. To change the name, place the mouse cursor in the box and delete the current contents, then type the new name. You can also highlight the contents by pressing the left mouse button and dragging it, and then pressing the *Delete* key. A maximum of 32 characters is allowed as input for this text box.

Output Directory: Use the **Directory** command button to choose a directory where the output files created by the **Process first output file** and **Process second output file** options will be automatically stored. This directory will also be used by other analyses (e.g. CRR, displacement, etc.) as the default directory for saving data files. After clicking on the **Directory** button, the **Choose Output Directory** form will be displayed. Use the mouse to select the drive and directory, and then click on the **Ok** button. The output directory will be displayed on the text box next to the **Output Directory** label.

Plot Options:

*To execute an option (except **Object Motion**), click on the option to select it. Then click on the **Get File** button to display the open file dialog box. If necessary change to the directory where the file is saved. Click on the file name, and then on the **Ok** button. You will return to the* **Main Menu** *form. The file name is displayed on the text box next to the option. Click on the **Ok** button to plot the data saved in the file*.

Acceleration, CSR, Shear Stress: The following plots are created by choosing this option: Strain-Compatible damping vs. Depth, Strain-Compatible Shear Modulus vs. Depth, Maximum Shear Strain vs. Depth, Maximum Shear Stress vs. Depth, Peak Acceleration vs. Depth, and Cyclic Stress Ratio vs. Depth. The data for this option are saved in the ***.GRF** file created by the **Process first output file** option. The maximum acceleration values are obtained from the Option 6 output section, and the other results from the Option 5 output section of the first SHAKE output file.

Acceleration time history: This option is used to plot the acceleration time history at the top of the layers specified using Option 6 of SHAKE. The data are stored in the ***.ACC** file created using the **Process second output file** option.

Stress/Strain time history: Use this option to plot the stress or strain time history at the top of the layers specified using Option 7 of SHAKE. The data are stored in the ***.STR** file created using the **Process second output file** option.

Response Spectrum: Select this option to display plots of response spectrum for different damping ratios computed from Option 9 of SHAKE. The different response spectra plotted are: Relative Displacement (S_d), Relative Velocity (S_v), Pseudo-Relative Velocity (PSV), Absolute Acceleration (S_a), and Pseudo-Absolute Acceleration (PSA) versus Period. The data for this option are saved in the ***.SPC** file created by the **Process first output file** option.

Amplification Spectrum: Select this option to plot the amplification spectrum computed from Option 10 of SHAKE. The data for this option are saved in the ***.AMP** file created by choosing the **Process first output file** option.

Fourier Amplitude Spectrum: Use this option to plot the Fourier amplitude spectrum computed from Option 11 of SHAKE. The data for this option are saved in the ***.FOU** file created by choosing the **Process first output file** option.

Material properties: This option is used to plot the dynamic properties, i.e., shear modulus reduction and damping ratio curves for the different materials. The data are obtained from either an ***.EDT** (SHAKE2000 main file) or an input file. After selecting this option, click on the **Ok** button to display the **Plot Dynamic Material Properties** form.

Object Motion - Scaling: This option is used to plot the acceleration time history for an earthquake record and to access the scaling feature of the program. For example, you can use this option to plot the object motion that is used as input for the SHAKE2 analysis. The **Plot Object Motion** form will be displayed to allow you to select the object motion to be plotted. To use the scaling feature, click on the **Scale** command button on the **Plot Object Motion** form.

Other Analyses and Utilities:

*To execute one of these options, first click on the option to select it and then on the **Ok** command button*.

Ground Motion File Utilities: Conversion & Database: With this option the user can convert ground motion files to different units and/or formatting. Also, the information on the database of ground motion files can be edited and data about new files added.

Ground Motion Prediction Equations: This option is used to plot ground motion prediction equations for peak ground acceleration and peak horizontal velocity with distance, and pseudo absolute acceleration and pseudo relative velocity response spectra. Several equations are used, as described in the **Ground Motion Prediction Equations** section of this manual.

Liquefaction-Induced Ground Deformation: Use this option to estimate the liquefaction induced ground deformation with any of the available models.

Probabilistic Seismic Risk Analysis - SEISRISK III: This option of SHAKE2000 is used to create input files for and to process the output file created with SEISRISK III.

Response Spectra for Ground Motion: This option is used to compute the response spectra for a ground motion.

Simplified Cyclic Stress Ratio Analysis: This option is used to calculate the Cyclic Stress Ratio using the equation formulated by Seed and Idriss in 1971. Further, you can also calculate the Cyclic Resistance Ratio using SPT, BPT, CPT or V_s data to evaluate the liquefaction resistance of the soil column. Refer to the **Simplified Cyclic Stress Ratio Analysis** section of this User's Manual for more detailed information.

Simplified Seismic Displacement Analyses: After selecting this option, click on the **Ok** button to display the **Displacement** form to select a method. The following simplified methods are included:

- **Bray & Travasarou Simplified Seismic Displacement:** This option is used to estimate permanent displacements due to earthquake-induced deviatoric deformations as proposed by Bray & Travasarou.

- **Makdisi & Seed Displacement Analysis:** This option uses the Simplified Makdisi & Seed Method to compute the displacement induced by ground motion on an earth embankment.

- **Newmark Displacement Analysis:** This function of SHAKE2000 allows you to determine permanent slope displacements due to earthquake shaking, using the Newmark Method.

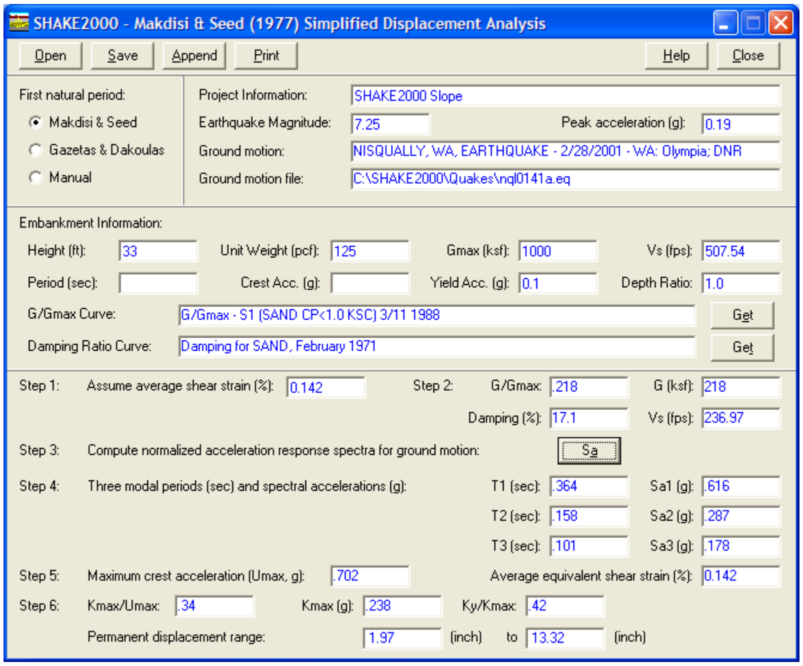
- **Rathje & Saygili Seismic Sliding Displacements:** This function of SHAKE2000 allows you to determine deterministic and pseudoprobabilistic sliding displacements due to earthquake shaking using the procedure developed by Rathje & Saygili.

U.S. Geological Survey Seismic Hazard: This form is used to retrieve the Peak Ground Acceleration from the files of gridded points used to make the 1996 USGS National Seismic Hazard Maps (Frankel et al., 1996), for the updates (Frankel et al., 2002; U.S. Geological Survey, 2003a and 2003b, 2008, 2010); and also, to plot the results of the seismic hazard deaggregation for a site in the conterminous states of the United States.

A copyright message, the version number, and the name of the registered user for this copy of SHAKE2000 can be displayed using the **About** command button.

Execution of SHAKE2000 is terminated by clicking on the **Exit** command button.

Makdisi & Seed - Displacement Analysis



There are three methods that can be used to compute/enter the first natural period of the embankment. Based on this, SHAKE2000 uses a different approach to compute the displacement based on the charts presented by Makdisi and Seed (1977, 1978, and 1979). The procedure to compute the displacement using this form will be explained for each of these methods. For more complete information on the Makdisi & Seed approach and the data needed for the calculations, please review the appropriate references.

Makdisi & Seed: This method is based on iterations of the shear strain to obtain strain compatible material properties, used then to compute the maximum crest acceleration and the natural period of the embankment. With these values, and other information entered by the user, the range of permanent displacements is obtained from the charts in Makdisi and Seed (1977).

To select this method, click on the **Makdisi & Seed** option of the **First natural period** options. Then, press the *Tab* key to move the cursor to the text box next to the **Earthquake magnitude:** label. Enter the earthquake magnitude used in the analysis. The acceptable range of magnitudes is **6.5** to **8.25**. Now, move the cursor to the text box next to the **Peak acceleration (g):** label, and enter the value of the maximum acceleration in g's (e.g. 0.20) for the earthquake used in the analysis. Next, you will need to enter some basic information about the embankment. Press the *Tab* key to move the cursor to the text box next to the **Height** label. Enter the height of the embankment in feet or meters. Move the cursor to the text box next to the **Unit weight** label and enter the unit weight for the embankment material in lb/ft^3 or kN/m^3. Now, enter either the maximum shear modulus in kips per square feet (ksf) or kN/m^2 in the text box next to the **Gmax** label, or the maximum shear wave velocity in feet per second (fps) or m/sec in the text box next to the **Vs** label. If you enter G_{max}, then V_s will be computed as $V_s = (G_{max}/\text{mass density})^{1/2}$. Accordingly, if you enter V_s, then G_{max} is computed as $G_{max} = (\text{mass density} * V_s^2)$. Press the *Tab* key to move the cursor to the text box next to the **Yield Acc. (g):** label. In this method, the first natural period and the maximum embankment crest acceleration are computed, thus, the text boxes next to the **Period (sec):** and **Crest Acc. (g):** labels are disabled. Enter the value of yield acceleration, or K_y, of the potential failure surface in g's. Place the cursor on the text box next to the **Depth ratio:** label and enter the depth ratio, or y/H ratio, for the failure surface. Now you need to select curves that represent the variation of shear modulus and damping as a function of shear strain for the embankment material. These curves are selected from the curves stored in the **shakey2k.mat** file, created as explained in the **Dynamic Material Properties - Database** section of this User's Manual. To retrieve the G/G_{max} curve, click on the **Get** command button next to the box for the **G/Gmax Curve:** label. This will display the **G/Gmax Curves - Database** form. Select a curve, and then click on the **Choose** command button to return to the **Makdisi & Seed** form. Next, click on the **Get** command button for the **Damping ratio curve:** label to display the **Damping Ratio Curves - Database** form. Select a curve, and then click on the **Choose** command button to return to the **Makdisi & Seed** form. The description for the curves will be shown on their respective boxes.

After you have entered the basic information needed, you can begin the iteration procedure for the computation of displacements. The procedure is divided in steps. **Step 1** consists of entering an assumed value for the average shear strain level in the embankment. Move the cursor to the text box next to the **Assume average shear strain (%):** label. Enter an estimate of the average shear strain as percentage. Press the *Tab* key to move the focus to the **Input** command button. Some information is computed and displayed on the text boxes for **G/Gmax**, **G**, **Damping**, **Vs**, and for the three modal periods **T1**, **T2** and **T3**.

To obtain the spectral accelerations corresponding to the computed damping ratio shown on the text box next to the **Damping (%):** label, click on the **Sa** command button to display the **Response Spectra for Ground Motion** form. This form is used to compute the response spectra for a ground motion. The routine used by SHAKE2000 is based on the SPECTR computer program (Donovan, 1972). Please refer to the **Response Spectra for Ground Motion** of this manual for more information on how to use this form. For the analysis of the response spectrum, you can enter up to 6 damping values. Thus, it is recommended that you enter a range of damping values that may include the above computed value, and other values less than and greater than this value. For example, say that a damping value of 12% was computed after you entered the assumed value of shear strain. Then, you would enter values of 0.05, 0.1, 0.12, 0.15, 0.20 and 0.25. When retrieving the values of spectral acceleration, and if there is not a spectrum for the specific value of damping, SHAKE2000 will interpolate between two available spectra. Hence, if for example, the value of damping were 17%, SHAKE2000 will interpolate between the spectra for 15% and 20% damping.

After the spectra are calculated, and before returning to the Makdisi & Seed form, SHAKE2000 will normalize the spectral accelerations, i.e. each spectra value will be divided by the spectral acceleration for a period of 0.01 seconds, thus the spectra values used in the calculation of the displacement are independent of peak acceleration. Upon returning to the Makdisi & Seed form, the values for spectral accelerations will be shown on the boxes next to the **Sa** labels.

After the spectral acceleration values are obtained, the value for the maximum crest acceleration, or U_{max}, is computed and shown on the box next to the **Maximum crest acceleration (Umax, g):** label. Also, the average equivalent shear strain value is computed and shown on the box next to the **Average equivalent shear strain (%):** label. Other values computed are for the K_{max}/U_{max} ratio, K_{max}, and K_y/K_{max} ratio. If this latest computed value of shear strain is not approximately the same as the assumed average value entered above, then repeat the above procedure beginning with **Step 1,** and using the computed average strain value. If the value is the same, or close, then the process is concluded and the range of permanent displacement is obtained from Figure 14 of Makdisi and Seed (1977) and shown on the bottom of the screen in the boxes next to the **Permanent displacement range:** label.

Gazetas & Dakoulas: This method uses the equation proposed by Dakoulas and Gazetas (1985) to calculate the fundamental period of the embankment. The user needs to enter values for earthquake magnitude, embankment height, unit weight of the embankment, maximum shear modulus or maximum shear wave velocity, embankment crest acceleration, yield acceleration, and depth ratio. Refer to the explanation for the **Makdisi & Seed** option described above for more information on how to enter these data. After these data are entered, values for K_{max}/U_{max} ratio, K_{max}, and K_y/K_{max} ratio are computed and shown on their respective boxes. Then, SHAKE2000 uses Figure 16 of Makdisi and Seed (1977) to obtain the average normalized displacement, and display it on the box next to the **U/KgTo** label. With this normalized displacement, the average displacement is computed and shown on the box next to the **Average permanent displacement:** label.

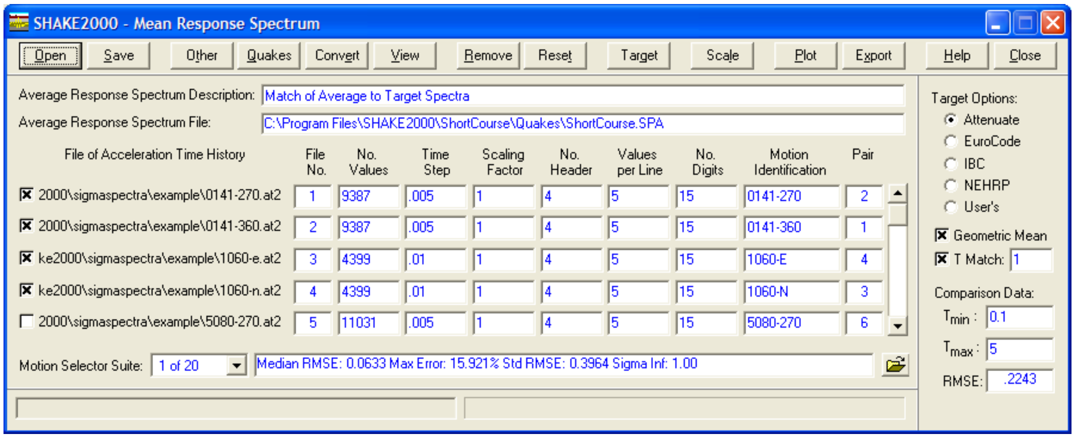
Manual: In this method the user needs to enter values for earthquake magnitude, first fundamental period, embankment crest acceleration, yield acceleration, and depth ratio. Refer to the explanation for the **Makdisi & Seed** option described above for more information on how to enter these data. After these data are entered, values for K_{max}/U_{max} ratio, K_{max}, and K_y/K_{max} ratio are computed and shown on their respective boxes. Then, SHAKE2000 uses Figure 16 of Makdisi and Seed (1977) to obtain the average normalized displacement, and display it on the box next to the **U/KgTo** label. With this normalized displacement, the average displacement is computed and shown on the box next to the **Average permanent displacement:** label.

The curves provided by Makdisi and Seed (1977) are for earthquake magnitudes of 6.5, 7.5 and 8.25. For other magnitudes, SHAKE2000 will interpolate between the curves to obtain the displacements.

To save the data click on the **Save** command button to display the save file dialog box. Enter a name for the text file where this information will be saved for future retrieval, using the **Open** command button. The **Append** command button can be used to add the current results at the end of the output file.

You can print the results by using the **Print** command button. This button will display the **Print Displacement Results** form.

Mean/Scaling Response Spectrum



This form can be used to obtain the mean spectral acceleration response spectrum for a series of ground motion records. The mean value can then be compared to a target spectrum in order to visually evaluate how well the shape of the average spectrum compares to the shape of the target spectrum. A more detailed explanation about selecting ground motion records for analysis based on how well they match a target spectrum is given by Bommer and Acevedo (2004), Hancock et al. (2005), Kottke and Rathje (2007), and PEER Ground Motion Selection and Modification Working Group (2009). To use the form, the user needs to select a number of ground motion files, a target spectrum; and, optionally, enter a range of periods of interest.

There are three different command buttons that can be used to select ground motion files. First, you can select an object motion listed in the earthquake records database by clicking on the **Quakes** button to display the **Earthquake Records Database** form. This form shows a listing of the records saved in the **SHAKEY2K.EQ** file. Once the list is displayed, you can choose a record by highlighting it and clicking on the **Ok** button, or by double clicking on it. The data for the record will be shown on their respective fields upon returning to this form.

To select files that are not included in the database of earthquake records, click on the **Other** command button to display the **Acceleration Time History File** dialog form. Switch to the appropriate folder, select the ground motion file and click on the **Open** command button. The file name and path will be displayed on the list shown below the **File of Acceleration Time History** label. In order to read and use the data saved in the file you need to enter:

1. The total number of acceleration values that form the object motion file in the **No. Values** text box;
2. The time interval between each acceleration value in the **Time Step** text box;
3. If the motion will be scaled to a different peak acceleration value, then enter the scaling value used to modify the acceleration in the **Scaling Factor** text box;
4. The number of lines at the beginning of the file that are used to describe the object motion in the **No. Header** text box; and,
5. The number of acceleration values on each line in the **Values per Line** text box; and, the number of digits that form an acceleration value in the **No. Digits** text box.

The **Other** command button can also be used to select multiple files at a time. Also, use the **Other** command button to select files downloaded from the PEER NGA Ground Motion Database, i.e. *.AT2 files. Please note that these files are not in a format compatible with SHAKE, but can still be used with this feature of the program. If you wan to convert some of these files to a format compatible with SHAKE after the scaling procedure, use the **Export** command button.

More detailed information about these values is provided in the **Plot Object Motion** or **Response Spectra for Ground Motion** sections of this manual.

The third option used to select ground motion files is with the **Convert** command button. This button is used to display the **Conversion of Ground Motion File** form that can be used to convert ground motion files from different units and/or formatting to a file that can be used with SHAKE2000. Further information on this feature is provided in the **Conversion of Ground Motion File** section of this manual. Upon returning to this form, the information used to read the file is displayed in their respective columns.

The **View** command button can be used to view the contents of a ground motion file. This will help you to collect the information needed to define the formatting of the file if necessary. To do this, first select a file by clicking on its name/path, then click on **View**. When you click on the file's name/path the check box will be selected or de-selected. Note that when the check box is not selected, the file will not be used for computation of the average spectrum.

The first 60 lines of the file will be displayed on a form, with the first characters displayed in red representing the numbers of each row of data in the file followed by a "|". These characters are not part of the source file and are only shown to number the rows. After the row numbers, the alphanumeric characters that constitute the information saved in the file for each row are shown. Note that the characters are displayed as blue on a white background, and that every tenth character is displayed in red. However, if the tenth character is a "blank space" then the character is not shown. This is done to guide the user when defining the order of the data in the file.

As noted before, the average spectrum will be compared to a target spectrum. There are six options used to select the target spectrum: **Attenuate**, **EuroCode**, **IBC**, **NEHRP**, and **User's**. Select one of these options and then click the **Target** command button to display the respective form. Further information for the first four options is provided in the respective sections of this manual. The **Other** option will display the **Response Spectra for Ground Motion** form. This form can be used to compute the response spectrum using the data saved in a ground motion file. If you would like to manually enter the values for period and spectral acceleration, select the **User's** option. This option will display the **User Defined Response Spectrum** form. In this form, you can enter values of period and spectra for a user defined response spectrum.

A period range of interest can be shown on the graph of results. Enter a lower and upper value in the $\mathbf{T_{min}}$ and $\mathbf{T_{max}}$ text boxes, respectively. A dashed line will be shown across the graph at each period value.

If you want to scale the spectra to a specific spectral value at a target period, enter the period in the **T match** text box and click on the check box to select this option. The program will compute the scaling factor necessary to scale each spectrum to that spectral value and display it in the **Scaling Factor** column.

If you want to use both horizontal components, select the Geometric Mean option. The program will compute the geometric mean spectrum and use this spectrum in the selection process. Before using this option, you need to define the corresponding pair for each motion. Enter the number of the file that is the pair for each file in the Pair column. For *.AT2 file, the program will automatically try to identify each corresponding pair. For example, in the screen shot in the previous page, the first file is file number one. For this file the corresponding pair is file number two. In the **Pair** text box for the firs file a 2 is shown indicating that file number 2 is the corresponding pair.

Once you have selected a suite of ground motion files and a target spectrum, click on the **Scale** command button to compute the average response spectrum. In SHAKE2000, the analysis consists of obtaining the 5% damping pseudo-acceleration response spectrum for each ground motions selected and then obtaining an average value of spectral acceleration for each period.

To aid in comparing the spectra, the fit is evaluated through the root-mean-square-error (RMSE) as recommended by Kottke and Rathje (2007):

$$RMSE = \sqrt{\frac{1}{n_p}\sum_{i=1}^{n_p}\left(\ln Sa_{scaled,avg,i} - \ln Sa_{t\arg et,i}\right)^2}$$

Where,

RMSE = root-mean-square-error.
n_p = number of periods in range of interest.
$Sa_{scaled,avg,i}$ = average scaled pseudo-spectral acceleration for records considered at period T_i, for periods within the period range of interest.
$Sa_{target,i}$ = target pseudo-spectral acceleration at the same period T_i for periods within the period range of interest.

The RMSE for the computed average spectrum is shown next to the RMSE label. Further, the fit is computed only for the range of periods of interest. For calculation of the response spectrum, 300 periods equally spaced in a log space, between 0.01 seconds and 10 seconds are used.

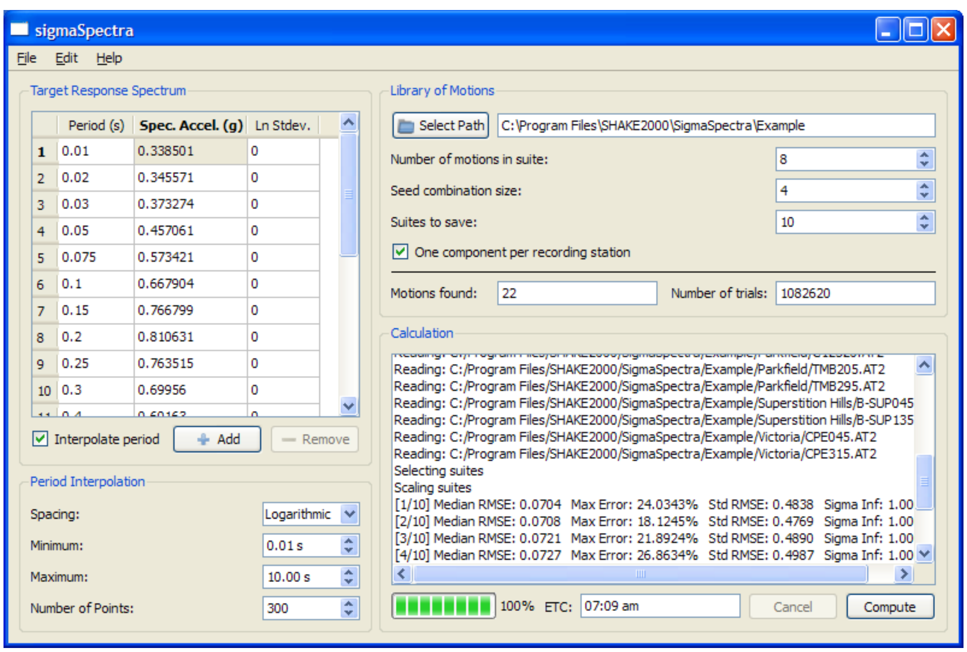
To plot the results click on the **Plot** command button.

To delete a ground motion file from the list of motions, click on the name/path for the file to highlight it and then on the **Remove** command button.

The input and output data can be saved to a text file using the **Save** command button. The data can be retrieved from the file using the **Open** command button. This file is an ASCII text file, thus, it can be open with other software applications for other purposes by the user.

An alternative way of finding the scaling coefficients is by using a computer program developed by Kottke and Rathje (Kottke and Rathje, 2007). This program, **sigmaSpectra**, selects and scales motions from a suite of a user provided library of motions so that their average fits a target response spectrum. After the user has executed sigmaSpectra, the results can be imported into SHAKE2000 and used to compute the mean and median spectra as explained previously. The installation file for sigmaSpectra is saved in the sigmaSpectra folder when SHAKE2000 is installed. Please run this installation file to install sigmaSpectra.

The following is a quick tutorial on the use of sigmaSpectra and on how to use the results with SHAKE2000. The main form for sigmaSpectra is shown below.



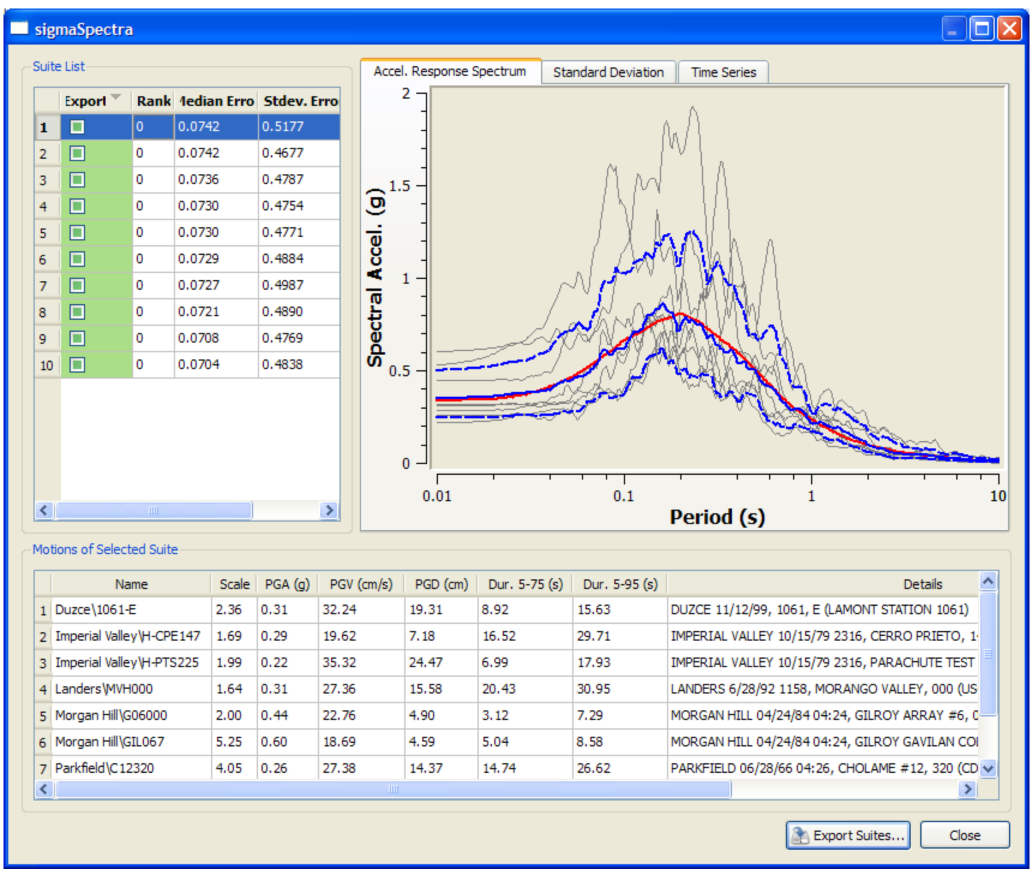
First, you need to create a library of ground motion files that will be used by sigmaSpectra to create different suites of ground motion files whose average closely match a target spectrum. This library is formed by ground motion records downloaded from the PEER web site at **http://peer.berkeley.edu/nga/**.

These files should have the extension *.AT2, which is typically the extension automatically given to the files downloaded from the PEER website. Further, these files should have the same names as those entered in the ***Motion Identification*** column of the **Mean Response Spectrum** form. For example, in the above form, the library of ground motion files is saved in the *c:\Program Files\SHAKE2000\SigmaSpectra\Example* folder. Within this folder, there may be other folders were files for specific seismic events are stored; e.g., the files for ground motion histories recorded for the 11/24/87 Superstition Hills event, B-SUP045.AT2 and B-SUP135.AT2, are located in the *Superstition Hills* subfolder.

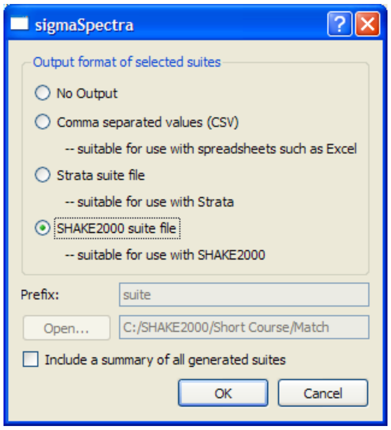
After the library is created, use the **Select Path** command button to select the path where the library of ground motion files is stored. As shown on the previous form, for this example the path selected would be *c:\Program Files\SHAKE2000\SigmaSpectra\Example*. Then use the **Number of motions in suite** and **Seed combination size** options to select the number of motions per suite and the size of the seed combination for the analysis, respectively. Refer to Kottke and Rathje (2007) for more detailed information on these options.

Data for the target response spectrum; i.e. period, spectral acceleration and standard deviation, are entered in their respective columns located on the **Target Response Spectrum** section of the previous form. The data can be entered manually, i.e. place the cursor on the text box and type in the numbers, or you can copy the data from another application, e.g. Excel, and paste them in the respective data colum using the **Paste** command of the **Edit** menu item. sigmaSpectra uses the periods entered for the target spectrum to compute the response spectrum for the ground motions used in the matching process. If you would like to increase the number of periods, you can use the **Interpolate period** option. Click on the check box for this option to select it, and then use the options in the **Period Interpolation** section of the form to define the settings and values for the interpolation.

After you have selected the ground motion library and set other options and values, click on the **Compute** command button to do the matching. Once the program has completed the calculations, the results for the first suite of ground motions will be automatically displayed as shown below.



This form shows the response spectra for each ground motion on the suite; the target, median and median ± standard deviation response spectra; and the ground motion files that form the suite. It also lists the different suites created on the upper left corner of the form. To view the results for other suite, click on the row for that suite to select.
To use these results with SHAKE2000, you need to export the data using the **Export Suites** command button. First, select the suites that you want to export by clicking on the check box for each suite on the **Export** column. Then click on the **Export Suites** command button to display the following file dialog form.



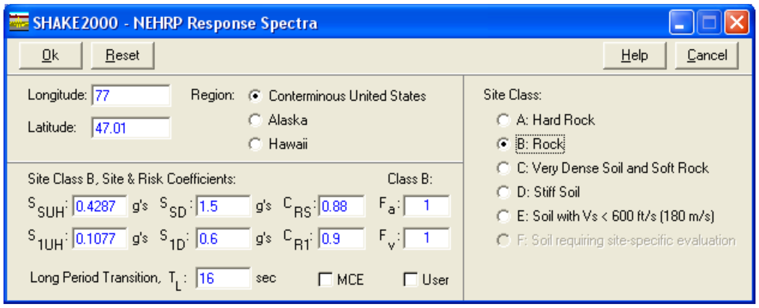
On this form, click on the **Open** command button to select the folder where the results file will be saved; then, click on the **SHAKE2000 suite file** option to select it. To create the results file, click on **Ok**. This file will be automatically given the ***SuiteLog.txt*** file name and extension.

In the **Mean Response Spectrum** form of SHAKE2000, click on the open folder icon next to the text box for **Motion Selector Suite** and use the file dialog form to select the ***SuiteLog.txt*** file created with **sigmaSpectra**, and then click on **Open**. The results for the first suite will be shown on the text box. To select a different suite, open the list by clicking on the down arrow, and then select the suite. The scaling coefficients for each motion in the suite will be updated and those for the motions not included in the suite will be changed to 1.0. Then, click on the **Scale** command button to conduct the matching analysis; and, use the **Plot** command button to display the results as explained before.

After you have obtained a suite of motions that fit the target spectrum, the information about the ground motions can be exported to an EDT file in the form of Option 3 used by SHAKE. To do this, first click on the **Export** command button to display the **Export as Option 3 to EDT File** dialog form. Select the EDT file you would like to add the information to, and then click on **Save**. If you wish to add this information for use with the random creation of data feature, first create the random EDT file before exporting the data.

PEER ACC Files: A number of ACC files downloaded from the PEER Ground Motion Database website (http://peer.berkeley.edu/peer_ground_motion_database) can also be used to save their information as Option 3 in an EDT file after the “matching” has been performed by PEER. To this end, follow the above procedure to select a group of ACC files and then use the “open folder” icon to open the Excel CSV file created with the “Save Search Spectra” command button of the PEER website. The scaling factors will be retrieved from the CSV file and shown on the respective columns for the corresponding ACC file. After this, follow the above procedure with the **Target** and **Scale** command buttons to create a target spectrum and to scale the motions, respectively; and, then use the **Export** command button to create the EDT file.

NEHRP Response Spectra



This form is used to select the options and/or enter the data necessary to plot a response spectrum in accordance with NEHRP (Building Seismic Safety Council, 2004a & 2004b, 2009). The program can use the USGS online data; or, the user can enter the T_L, S_{SUH}, S_{SD}, C_{RS}, S_{1UH}, S_{1D}, and C_{R1} values manually.

If you want to use the USGS online data to obtain the spectral accelerations S_s and S_1, enter the coordinates of your site in the Longitude and Latitude text boxes. There is no need to enter a negative sign for the longitude value as required by the online USGS website. The spectral values for the four grid points that surround your site are retrieved from the files, and if necessary, the values interpolated between the four grid points. The S_{SUH}, S_{SD}, C_{RS}, S_{1UH}, S_{1D}, and C_{R1} values are displayed in their corresponding text boxes on the form.

By default, a Long-period transition period, T_L, of 4 seconds is shown on the T_L text box. If you would like to use a different value, enter the appropriate value in this text box. The program will only accept values of 4, 6, 8, 12 or 16 seconds for T_L as these are the only values used in the NEHRP maps.

Next, select the site class by choosing one of the **Site Class** options. The F_a and F_v values will be computed and displayed in their corresponding text boxes on the upper right corner of the form.

By default, the program will compute the design spectrum. If you need to use the MCE spectrum, click on the **MCE** check box to select it. When the spectrum is plotted, either **Design** or **MCE** will be shown on the plot label to indicate which spectrum is being used. When this form is called from the RRS form, the default spectrum will be MCE.

If you would like to manually enter the values for T_L, S_{SUH}, S_{SD}, C_{RS}, S_{1UH}, S_{1D}, and C_{R1}, select the **User** option.

After you have entered the above input information, click on the **Ok** button to compute the spectrum and to return to the **Response Spectrum Plot Menu** form. If you click on the **Cancel** button, you will return to the plot menu form without modifying the input information if any had been selected previously.

If the **User** option is not selected to manually enter the coefficients, the program will use the data provided by the USGS website at:

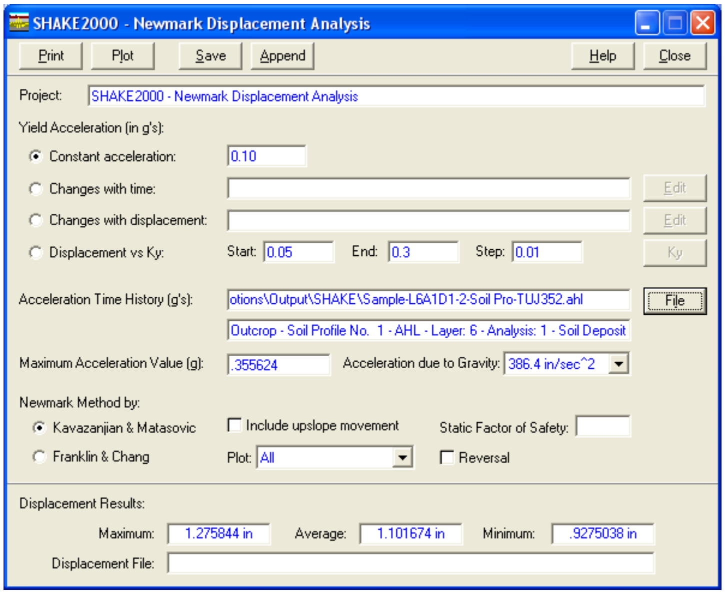
http://earthquake.usgs.gov/hazards/designmaps/usdesign.php

Alternatively, you can obtain the most-up-to-date parameters using the on-line application at:

http://earthquake.usgs.gov/designmaps/us/application.php

The **Reset** button is used to set the values of the form to their default values.

Newmark Method - Displacement Analysis



This feature of SHAKE2000 allows you to determine permanent slope displacements due to earthquake shaking, using the Newmark Method. For more complete information on the methodology and data used in this feature, please refer to the papers by Houston et al. (1987), Matasovic et al. (1998) and Newmark (1965).

In SHAKE2000 two different approaches are used to create an algorithm for the Newmark Method as recommended by Kavazanjian & Matasovic (1998; Houston et al., 1987) and by Franklin and Chang (1977).

The approach by Kavazanjian & Matasovic allows the use of the upslope component of the yield acceleration in order to account for upslope movement. However, when only the downslope component of the yield acceleration is used, both approaches yield similar results. To select a method, click on the radio button for the method's option.

When this form is first displayed, the cursor is on the **Project** text box. Enter the description (up to 80 characters) for the analysis you will be doing. Press the *Tab* key, or use the mouse pointer to move the cursor to one of the **Yield Acceleration** options. The first option, **Constant Acceleration**, allows you to use a constant value for the yield acceleration. When this option is selected, the text box next to the label is enabled, and the cursor is placed on it. Enter the value for the yield acceleration.

The second option, **Changes with time**, allows you to enter values of yield acceleration that vary as a function of time. After you select this option, the **Edit** command button next to the text box will be enabled. Click this button to display the **Yield Acceleration Function** form. Enter the data for time, yield acceleration and a brief description for the function in the **Description** text box. Then click on the **Ok** command button. Upon returning to the displacement screen, the description will be displayed on the text box.

The next option, **Changes with displacement**, allows you to enter values of yield acceleration that vary as a function of displacement. Matasovic et al. (1998) provide an example of this application. These data are entered as described previously for the **Changes with time** option.

The **Displacement vs Ky** option is used to compute displacements for a range of yield acceleration, K_y, values. The range of K_y values is determined by the values entered in the **Start** and **End** text boxes. The value in the **Step** text box sets the increment value for the computations. The results will be saved automatically to a coma separated values (*.CSV) file that can be open with Excel to create your own custom plots. To compute the displacements for the range of K_y values, click on the **Ky** command button. The results can be graphed by clicking on the **Plot** command button. If there are different groups of ground motion files selected with the **Newmark Displacement Ground Motion File** form, the program will first compute an average file for each group and then compute the displacements for each group separately.

To select an acceleration time history to use in the displacement analysis, click on the **File** command button on the **Acceleration Time History** line to display the **Newmark Displacement Ground Motion File** form. Use this form to select a time history file; or, to create a weighted-file from up to 5 files that may represent different columns on the soil profile.

If you would like to scale this acceleration time history to a different value of maximum peak acceleration, place the cursor on the **Maximum Acceleration Value** text box and enter the value for the new peak acceleration in g's. If you enter 0 (zero), a scaling factor of 1 (one) will be used and the record will not be changed.

An option to account for the upslope movement is included in SHAKE2000. Normally, the error in not including the upslope movements is not significant (Jibson, 1993; Newmark, 1965). To include the upslope movement, click on the check box for the **Include upslope movement** option. If you select this option, you need to enter a value for the static factor of safety. Based on the method proposed by Houston et al. (1987), the static factor of safety is used to compute the upslope component of the yield acceleration based on the following equation:

$$a_{y,upslope} = a_{y,downslope}\left[\frac{FS_{static}+1}{FS_{static}-1}\right]$$

Where $a_{y,downslope}$ is the downslope value of yield acceleration. To enter the static factor of safety, place the cursor on the text box next to the **Static Factor of Safety** label and enter the value.

When working with English units, a default value of 386.4 in/sec^2 is used for the acceleration due to gravity. A value of 981 cm/sec^2 is used when working with SI units. However, you can change this value to obtain the results using a different system of units. Select a different acceleration value by clicking on the down arrow key of the list box next to the **Acceleration due to Gravity** label and choose a new value.

After you have entered all the information, the displacements are computed automatically. The results will be displayed in the **Maximum**, **Minimum** and **Average** displacement text boxes. A value of displacement is computed by using the acceleration data as they are saved in the input file.

If the acceleration time history is significantly unsymmetrical, then Houston et al. (1987) recommend that the history be reversed. A second value of displacement is calculated by first reversing the acceleration time history, i.e. the sign of each value is changed, and then by conducting the analysis a second time. The displacement values are compared to determine the maximum and minimum, and an average value is computed.

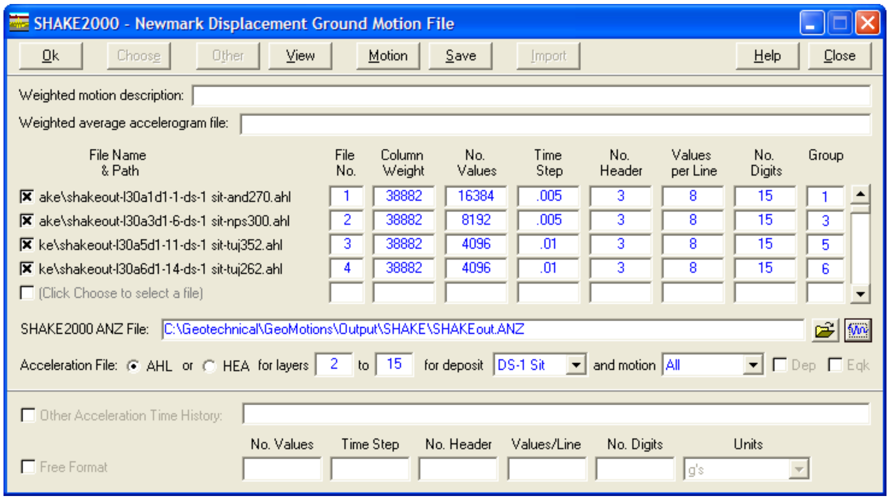
You can print the results by using the **Print** command button. This button will display the **Print Displacement Results** form.

The data can be saved to a text file by clicking on the **Save** command button. This will display the save file dialog box. Enter a name for the text file where all this information will be saved for future retrieval using the **Open** command button. The acceleration, velocity and displacement time histories are also saved in this data file. The **Append** command button can be used to add the current results at the end of the output file.

To plot the results, click on the **Plot** command button. You can select to plot the three graphs at the same time or each graph separately. When using the **Franklin & Chang** option, plots of the relative values for acceleration, velocity and displacement are also available.

The **Reversal** option allows you to plot the results obtained using the reversed acceleration time history.

Newmark Method - Select Accelerogram File



There are four options for selecting an accelerogram for the Newmark's method:

- The first one is to use a file that was obtained from processing of the second output file from SHAKE2000. The file is given a name such as **L##A#D#-##-@@@@@@@@-$$$$$$$$.AHL** or **L##A#D#-##-@@@@@@@@-$$$$$$$$.HEA**, where **L** means layer and is followed by two numbers which are the layer number; **A** stands for analysis, and the number following it is the analysis number; and, **D** is for soil deposit and the number is the number of the soil deposit as defined in option 2. The last 2 numbers after the "-" show the position of this time history in the output file. The **@@@@@@@@** string identifies the soil profile in more detailed and it is obtained from the first 8 characters of the string entered in the **Identification for Soil Profile** text box in Option 2. Similarly, the **$$$$$$$$** string is the string of characters entered in the **Earthquake Identification** text box in Option 3. Files obtained from earlier versions of SHAKE2000 may not have these two strings.

  For example, the very first time history in the second output file will have the "-01" numbers after the deposit number. More information on the analysis number is given in the introduction section of this manual, and the files are saved in the output directory selected in the Main Menu form of SHAKE2000. Files identified with the extension *.AHL (or acceleration history at layer) are those created for the acceleration time histories requested in Option 6; and, those with the extension *.HEA (or horizontal equivalent acceleration) are those created from the shear stress time histories requested in Option 7. The *.AHL files stores the same data saved in the *.ACC file. The difference is that each AHL file only saves one acceleration time history, i.e. the acceleration time history at the top of the layer. As explained in Bray et al. (1995) for the seismic analysis of landfills, the HEA, or horizontal equivalent acceleration, at a specific depth and time can be obtained as the ratio of the shear stress to the total vertical overburden stress. Accordingly, these files are created using the shear stress histories from option 7 and the overburden stress computed using the thicknesses and unit weights from option 2 for the corresponding SHAKE column and analysis.

  To select a file, click on the check box next to the first **(Click Choose to select a file)** label. Then on the **Choose** command button to open the **Open Acceleration Time History** dialog box. Select a file and then click on **Ok** to return to the form. Some information will be displayed on the boxes next to the file name. Click on **Ok** to return to the **Newmark Displacement Analysis** form.

- The second option is to create an average file from a series of files. These files were created when the second output file from SHAKE2000 was processed, and named as described above. The weight of the column above the layer where the ground motion was calculated is obtained using the data from Option 2, and saved in the acceleration time history file. The method used to compute an average accelerogram in SHAKE2000 is as recommended by Abramson et al. (1996). In this method, a weighted average approach is used to compute an average file from a series of **n** files based on the equation:

$$Acc_{avg} = \frac{\sum_{i=1}^{i=n} m_i \, a_i(t)}{\sum_{i=1}^{i=n} m_i}$$

Where, m_i = mass of unit column directly above point **i**
$a_i(t)$ = acceleration response at point **i**

To create the average accelerogram, first select up to fifty motion files. To do this, click on the check box next to the first **(click Choose to select a file)** label (an **x** is shown on the box when a file is selected), then on the **Choose** command button to display the **Open Acceleration Time History** dialog box. Select a file then click on **Ok** to return to the form. Some information will be displayed on the boxes next to the file name. Use the scroll bar to display check boxes for additional files. After selecting the files, you need to choose a name for the average file. By default SHAKE2000 will give this file the name **output.nmk,** and will save it in the directory selected for the output files in the Main Form. The name and path will be shown on the text box next to the **Weighted average accelerogram file** label. If you would like to use a different name and/or path, click on the **Save** command button to display the **Save Accelerogram File** form. Then, select a file or enter a new name in the **File name:** text box. This file is given the extension *.NMK by default. Click on **Ok** to return to the file selection form.

After you have selected the files and have chosen a name, click on the **Motion** command button to create the file. Only the files for which an **x** is shown on the check box will be used in the calculation of the average file. Finally, click on the **Ok** command button to return to the Newmark Displacement Analysis form.

- Import an acceleration file created by another application (e.g. ProShake, Quake/W). In short, first, you will select an output file created by another application, e.g. ProShake; then, read that output file to determine if there are any acceleration time histories and how many there are (however, SHAKE2000 will only read the first 6 acceleration time histories found in the file); and finally, create a series of output files, i.e. one per acceleration time history, in the format used by SHAKE2000 to perform the displacement analysis with the Newmark Method. To access this feature, click on the **Import** command button to display the **Import Acceleration Data** form.

- **Using other acceleration history file**: If you want to use the data saved in a file different from the ones described above, use the **Other** command button to display the **Acceleration Time History** dialog box to select the file that you want to use. The name of the file will be displayed next to the option button on the bottom section of the form. Now you need to enter the following information on the data cells below the file name. First, you need to select the file by clicking on the button next to the **Other Acceleration Time History** label. This will enable (i.e. the mouse cursor changes to the *I-beam* appearance when placed on the cells) the data cells to enter the data. We'll use the following example to explain the information necessary to plot the object motion.
Example:

```
SHAKE2000 Sample Object Motion
Time Period = 0.01          Number of Points = 2048
 0.024455  0.000868  -0.019352  -0.012488   0.003331   0.030202   0.021586
-0.022183  1
-0.050340 -0.025930   0.000123   0.020366  -0.000176  -0.008401  -0.013457
-0.014927  2
```

No. Values: This is the total number of acceleration values that form the object motion file. For the above example, there are 2048 points in the file, thus, you will enter 2048 in this cell.

Time step: Enter the time interval between each acceleration value. For this example, it is 0.01 seconds.

No. Header (or Number of header lines): Enter the number of lines at the beginning of the file that are used to describe the object motion. In the above example, the first two lines are the header lines. Thus, you will enter a 2 in this data cell.

Values/Line (or Number of values per line): Enter the number of acceleration values on each line. For the above example, there are 8 values on each line. The last number (e.g. 1) only identifies the row number. Thus, you would enter an 8 in this cell for this specific example.

No. Digits (or Number of digits per value): Enter the number of digits that form an acceleration value. In the above example, each value is defined by 9 digits, including the spaces. Therefore, you would enter a 9 for this specific example.

Units: For the Newmark Displacement Analysis the values of acceleration are in g's. If the values saved in the file are in other units (e.g. ft/sec^2, cm/sec^2, or mm/sec^2), then select the appropriate units by clicking on the up or down arrows to scroll through the different options. This way, the data will be converted from these units to g's. For example, if the data in the file were in ft/sec^2, then you scroll down until **ft/sec/sec** is shown on the **Units** box. The values will be divided by 32.2 to transform them to g's.

Free format: With this option the data from the file are read "free format", i.e. no consideration is given to the number of digits in each column, or to the number of columns in a row. When you select this option (an **x** is shown on the check box), you only need to provide the **No. Values**, **Time Step** and **No. Header** values, and then select the units for the acceleration values by clicking on the up or down arrow keys next to the **Units** text box. To be "free format" the data in the file have to be separated by at least one blank space, a comma, a tab, or be in different lines.

An alternative way of choosing files for the Newmark displacement analysis is to extract the information about the AHL and HEA files created during processing of the SHAKE output files from the ANZ file created. The ANZ file is a file that stores summary information about the options and results of the SHAKE analysis. To this end, first click on the open folder icon next to the text box for the **SHAKE2000 ANZ File** text box. When the open file dialog form is displayed, browse to the directory where the ANZ file is saved, then select and open the file. Upon returning to the Newmark File form, the information about the different soil deposits and ground motions used in the SHAKE analysis will be displayed in the **deposit** and **motion** list boxes. Based on the naming configuration described at the beginning of this section (e.g., **L##A#D#-##-@@@@@@@@-$$$$$$$$**) enter a start and end layer number to define the L## part of the file name in the **for layers to** text boxes; choose a deposit identification from the **deposit** list box to define the @@@@@@@@ part of the file name; and, select a motion from the motion list box to define the $$$$$$$$ part of the file name.

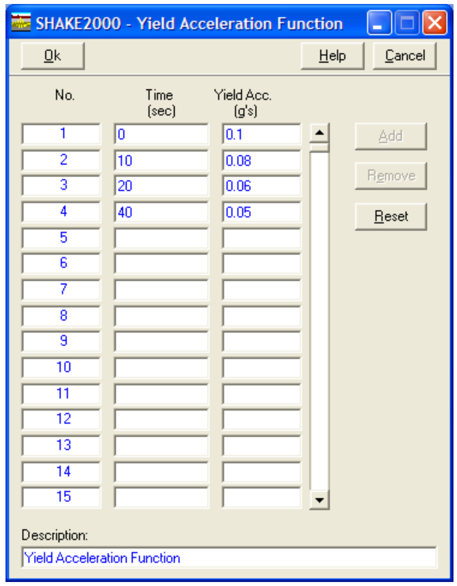
The ground motion files can be grouped so that they can be use to compute displacements vs K_y by group and then plot the results for all the groups together. When the files are read from the ANZ file, the group numbers will be assigned automatically. However, you can also enter the group number manually. If an average ground motion is computed with the Motion command button, grouping will not have any effect on the result, i.e., the grouping is ignored and to compute the average only the files with check mark, i.e., an ***x*** on the check box, will be used.

When extracting the file information from the ANZ file, the files will be grouped automatically. The grouping will depend on the **Dep** and **Eqk** options. If neither option is selected, or if the **Eqk** option is selected, the files will be grouped based on the information shown on the motion list. If the **Dep** option is selected, the files will be grouped according to the information on the deposit list. If both the **Dep** and **Eqk** options are selected, then the files are grouped based on the information shown on both the deposit and motion lists.

After you have entered and selected the information needed, click on the motion icon located next to the open folder icon to search for the files that meet these requirements. For example, based on the information provided on the screen shot at the beginning of this section, the program will search for the L2A#D#-Column 1-CHY-28-N.hea, L3A#D#-Column 1-CHY-28-N.hea, L4A#D#-Column 1-CHY-28-N.hea, and L5A#D#-Column 1-CHY-28-N.hea files, regardless of the analysis (i.e. A#) and deposit (i.e., D#) numbers. If the file exists, the file name and information will be displayed on the form.

The **View** command button can be used to view the contents of a ground motion file. This will help you to collect the information needed to define the formatting of the file if necessary. To do this, first select a file using the **Other** button to select other files. The first 60 lines of the file will be displayed on a form, with the first three characters displayed in red representing the numbers of each row of data in the file followed by a "|". These characters are not part of the source file and are only shown to number the rows. After the row numbers, the alphanumeric characters that constitute the information saved in the file for each row are shown. Note that the characters are displayed as blue on a white background, and that every tenth character is displayed in red. However, if the tenth character is a "blank space" then the character is not shown. This is done to guide the user when defining the order of the data in the file.

Newmark Method - Yield Acceleration Function



This form is used to enter data to define a yield accleration (K_y) function, i.e. a description of a change in K_y with time or displacement (Houston et al., 1987; Matasovic et al., 1998). You need to enter a value for either time in seconds, or for displacement in the longitude units similar to the longitude units in the value of gravity in the **Newmark Displacement Analysis** form; and, a value for yield acceleration in g's.

To enter the data, first place the cursor on the text box for the **Time/Displacement** column and type in the value. Next, press the *Tab* key once to move the cursor to the text box for the **Yield Acc.** column and type in the value for K_y.

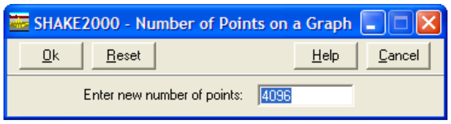
It is recommended that the first value entered should be that for a time/displacement of zero. Additionally, the last value for time should be greater than or equal to the length of the acceleration time history used; or, that the last value of displacement should be greater than the greatest value expected. The values of yield acceleration between two points of the function are obtained by linear interpolation. For a constant value of yield acceleration, the two values for the function between two time/displacement points should be equal.

A description of the function will be shown on the text box below the **Description** label. This description can be modified/entered manually by placing the cursor in the text box and typing in the desired information.

After you have entered the information for each time/displacement - K_y pair, click on the **Ok** command button to return to the **Newmark Displacement Analysis** form.

Each time you place the cursor on either the **Time/Displacement** or **Yield Acc**. columns the **Add** and **Remove** command buttons are enabled. If you want to add data for a new pair, place the cursor on the row where the new values will be located, and click on the **Add** button. A new pair will be created, and the values for the new pair will be the same as those for the pair immediately below. Now, you need to modify the information for the time/displacement and yield acceleration. The **Remove** button is used to delete a pair from the table. Place the cursor on either the **Time/Displacement** or **Yield Acc.** column and then click on the **Remove** button. The data for the pair will be removed from the table, and the information for the other pairs updated accordingly. The **Reset** command button will delete all the information on the table.

Number of Points on a Graph

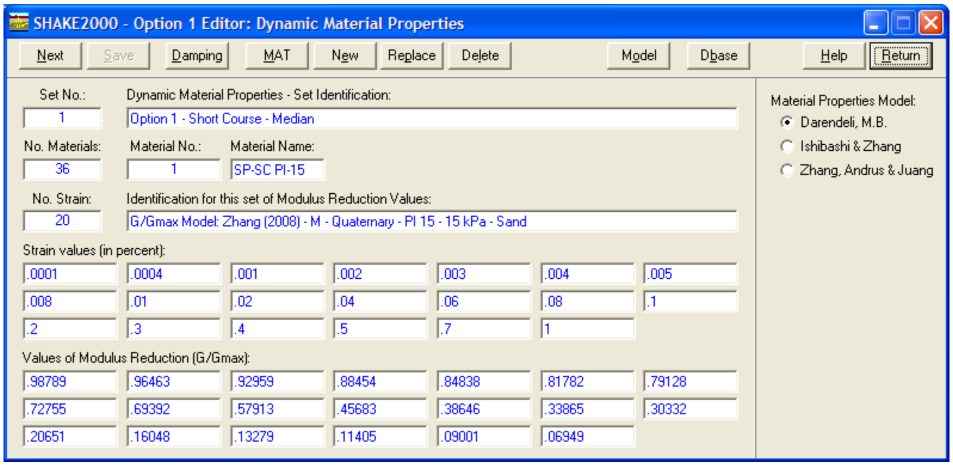


This form is used to change the number of data points plotted on the graph.

When the form is displayed, the current number of points appears in the text box. If you enter a different number, N, then the first "N" points of the graph will be plotted. For example, assume that 2048 points define an acceleration time history at a time step of 0.02 seconds, i.e. a history with a length of 40.94 seconds. If you enter a different number, say 512, then only the first 512 points of the time history will be displayed, i.e. from 0 seconds to 10.22 seconds. The section of the history between 10.24 to 40.94 seconds will not be displayed.

To change the number of points, place the cursor on the text box and type in the new number. To reset the number of points to the maximum value, click on the **Reset** button. Click on the **Ok** button to return to the graphics window, and plot the curve using the new number of points.

Option 1 Editor: Dynamic Material Properties



Dynamic Material Properties - Set Identification: A description of this Option 1 data set can be entered in this text box. As with the other options, the first word should always be **Option** followed by a space and then the option number, in this case **1** (i.e., **Option 1**). This is the code that SHAKE2000 will use to identify this data set as option 1 for subsequent operations, such as creating an input file. This is also **Line No. 1** for this option. SHAKE2000 will automatically input a 1 as **Line No. 2** in the *.EDT and input files.

Some of the following information is taken literally from the SHAKE91 and SHAKE User's Manuals (Idriss and Sun, 1992; Schnabel et al., 1972), and other class and technical seminar notes. This information is italicized. Further information on this option can be found in Section 4.2 of the **Introduction**.

No. Materials: *Number of materials included* (maximum is 100 in SHAKE2000). This value cannot be edited by the user. It is automatically set by SHAKE2000.

No. of Strain: *Number of strain values to be read (maximum is 20)*. This value cannot be edited by the user. It is automatically set by SHAKE2000.

Material Name: This is a 12 character label that can be used to identify the material, and that together with the information entered in the **Identification for this set of Modulus Reduction Values** (or **Identification for this set of Damping Values**) text box, will form the identification label for the material in the SHAKE option 1 data. The information entered in this text box will be included in the table of results to help you identify each soil layer with a material name. For example, if you entered **Sand** in this text box, and **Lower bound (Seed and Idriss 1970)** on the **Identification for this set of Modulus Reduction Values (or Identification for this set of Damping Values)** text box, the label for this material in Option 1 will be formed by adding the two labels, i.e. **Sand Lower bound (Seed and Idriss 1970)**.

Identification for this set of Modulus Reduction Values & Identification for this set of Damping Values: Enter up to 54 characters to identify the dynamic properties for this set. SHAKE2000 uses this description in the graph title.

Strain Values (in percent): *Beginning with the lowest value. Eight entries per line (maximum is 20)*. To delete a value, place the cursor on the data cell and press the *Delete* key. Use the *Tab* key to move the cursor to the following cell. The data on the following cells, if any, will automatically scroll to occupy the cell where data was deleted. The modulus/damping value corresponding to this strain value will also be deleted, and the other values reorganized. When entering data on the first blank cell for this option, default values for modulus/damping will be automatically placed on the corresponding cell. When deleting and adding values, the number of strain values is automatically changed and shown on the ***No. of Strain*** cell.

Values of Modulus Reduction (G/G_{max}) & Values of Damping (%): *Values of modulus reduction (G/Gmax) each corresponding to the shear strain provided in the previous lines; these values should be in decimal not in percent.* To delete a value, place the cursor on the data cell and press the *Delete* key. Use the *Tab* key to move the cursor to the following cell. The data on the following cells, if any, will automatically scroll to occupy the cell where data was deleted. The strain value corresponding to this modulus/damping value will also be deleted, and the other strain values reorganized. When entering data on the first blank cell for this option, a default value for strain will be automatically placed on the corresponding cell. When deleting and adding values, the number of strain values is automatically changed and shown on the **No. of Strain** cell.

The second set for the same material will consist of identical information except that values of damping (in percent) are provided as illustrated in Table 1 of Idriss and Sun (1992).

After the last set is completed, the following information is to be provided:
number, N, of materials to be used in this analysis.
first material number which will be used
second material number to be used
etc., until all N materials are identified.

Values of G/Gmax and D versus strain for these N materials will then be saved in output file No. 1 so that only the material properties used in this analysis are saved in this file. This feature was added for the convenience of the user who can include up to 13 (this has been increased in SHAKE2000 to 100) *sets of materials properties in the input file but for any one analysis use fewer than 13. This feature also provides a check that the intended material properties were utilized in the analysis.* SHAKE2000 will automatically save all of the materials used in the analysis in the first output file.

Database of dynamic material properties: The **MAT** command button can be used to display a list of the different dynamic material properties curves included in the database file. This option is further explained in the **Database of Dynamic Material Properties** section of this manual. You can select up to 13 materials to be included in the current set of Option 1. Remember to select both sets of damping and moduli curves for each material.

When editing an existing set of data, or creating a new material curve, the **Dbase** command button will display the **G/Gmax Curves Database** or **Damping Ratio Curves Database** forms, depending if you are editing moduli or damping data respectively. These forms are used to add the current material in the Option 1 form to the database of material properties, to delete a material from the database, or to update the database using a file of properties downloaded from the SHAKE2000 web site. Refer to the **G/Gmax Curves Database** or **Damping Ratio Curves Database** sections of this manual for further information.

A number of relationships developed to estimate the normalized shear modulus and damping ratio of soils are included with SHAKE2000. More information for these relationships is provided in Ishibashi and Zhang (1993), Zhang et al. (2005, 2008), Andrus et al. (2003) and Darendeli (2001). After selecting one of these options, click on the **Model** command button to display the **Dynamic Material Properties Model** form used to enter the data for the relationship selected. Upon returning to this form, the computed values for G/G_{max} and Damping and their respective strains will be displayed in the corresponding text boxes. The new values will replace the current values in the form.

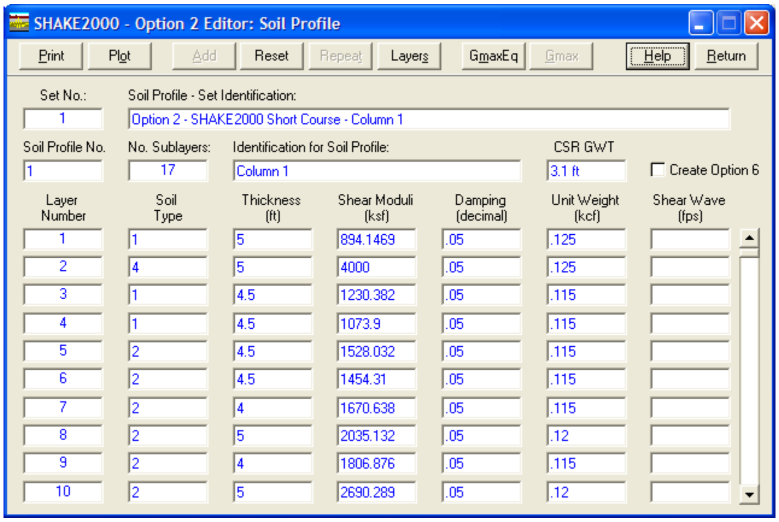
Use the **New** command button to enter data for a new material. This new material will be added to the current option 1. When you click on the **New** command button, the form is cleared of the current data. You can enter the values for G/Gmax or Damping vs. Strain manually, or you can click on the **MAT** command button to display the **G/Gmax Curves Database** or **Damping Ratio Curves Database** forms, depending if you are editing moduli or damping data respectively. If you select a curve, the current data for the material will be shown on the form if you accept the changes. After you have entered the data, click on the **Save** command button to add this new material to the current Option 1. If you don't want to include this new material, click on the **Cancel** command button to cancel the operation and return to the material properties form.

To delete a material from the current Option 1, click on the **Delete** command button. The **Delete** button will delete the material dynamic properties curves for the current material. This action cannot be undone, thus, once you delete a material you cannot recover it. To switch between the Modulus Reduction and the Damping Ratio curves, click on the **Damping** button. This button will change to **Moduli** when the Damping Ratio curves are being displayed.

The **Replace** command button can be used to “replace” the current material properties with one selected from the database of material properties.

When there is more than one material in the Option 1, you can display the properties for other materials by clicking on the **Next** command button.

Option 2 Editor: Soil Profile



Some of the following information is taken literally from the SHAKE91 and SHAKE User's Manuals (Idriss and Sun, 1992; Schnabel et al., 1972), and other class and technical seminar notes. This information is italicized. Further information on this option can be found in Section 4.2 of the **Introduction**.

Soil Profile - Set Identification: A description of this Option 2 data set can be entered in this text box. As with the other options, the first word should always be **Option** followed by a space and then the option number, in this case **2** (i.e., **Option 2**). This is the code that SHAKE2000 will use to identify this data set as option 2 for subsequent operations, such as creating an input file. This is also **Line No. 1** for this option. SHAKE2000 will automatically input a 2 as **Line No. 2** in the *.EDT and input files.

Soil Deposit No.: Enter the number that identifies the soil deposit described by the Option 2 data set.

Identification for Soil Profile: Enter up to 36 characters to identify the soil profile. SHAKE2000 uses this description as the project name. The first 8 characters of the string will also be used to create a name-string to identify the different analyses and when creating the name for the *.AHL and *.HEA files.

CSR GWT: Enter the depth to the water table. This value is used by SHAKE2000 to estimate the effective stress using the total unit weights entered in this form and the peak shear stress obtained from the SHAKE analysis to compute the cyclic stress ratio (CSR).

Soil Type: *Soil type (corresponding to numbers assigned to each material in Option 1). [Note that if this material type is given as 0 (zero) for all sublayers, then the calculations are conducted for only one iteration using the properties (modulus, or shear wave velocity, and damping) specified in this input].*

Thickness: *Thickness of sublayer, in feet* or meters. *With the wave propagation method, the responses can be computed in a homogeneous layer of any thickness. A soil deposit will, however, have varying properties not only due to the variation in the soil itself but also due to the differences in the strain-level induced during shaking. Since the soil deposit must be represented by a set of homogeneous layers, each with a constant value of modulus and damping, the thickness of each layer must be limited based on the variation in the soil properties. For a fairly uniform deposit, a sublayer thickness increasing from about 5'* (or ≈1.5 meters) *at the surface to 50-200'* (or ≈ 15.25 – 61 meters) *below 100'* (or ≈ 30.5 meters) *depth should give sufficient accuracy. Accuracy may be checked by making a trial run and comparing results with a subsequent run where more layers and/or sublayers are used*.

Shear Moduli: *Maximum shear modulus for the sublayer, in ksf* or kN/m^2 *(leave blank if maximum shear wave velocity for the sublayer is given).* Either a value for the **Shear Moduli** or the **Shear Wave** should be entered for each layer. SHAKE2000 will automatically leave the **Shear Wave** cell blank if a value for **Shear Moduli** is entered. Accordingly, the cell for **Shear Moduli** will be left blank if a value for **Shear Wave** is given.

Damping: *Initial estimate of damping (decimal).*

Unit Weight: *Total unit weight, in kcf* or kN/m^3. When using a geomembrane as a layer in the SHAKE column, it is recommended to use a value of 0.001 kcf or 0.16 kN/m^3 for the unit weight of the geomembrane (Yegian et al., 1998).

Shear Wave: *Maximum shear wave velocity for the sublayer, in ft/sec* or m/sec *(leave blank if maximum shear modulus for the sublayer is given).* Either a value for the **Shear Moduli** or the **Shear Wave** should be entered for each layer. SHAKE2000 will automatically leave the **Shear Wave** cell blank if a value for **Shear Moduli** is entered. Accordingly, the cell for **Shear Moduli** will be left blank if a value for **Shear Wave** is given.

The maximum shear modulus for the layers can be computed using the equations defined through the **Shear Moduli Equations** form. However, it is recommended that you enter the soil type, thickness, damping, unit weight, and if necessary, the shear wave velocity data for each layer before using the equations. Click on the **GmaxEq** command button to display the equations form, and then on the **Gmax** button to compute the maximum shear modulus. The coefficients for the equations are deleted from memory upon returning to the **EDT File's Options List** form; thus, saving the coefficients for the G_{max} equations using the **Save** command button in the **Shear Moduli Equations** form is recommended.

Use the **Plot** command button to display graphs of soil profile, G_{max} vs. depth, Unit Weight vs. depth, and shear wave velocity vs. depth for the SHAKE column.

When you select the **New Option 6** checkbox, corresponding sets of Option 6 will be automatically created for this set of Option 2 when returning to the **Earthquake Response Analysis** form. You will still need to edit the option 6 created to select for which layers you would like to obtain acceleration time histories, etc.

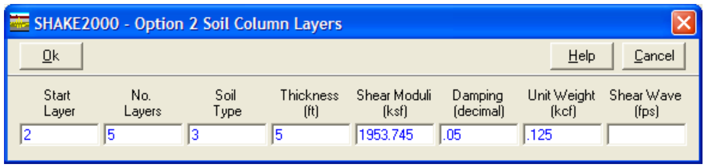
The **Layer** command button is used to subdivide each soil stratum of the SHAKE column into a number of sublayers that meet the criteria that the maximum layer thickness be less than approximately the thickness of the stratum divided by four times a maximum frequency of 25 Hz. This arbitrary limit is set to help with the creation of a soil column for further analysis with the nonlinear program D-MOD2000. For example, if the thickness of a stratum is 125 feet, with a shear wave velocity of 750 feet/second, the stratum will be subdivided into 16 layers with a thickness of 7.35 feet and one more layer with a thickness of 7.40 feet.

Jonathan Bray (2008, personal communication) points out that "…….*layering in a SHAKE column is required to capture variations in V_S with depth (non-homogeneous) and to capture the fact that for a thick layer with constant V_S that the shear strain will vary within its thickness (strain dependence). The layer thickness has an effect only with respect to strain-dependent properties, because dividing a thick layer into two or more thinner sublayers gives each sublayer a different effective shear strain and hence different shear modulus and damping values if these properties are strain-dependent. In SHAKE, the maximum shear strain vs. depth profile should be evaluated and if it varies significantly with depth it is then recommended to use thinner layers to capture this highly non-uniform variation in strain vs. depth. Where it is fairly uniform over a depth and the V_S is constant over that depth, thicker layers may be used without a compromise in the results. It is also important to point out that earthquake waves are tens of feet to hundreds of feet long, so the use of very thin layers with significant jumps in V_S is not recommended as this will trap energy and lead to non conservative estimates of surface motions*".

To print a copy of the soil profile data, use the **Print** command button to display the **Print Soil Profile Data** form.

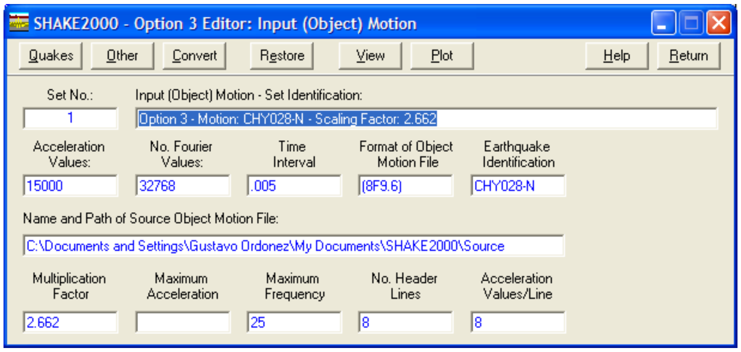
Each time you place the cursor on a soil layer row the **Add** and **Remove** command buttons are enabled. If you want to add data for a layer, place the cursor on the layer where the new layer will be located, and click on the **Add** button. A new layer will be created, and the data for the new layer will be the same as those for the layer immediately below. Now, you need to modify the values for the new layer. The **Remove** button is used to delete a layer from the soil column. Place the cursor on any column for the soil layer and click on the **Remove** button. The data for the layer will be removed from the soil column, and the values for the other layers updated accordingly. If you want to create more than one layer at a time, place the cursor on the soil layer that you want to copy and then click on the **Repeat** command button. This will display the **Option 2 Soil Column Layers** form. Use this new form to enter the number of times the layer will be repeated and the data that will be used for the new layers.

Option 2 Soil Column Layers



This form is used to create more than one layer for a soil column. The number of layers shown in the **No. Layers** text box will be added beginning one layer after the number of the layer shown in the **Start Layer** text box. For example, in the above form 5 layers will be created after layer 2, i.e. new layers 3, 4, 5, 6 and 7 and the values shown for soil type, thickness, shear moduli or shear wave, damping and unit weight will be used for each layer. If there are any existing layers 3 through 7, the information on those layers will be scrolled up and will form layers 8, through 12. After entering the information for the new layers, click on the **Ok** command button to return to the Option 2 form and create the new layers. Click on **Cancel** to return to the Option 2 form without creating the new layers.

Option 3 Editor: Input (Object) Motion



Some of the following information is taken literally from the SHAKE91 and SHAKE User's Manuals (Idriss and Sun, 1992; Schnabel et al., 1972), and other class and technical seminar notes. This information is italicized. Further information on this option can be found in Section 4.2.

Input (Object) Motion - Set Identification: A description of this Option 3 data set can be entered in this text box. As with the other options, the first word should always be **Option** followed by a space and then the option number, in this case **3** (i.e., **Option 3**). This is the code that SHAKE2000 will use to identify this data set as option 3 for subsequent operations, such as creating an input file. This is also **Line No. 1** for this option. SHAKE2000 will automatically input a 3 as **Line No. 2** in the *.EDT and input files.

Acceleration Values: *Number, NV, of acceleration values to be read for input motion. The acceleration values between NV and MA (see No. Fourier Values below) are set equal to 0 in the program. Cyclic repetition of the motion is implied in the Fourier transform and a quiet zone of 0.'s or low values are necessary to avoid interference between the cycles. For most problems a quiet zone of 2-4 seconds is adequate with longer time required for profiles deeper than about 250 ft and/or damping values less than about 5 percent. If the NV parameter is relatively close to (but less than) a particular power of 2, skip the next immediate power of 2 and use the following value. For instance, if NV = 4000, it would be better to use MA = 8192, instead of 4096, to insure that a proper "quiet zone" between successive trains of accelerograms develops. To insure that no interference between each record is occurring, you can check the acceleration ratio for the quiet zone listed in the Option 6 section of the output file. This ratio should be close to zero (Vinson and Dickenson, 1993). If not, use a large power of 2. Make sure MA > NV + 200.*

No. Fourier Values: *Number, MA, of values for use in Fourier Transform; MA should be a power of 2 (typically, this number is 1024, 2048 or 4096). Note that MA should always be greater than NV. The following may be used as a guide: for NV <= 800, MA can be 1024, for NV <= 1800, MA can be 2048 and for NV <= 3800, MA can be 4096*.

Time Interval: *Time interval between acceleration values, in seconds.*

Name of Object Motion File: *Name of file for input (object) motion.* **Regardless of the system of units used in the analysis, the acceleration values in the ground motion input file should be in g's.**

Format of Object Motion File: *Format for reading acceleration values.* Examples: (8F9.6, 1F10.6). The format string tells SHAKE how to read the ground motion values from the file. This string is based on the syntax used in the Format statement of the FORTRAN computer language. In this statement, edit descriptors specify how the values are read. The edit descriptors supported by SHAKE2000 are:

F*w.d*	Real values
E*w.d* [E*e*]	Real values with exponents
G*w.d*	Real values, extended range
D*w.d*	Double-precision real values
I*w*	Integer values

In these descriptors, the field is ***w*** characters wide, with a fractional part ***d*** decimal digits wide, and an optional exponent width of ***e***. You can also indicate that a given data format is repeated a number of times. For example, 8F9.6 repeats a nine-character real value with six decimal digits descriptor 8 times. The first character on the format field should be a "(" and the last character a ")", e.g. (8F9.6). Examples of data saved in the ground motion files included with SHAKE2000 and the format used to define them follow:

Format: (4E15.7):
```
  -.1059027E-04  -.1461820E-04  -.1690261E-04  -.1506594E-04
```

Format: (8F9.6):
```
  0.00000 -0.00434  0.00860  0.00540 -0.00565 -0.00944 -0.00369 -0.00669      1

-0.000001-0.000001-0.000001-0.000001 0.000000 0.000000 0.000000 0.000001
```

For more information on format types, please refer to a FORTRAN Programming Language book.

Earthquake Identification: Enter a string of up to 8 characters to describe the ground motion record or earthquake used in the analysis. This string will be used in conjunction with the string from Option 2 to describe the analysis and to use in the creation of the names for the *.AHL and *.HEA files created when processing the output files.

Multiplication Factor: *Multiplication factor for adjusting acceleration values; use only if Maximum Acceleration value is left blank.*

Maximum Acceleration: *Maximum acceleration to be used, in g's;* each acceleration value will be scaled proportionally to the ratio of the specified maximum acceleration to the maximum acceleration of the time history. *Leave Multiplication Factor value blank if a multiplication factor is entered.* Either the Multiplication Factor or the Maximum Acceleration value should be entered. SHAKE2000 will automatically leave the other data cell blank.

Maximum Frequency: *Maximum frequency (i.e., frequency cut-off) to be used in the analysis. Frequencies above 10-15 cps carry a relatively small amount of the energy in the earthquake motions, and the amplitude of these frequencies can often be set equal to 0 without causing any significant change in the responses within a soil system. In the computation of responses in deep soil systems from a motion given near the surface of the deposit, errors in the higher frequencies will be amplified and may cause erroneous results. To avoid this source of error, the amplitudes of all frequencies above 10-20 cps may be set equal to 0, since these frequencies generally are of little interest and do not affect the response. Several runs should be performed with different amounts of the higher frequencies removed to investigate the effect on the response and to ensure a stable solution. Removal of the higher frequencies in a motion has a smoothening effect on the acceleration time history as shown in Figure 10 for a segment of the Pasadena motion. In this case the maximum acceleration for the modified and original motions were approximately equal, but the maximum accelerations may decrease or increase with the removal of the higher frequencies depending on the shape of the acceleration curve near the maximum value. The maximum frequency is chosen consistently with the time step, DT. The maximum frequency that can be analyzed is:*

$$FMAX = \frac{1}{2(DT)}$$

For example, if DT is 0.02 sec (which is commonly what many records have been digitized to), the maximum frequency, FMAX, would be 25 cps. It is usually ok not to include all of the high frequency motions (above say 20 cps or so) because they carry a relatively small portion of the total earthquake energy. In addition, the elimination of higher frequencies accounts for a shorter execution time. The manual illustrates this idea on p. 18 (of original SHAKE manual). FMAX = 20 cps is good for a 0.02 sec time step (Vinson and Dickenson, 1993).

No. Header Lines: *No. Header Lines: Number of header lines in file containing object motion*.
Acceleration Values/Line: *Number of acceleration values per line in file containing object motion.* Note: *Please note that SHAKE91 permits the user to specify the format for the input time history. However, unless the time*

history points are arranged to have an even number of points per line, the input to the program will not be correct. For correct reading of the time history points, an even number of points should be given per line (i.e. 2, 4, 8, etc.). (Error report about SHAKE91, posted by Dr. Farhang Ostadan at the NISEE web site: http://www.eerc.berkeley.edu).

Earthquake Records: You can select an object motion listed in the earthquake records database by clicking on the **Quakes** button to display a listing of the records saved in the **SHAKEY2K.EQ** file. Once the list is displayed, you can choose a record by highlighting it and clicking on the **Ok** button, or by double clicking on it. The data for the record will be shown on their respective fields in the form. Please note that SHAKE2000 only accepts up to 72 characters in the **Name and Path of Object Motion File** field. Thus, check that the file name and the path to the file are displayed in their entirety. In the event the path and file name take more than 72 characters, SHAKE2000 will cut off beyond the 72nd character; and more than likely, the name of the file or its extension will be deleted.

If you want to use the data saved in a file that is not included in SHAKEY2K.EQ, use the **Other** command button to display the **Object Motion File** dialog box to select the file. After you choose a file, the name of the file will be displayed on the text box below the **Name and Path of Object Motion File** label. Please note that you need to manually enter or change the other information (i.e. Acceleration Values, No. Fourier Values, etc.) for this file.

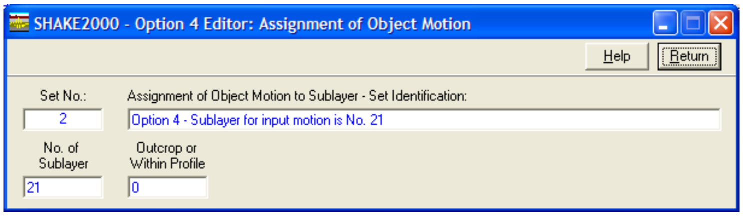
The **View** command button can be used to view the contents of a ground motion file. This will help you to collect the information needed to define the formatting of the file if necessary. To do this, first select a file using the **Other** button to select other files. The first 60 lines of the file will be displayed on a form, with the first characters displayed in red representing the numbers of each row of data in the file followed by a "|". These characters are not part of the source file and are only shown to number the rows. After the row numbers, the alphanumeric characters that constitute the information saved in the file for each row are shown. Note that the characters are displayed as blue on a white background, and that every tenth character is displayed in red. However, if the tenth character is a "blank space" then the character is not shown. This is done to guide the user when defining the order of the data in the file.

The **Convert** command button is used to display the **Conversion of Ground Motion File** form that can be used to convert ground motion files to different units and/or formatting. Further information on this feature is provided in the **Conversion of Ground Motion File** section of this manual. Upon returning to the Option 3 form, the information for this set of Option 3 will be updated based on the data for the converted ground motion.

A copy of the ground motion file is saved in the EDT file. If you wish to restore the file, click on the **Restore** command button. A copy of the file with the same name will be then created in the same folder where the input file is saved.

It is common practice in Geotechnical Earthquake Engineering to use baseline-corrected acceleration time histories. It is also standard practice in Engineering Seismology to baseline-correct ground motions before disseminating then. All accelerograms posted on openly-accessible databases such as PEER are baseline-corrected. If you have access to proprietary records that have not been corrected, we highly recommend to baseline-correct them before using them with SHAKE.

Option 4 Editor: Assignment of Object Motion



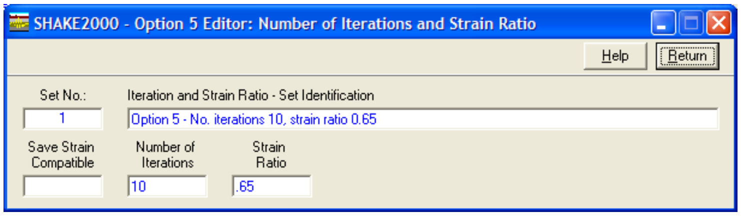
Some of the following information is taken literally from the SHAKE91 and SHAKE User's Manuals (Idriss and Sun, 1992; Schnabel et al., 1972), and other class and technical seminar notes. This information is italicized. Further information on this option can be found in Section 4.2 of the **Introduction**.

Assignment of Object Motion to Sublayer - Set Identification: A description of this Option 4 data set can be entered in this text box. As with the other options, the first word should always be **Option** followed by a space and then the option number, in this case **4** (i.e., **Option 4**). This is the code that SHAKE2000 will use to identify this data set as option 4 for subsequent operations, such as creating an input file. This is also **Line No. 1** for this option. SHAKE2000 will automatically input a 4 as **Line No. 2** in the *.EDT and input files.

No. of Sublayer: *Number of sublayer at the top of which the object motion is assigned.*

Outcrop/Within: *Use 0 (zero) if the object motion is to be assigned as outcrop motion (see section 2.2 of SHAKE manual for more information), otherwise use 1 (one) if the object motion is applied within the soil profile at the top of the assigned sublayer. Type of sublayer refers more to where the rock motion was recorded. Outcropping: motion was recorded on a rock outcrop. For motions recorded on rock WITHIN the soil profile or felt to represent the motion in the rock within the soil deposit, a "1" should be used and the record will not be modified (Vinson and Dickenson, 1993).* Steidl et al. (1996) present some helpful information related to the use of a nearby bedrock site as the reference motion.

Option 5 Editor: Number of Iterations and Strain Ratio



Some of the following information is taken literally from the SHAKE91 and SHAKE User's Manuals (Idriss and Sun, 1992; Schnabel et al., 1972), and other class and technical seminar notes. This information is italicized. Further information on this option can be found in Section 4.2 of the **Introduction**.

Iteration and Strain Ratio - Set Identification: A description of this Option 5 data set can be entered in this text box. As with the other options, the first word should always be **Option** followed by a space and then the option number, in this case **5** (i.e., **Option 5**). This is the code that SHAKE2000 will use to identify this data set as option 5 for subsequent operations, such as creating an input file. This is also **Line No. 1** for this option. SHAKE2000 will automatically input a 5 as **Line No. 2** in the *.EDT and input files.

Save Strain Data: *Parameter used to specify whether the strain-compatible soil properties are saved after the initial iteration; set = 1 if these properties are to be saved; otherwise leave columns 1-5 blank.*

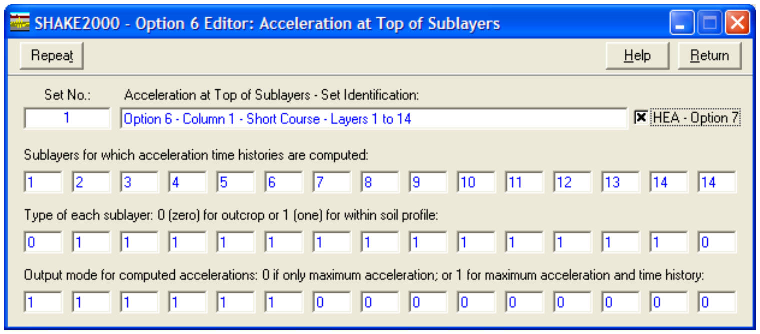
Number of Iterations: *Number of iterations. The iterations stop when the specified maximum number of iterations (ITMAX) is reached or when the difference between the modulus and damping used and the strain-compatible modulus and damping values is less than the acceptable difference (ERR). Usually 3-5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

Strain Ratio: *Ratio of equivalent uniform strain divided by maximum strain (in decimal); typically, this ratio ranges from 0.4 to 0.75 depending on the input motion and which magnitude earthquake it is intended to represent. The following equation may be used to estimate this ratio:*

$$ratio = \frac{M-1}{10}$$

in which M is the magnitude of the earthquake. Thus for M = 5, the ratio would be 0.4, for M = 7.5, the ratio would be 0.65 ... etc.. The effective strain is used to compute new soil properties. The ratio between the effective and the maximum strain has been empirically found to be between 0.5 and 0.7. The responses, however, are not highly sensitive to this value and an estimate between 0.55 to 0.65 is usually adequate, with the higher value appropriate for giving more uniform strain histories.

Option 6 Editor: Acceleration at top of Sublayers



Some of the following information is taken literally from the SHAKE91 and SHAKE User's Manuals (Idriss and Sun, 1992; Schnabel et al., 1972), and other class and technical seminar notes. This information is italicized. Further information on this option can be found in Section 4.2 of the **Introduction**.

Acceleration at Top of Sublayers - Set Identification: A description of this Option 6 data set can be entered in this text box. As with the other options, the first word should always be **Option** followed by a space and then the option number, in this case **6** (i.e., **Option 6**). This is the code that SHAKE2000 will use to identify this data set as option 6 for subsequent operations, such as creating an input file. This is also **Line No. 1** for this option. SHAKE2000 will automatically input a 6 as **Line No. 2** in the *.EDT and input files.

Sublayer for which acceleration time histories are computed: *Array to indicate the numbers of the sublayers at the top of which the acceleration is to be calculated*. To delete a layer on this option, place the cursor on the layer's cell, use the *Delete* key to delete the value, and then press the *Tab* key to move the cursor to the following cell. The data on the following cells, if any, will automatically scroll to occupy the cell where data was deleted. **Please note that if you delete a layer, then the layers may not display correctly when plotting the profile on a graph.** When entering data on the first blank cell for this option, default values of 1 for type of sublayer and 0 for mode of output will be automatically placed on the corresponding cells.

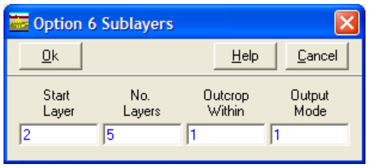
Type of each sublayer: 0 (zero) for outcropping, 1 (one) for within soil profile, or 2 (two) for incident wave: The value on the first blank cell cannot be deleted on this option, only modified. A code of **2 (two) for incident** is also acceptable for layers 2 through the halfspace. With this code, the incident wave will be computed for the layer. Refer to Section 2 of this manual for more detailed information about the incident and reflected waves. An example and recommendations for the application of the incident wave is provided by Mejia and Dawson (2006).

Mode of Output for computed accelerations: 0 if only max. accelerations or 1 for max. acceleration and time history: *Array to specify the mode of output for the computed accelerations: 0 (zero, see section 2.2 for explanation) if only maximum accelerations is desired or 1 (one) if both the maximum acceleration and the time history of acceleration are to be calculated and saved*. This value cannot be deleted, only set to either 1 or 0. Further, data on the first blank cell cannot be entered on this option, only modified. When using the incident wave option above, the first line of the time history file will be a header line; the second line will have the number of values and the time step separated by a coma; and, the acceleration values will be saved as one value per row beginning in line 3.

If you want to enter the data for more than one sublayer at a time, place the cursor on the sublayer that you want to copy and then click on the **Repeat** command button. This will display the **Option 6 Sublayers** form. Use this new form to enter the number of times the sublayer will be repeated and the data that will be used for the new layers.

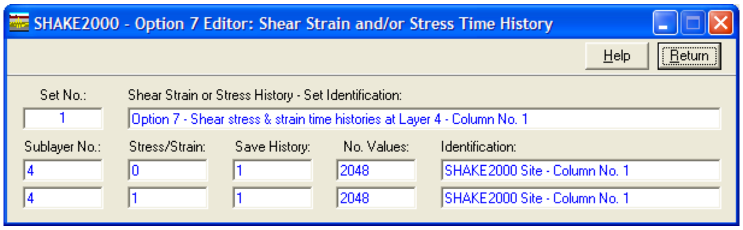
The **HEA – Option 7** option allows you to create sets of Option 7 for the same layers for which acceleration time histories will be created; i.e., those layers for which a value of 1 has been entered in the bottom row of the form. The sets of Option 7 will be created upon returning to the SHAKE analysis form.

Option 6 Sublayers



This form is used to create new sublayers in Option 6 by repeating the layer selected a number of times. The number of layers shown in the **No. Layers** text box will be created starting one number higher than the number shown in the **Start Layer** text box. The new layers will have the values for outcrop/within and output mode entered in the respective text boxes. After entering the data, click on the **Ok** command button to return to the Option 6 form and create the new sublayers.

Option 7 Editor: Shear Strain and/or Stress Time History



Some of the following information is taken literally from the SHAKE91 and SHAKE User's Manuals (Idriss and Sun, 1992; Schnabel et al., 1972), and other class and technical seminar notes. This information is italicized. Further information on this option can be found in Section 4.2 of the **Introduction**.

Shear Strain or Stress History - Set Identification: A description of this Option 7 data set can be entered in this text box. As with the other options, the first word should always be **Option** followed by a space and then the option number, in this case **7** (i.e., **Option 7**). This is the code that SHAKE2000 will use to identify this data set as option 7 for subsequent operations, such as creating an input file. This is also **Line No. 1** for this option. SHAKE2000 will automatically input a 7 as **Line No. 2** in the *.EDT and input files.

Sublayer No.: Number of sublayer.

Strain/Stress: S*et equal to 0 (zero) for strain or 1 (one) for stress*. You cannot enter any other value.

Save History: *Set equal to 1 (one) to save time history of strain or stress*. The value for this cell is either 0 (zero) or 1 (one). You cannot enter any other value.

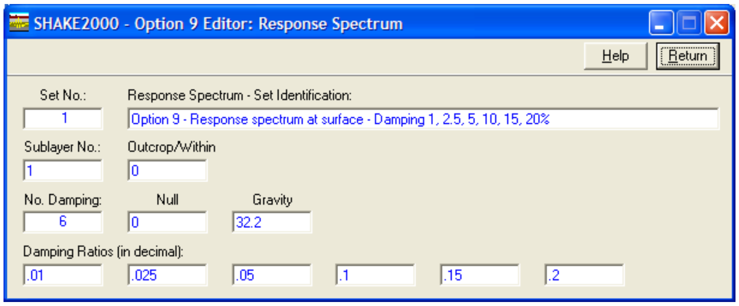
No. Values: *Number of values to be saved; typically this should be equal to the number NV* (see Option 3).

Identification: Enter up to 30 characters to identify the shear stress/strain time history. SHAKE2000 may use this description in the graph title.

Note that the time histories for shear stresses or strains are calculated at the top of the specified sublayer. Thus, if the time history is needed at a specific depth within the soil profile, that depth should be made the top of a sublayer. The time history of stresses or strains is saved in the second Output file.

This option should be specified after Option 6.

Option 9 Editor: Response Spectrum



Some of the following information is taken literally from the SHAKE91 and SHAKE User's Manuals (Idriss and Sun, 1992; Schnabel et al., 1972), and other class and technical seminar notes. This information is italicized. Further information on this option can be found in Section 4.2 of the **Introduction**.

Response Spectrum - Set Identification: A description of this Option 9 data set can be entered in this text box. As with the other options, the first word should always be **Option** followed by a space and then the option number, in this case **9** (i.e., **Option 9**). This is the code that SHAKE2000 will use to identify this data set as option 9 for subsequent operations, such as creating an input file. This is also **Line No. 1** for this option. SHAKE2000 will automatically input a 9 as **Line No. 2** in the *.EDT and input files.

Sublayer No.: *Sublayer number. Use 0 (zero) if the response spectra are to be computed for the object motion*.

Outcrop/Within: *Type of sublayer. Set equal to 0 (zero) for outcropping or equal to 1 (one) for within. The response spectra are computed for the motion at the top of the sublayer. May be left blank if Sublayer No. is 0 (zero).*

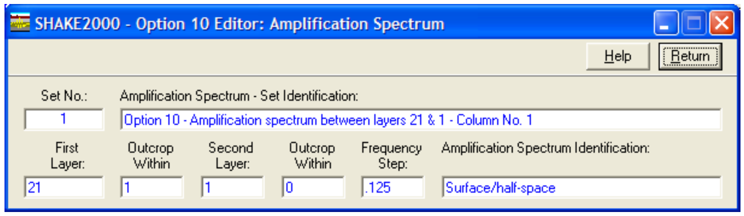
No. Damping: *Number of damping ratios to be used. Maximum 6 values.* The value in this cell cannot be edited. It will automatically change every time the **Damping Ratios** values are increased or decreased.

Null: This value cannot be edited. It will always be set at 0 by SHAKE2000.

Gravity: *Acceleration of gravity*, 32.2 ft/sec^2 for English units or 9.81 m/sec^2 for SI units.

Damping Ratios: *Array for damping ratios (in decimal)*. To add a new ratio, place the cursor on the first blank cell and enter the value in decimal. The number of damping ratios will be increased automatically. To delete a ratio, place the cursor on the corresponding cell, and use the *Delete* key. Then press the *Tab* key to move the cursor to a different cell. The number of damping ratios will be decreased, and the ratios will move to occupy the empty cells.

Option 10 Editor: Amplification Spectrum



Some of the following information is taken literally from the SHAKE91 and SHAKE User's Manuals (Idriss and Sun, 1992; Schnabel et al., 1972), and other class and technical seminar notes. This information is italicized. Further information on this option can be found in Section 4.2 of the **Introduction**.

Amplification Spectrum - Set Identification: A description of this Option 10 data set can be entered in this text box. As with the other options, the first word should always be **Option** followed by a space and then the option number, in this case **10** (i.e., **Option 10**). This is the code that SHAKE2000 will use to identify this data set as option 10 for subsequent operations, such as creating an input file. This is also **Line No. 1** for this option. SHAKE2000 will automatically input a 10 as **Line No. 2** in the *.EDT and input files.

First Layer: *Number of first sublayer*.

Outcrop/Within: *Set equal to 0 (zero) for outcropping or equal to 1 (one) for within*. You cannot enter any other value.

Second Layer: *Number of second layer*.

Outcrop/Within: *Set equal to 0 (zero) for outcropping or equal to 1 (one) for within*. You cannot enter any other value.

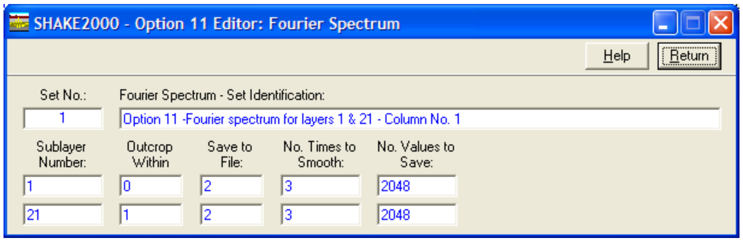
Frequency Step: *Frequency step (in cycles per second); the amplification spectrum is calculated for 200 frequencies using this frequency step and starting with 0*.

Amplification Spectrum Identification: Enter up to 48 characters to identify the amplification spectrum. SHAKE2000 uses this description in the graph title.

[The amplification spectrum is the ratio of the amplitude of motion at the top of the second sublayer divided by that at the top of the first sublayer].

If the amplification spectrum is desired for two other sublayers, Option 10 can be repeated as many times as needed.

Option 11 Editor: Fourier Spectrum



Some of the following information is taken literally from the SHAKE91 and SHAKE User's Manuals (Idriss and Sun, 1992; Schnabel et al., 1972), and other class and technical seminar notes. This information is italicized. Further information on this option can be found in Section 4.2 of the **Introduction**.

Fourier Spectrum - Set Identification: A description of this Option 11 data set can be entered in this text box. As with the other options, the first word should always be **Option** followed by a space and then the option number, in this case **11** (i.e., **Option 11**). This is the code that SHAKE2000 will use to identify this data set as option 11 for subsequent operations, such as creating an input file. This is also **Line No. 1** for this option. SHAKE2000 will automatically input an 11 as **Line No. 2** in the *.EDT and input files.

Sublayer No.: *Number of the sublayer.*

Outcrop/Within: *Set equal to 0 (zero) for outcropping or equal to 1 (one) for within*. You cannot enter any other value.

Save to File: *The value for this cell is 2 (two).* You cannot enter any other value.

No. Times to Smooth: *Number of times the spectrum is to be smoothed.*

No. Values to Save: *Number of values to be saved.*

The following expression (Schnabel et al., 1972) is used to smooth the Fourier spectrum:

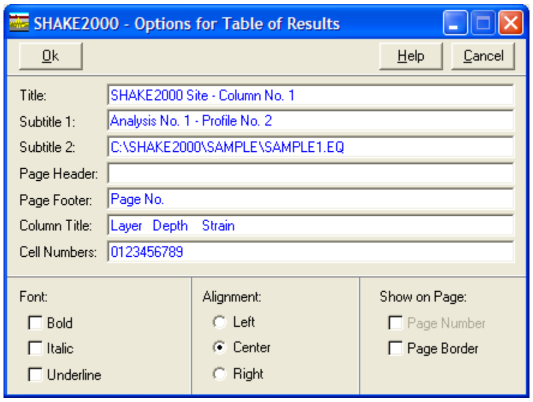
$$A_i = \frac{A_{i-1} + 2A_i + A_{i+1}}{4}$$

in which A_i is the amplitude of the spectrum for the i^{th} frequency.

A second line is always needed when using Option 11. Thus, the user should either provide a second line for another sublayer or repeat the information provided in the first line in a second line.

It may be noted that calculation of Fourier amplitudes for a specific accelerogram is best accomplished in an auxiliary program.

Options for Table of Results



This form is used to change the title and subtitles of the analysis, and their font attributes. You can also add a footer and a header to the printout. By default, when the form is displayed, the cursor is set to the **Title** cell. You can use the *Tab* key or the mouse to place the cursor on the other cells.

To change the properties of a cell, place the cursor on the cell, and then click on the different options on the bottom section of the form. For example, to display the title in bold face, and aligned with the left margin, place the cursor on the **Title** cell and click on the **Bold** check box, then on the **Left** option button. The text on the cell will be displayed in bold face.

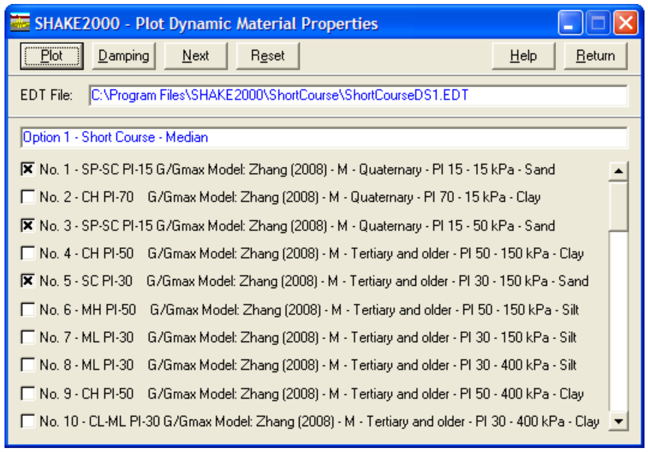
When the cursor is moved between cells, the current options for each cell are shown with an **x** on the check box for the font attributes, and by a **dot** on the option button for the alignment options.

The **Page Header** and **Page Footer** options use the same font attributes, and will display the last options set. However, they do not use the same alignment option.

Option List

This form is used to select SHAKE options that are not already included in the *.EDT file, or to create new sets of an option. Default values will be given to the option. To select an option, click on the option to highlight it and then click on the **Choose** button to return to the **Earthquake Response Analysis** form. The new option will be shown on the option list. You can also double click on the option to select it.

Plot Dynamic Material Properties



Select a number of curves by clicking on the check box next to each material description. An **x** is shown on the box when a curve is selected. Then click on the **Plot** button to display the curves.

To switch from the list of Modulus Reduction curves to the list of Damping Ratio curves, click on the **Damping** button. This button will change to **Moduli** when the Damping Ratio curves are being displayed.

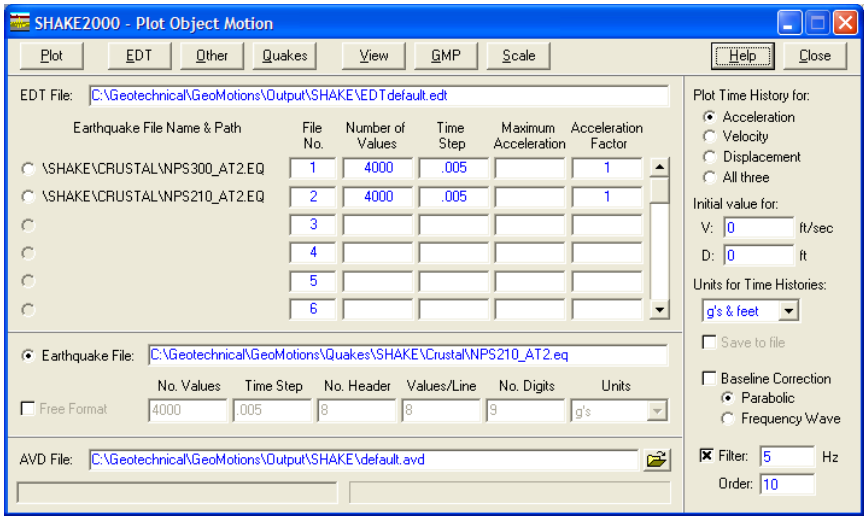
To switch from the list of Damping Ratio curves to the list of Modulus Reduction curves, click on the **Moduli** button. This button will change to **Damping** when the Modulus Reduction curves are being displayed.

The **Next** command button is used to display the list of material properties for the next set of Option 1 data.

Use the scroll bar to display more material properties curves.

To deselect all of the material property curves that have been selected for plotting, click on the **Reset** command button.

Plot Object Motion



Using object motion files included as Option 3 sets in an *.EDT file: You can plot the object motions included as Option 3 in an *.EDT file. To do this, click on the **EDT** command button to open the **Open EDT File with Object Motion Files** dialog box to select the file. The file name and path are displayed on the text box next to the **EDT File** label, and the name of the object motion files (from the Option 3 sets) displayed next to the option buttons on the upper part of the form. Additional information on the object motion is shown next to each file. To plot a file, click on the option button for the file, and then click on the **Plot** command button. After a few seconds, the object motion will be plotted on the screen.

Using an object motion file not included in an *.EDT file: If you want to use the data saved in a file that is not included as an Option 3 in an *.EDT file, use the **Other** command button to display the **Open Object Motion File** dialog box to select the file that you want to plot. The name of the file will be displayed next to the option button on the bottom section of the form. Now you need to enter the following information on the data cells below the file name. First, you need to select the file by clicking on the option button. This will enable the data cells to enter the data. We'll use the following example to explain the information necessary to plot the object motion.

Example:

```
STATION:  2702 AMU  ANCHORAGE, GOULE HALL                 .
61.189N 149.801W   SL GLACIAL TILL  GRND LEV 2 STORY BLDG .
AR-240 CHANNEL 1 N315E SCALE=1.925(*) PER=.0520 DAMP=.59  .
EVENT: 1975 JAN 01 03:55  61.920N 149.720W  58KM M=6.0 V  .
EPIC DIST = 81KM   AZIMUTH AT STN = 183
FILTERS: HI-PASS 0.15HZ ORD 3  LO 50-100HZ TAPER  BASELINE.
 YEAR=   0 JULIAN DAY=  0 HOUR= 0 MINUTE= 0 SECOND= 0 COMPONENT=
 SAMPLES/SEC=200 FILTER TYPE=BUTTERWORTH  CORNER= 0.15 ORDER=3 DATA TYPE=AC
 NO OF POINTS=  3720, UNITS=CM/SEC**2, CM/SEC, AND CM
  0.049344 -0.011564  0.044214  0.036526  0.027073  0.039972  0.039483  0.030785
  0.035475  0.026584  0.014714  0.013246  0.000550  0.000876 -0.007465 -0.015113
 -0.009943 -0.012849 -0.011799 -0.012492 -0.013971 -0.011197 -0.011350 -0.016224
............
............
 -0.002152 -0.000184 -0.001245 -0.003100 -0.001377 -0.001204 -0.003773 -0.003376
 -0.002223 -0.002468 -0.002356 -0.001785 -0.000602 -0.000215 -0.000439 -0.000572
```

This example shows the top 12 and bottom 2 lines of an acceleration time history file. Using this information, you will need to enter the following data to describe the time history:

No. Values: This is the total number of acceleration values that form the object motion file. For the above example, there are 3720 points in the file, thus, you will enter 3720 in this cell.

Time step: Enter the time interval between each acceleration value. For this example, it is SAMPLES/SEC or 1/200 = 0.005 seconds.

No. Header (or Number of header lines): Enter the number of lines at the beginning of the file that are used to describe the object motion. In the above example, the first nine lines are the header lines. Thus, you will enter a 9 in this data cell.

Values/Line (or Number of acceleration values per line): Enter the number of acceleration values on each line. For the above example, there are 8 values on each line. Thus, you would enter an 8 in this cell for this specific example.

No. Digits (or Number of digits per acceleration value): Enter the number of digits that form an acceleration value. In the above example, each value is defined by 10 digits, including the spaces. Therefore, you would enter a 10 for this specific example.

Units: This list provides you with a series of units that are used to plot the correct units on the graph, or to select the acceleration units of your file when computing the ground motion parameters using the **GMP** command button. This list is only enabled when a file is selected using the **Other** button. For ground motion files selected with either the **EDT** or **Quakes** command buttons, the program assumes that the acceleration values in the file are in units of g's. In the above example the original units of the file were in cm/sec^2, however the values shown are in g's, the original header lines were kept to maintain consistency with the source file.

Free Format: Select this option if the values in the file are separated by at least one blank space, and if each row of acceleration values is formed only by acceleration data (i.e. some old ground motion files used to have an integer number either at the beginning or at the end of the row that identified the row number, this number is not an acceleration value and thus should not be read. If you select the free format option, then this value will be read.). If this check box is selected (an **x** is shown), then you don't need to enter values for **Values/Line** and **No. Digits**. If the values in the file are not separated by blank spaces, i.e. they appear as a continuos row of numbers, then the numbers entered in the **Values/Line** and **No. Digits** columns are used as a means of separating the numbers in columns.

After you have entered the information above, or selected a file with either the **EDT** or **Quakes** command button, click on the **Plot** button to display the time history. The **All three** option of the **Plot Time History for** options allows you to plot the acceleration, velocity and displacement time histories in one graph.

The **View** command button can be used to view the contents of a ground motion file. This will help you to collect the information needed to define the formatting of the file if necessary. To do this, first select a file from the list of ground motions in the EDT file, use the **Quakes** command button to select a file from the database of ground motion files, or use the **Other** button to select other files. The first 60 lines of the file will be displayed on a form, with the first characters displayed in red representing the numbers of each row of data in the file followed by a "|". These characters are not part of the source file and are only shown to number the rows. After the row numbers, the alphanumeric characters that constitute the information saved in the file for each row are shown. Note that the characters are displayed as blue on a white background, and that every tenth character is displayed in red. However, if the tenth character is a "blank space" then the character is not shown. This is done to guide the user when defining the order of the data in the file.

Earthquake Records: You can plot the object motions listed in the ground motion files database by clicking on the **Quakes** button to display a listing of the files saved in the **SHAKEY2K.EQ** file. Once the list is displayed, you can choose a record by highlighting it and clicking on the **Ok** button, or by double clicking on it. The data for the ground motion will be shown on the **Other** section of the form. To plot the object motion click on the **Plot** button.

Analysis of Ground Motions: A series of options are included that may help the user with the visual analysis of the ground motions. This is helpful to evaluate the reliability of the ground motion record for use in geotechnical analyses. For example, for some ground motion files the displacement time history obtained from double integration of the acceleration time history may be unreasonable (e.g. it may increase or decrease without bounds). One possible explanation for this incompatibility is that in practice, when a ground motion history is processed, the velocity and displacement time histories are obtained by applying additional corrections (Trifunac and Lee, 1973). However, the acceleration time history may not reflect these corrections. Accordingly, the three histories are not fully compatible with one another, although each may represent the best estimate of the quantity at the site. A similar problem has been evaluated by Crespellani et al. (2003) who studied the effect of the techniques used for processing strong ground motion records on the results obtained from Newmark displacement analyses.

A simplified baseline correction of the acceleration time history is done by applying a parabolic baseline correction to the acceleration time history with minimization of the mean square of the resulting velocity (Brady, A.G., 1966, as referenced in Nigam & Jennings, 1968); or, by applying a frequency wave correction (Itasca Consulting Group, 2005). The "corrected" time histories for acceleration, velocity or displacement will be displayed when the respective time history and the **Baseline corrected** options are selected.

For integration of the acceleration time history, SHAKE2000 will use a default value of 0.0 for both the initial velocity and displacement. If the user wishes to use a different value, the initial value for velocity should be entered in the text box next to the **V** label; and, the initial value for displacement entered in the text box next to the **D** label. The units for these initial values should be as shown by the respective unit labels.

When the acceleration time history values are given as ratios of gravity (i.e. g's), the user has the option to plot and/or save the input acceleration, derived velocity and displacement, and corrected time histories in a different set of units, e.g. cm/sec^2, gals, etc.. To do this, select a set of units from the **Units for Time Histories** list of options. Some options show two sets of units, e.g. **g's & ft** or **gals & cm**; and, a few others only the units for acceleration, e.g. **ft/sec^2**. For options that show two sets of units, the acceleration values will be provided based on the first set and the velocity and displacement values will be based on the second set (e.g. acceleration in g's and velocity and displacement in ft/sec and ft, respectively). Please note that these options will not be used when the input acceleration values are in units other than g's.

Today, the user can obtain ground motion records from a variety of sources. Many of these sources provide the acceleration, velocity and displacement time histories in the same file. Usually these are the "processed" histories. Accordingly, if the user wishes to obtain the best estimate of either the velocity or the displacement time history, he/she should use that provided with the original source file for the ground motion. For the ground motions provided with SHAKE2000, the web addresses of the sources from which most of the files were obtained are included in the **Database of Earthquake Records** section of this manual. The processed velocity and displacement time histories may also be obtained from these same sources. As a simplifying alternative, an option is included in SHAKE2000 that saves the computed velocity and displacement time histories from the original ground motion record, and the baseline corrected acceleration, velocity and displacement time histories for further use. To create the file, first select the **All three** and **Baseline corrected** options. Next, click on the **Save to file** check box. A default file name and path are shown on the text box at the bottom of the form next to the **AVD File** label. To select a different file, click on the open-folder icon. Then, click on the **Plot** command button to display the graph of the time histories. Please note that is up to the user to decide on the suitability of these computed time histories for further use in other analyses.

The **Filter** option is used to remove frequencies greater than the value entered from the acceleration record. A Butterworth filter is applied as presented by Rabiner and Gold (1975) and coded by Itasca (2007). The order value for the filter is entered in the **Order** text box. When using the **Baseline Correction** option, the filter will be applied before the record is baseline corrected.

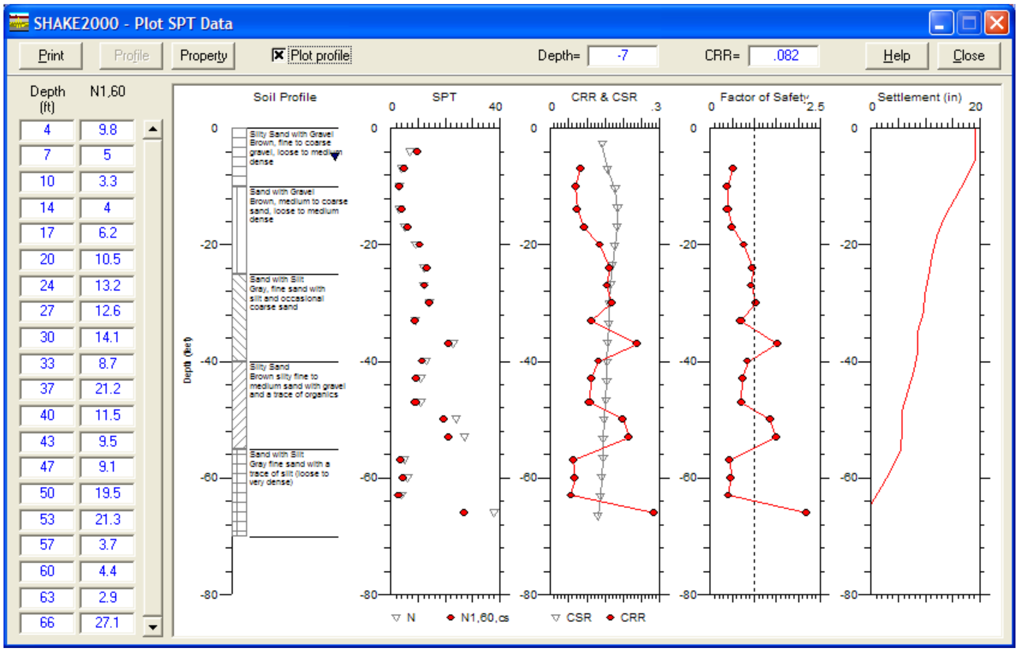
The **Scale** command button is used to display the **Mean Response Spectrum** form. This form can be used to obtain the mean spectral acceleration response spectrum for a series of ground motion records. The mean value can then be compared to a target spectrum in order to visually evaluate how well the suite of ground motions selected match the target spectrum.

Ground Motion Parameters: Various parameters used to characterize a ground motion can be obtained by using the **GMP** command button. These parameters include peak ground acceleration, Arias Intensity, Root-Mean-Square of the acceleration time history (RMSA), bracketed duration, Trifunac & Brady duration, predominant period, average period and mean period. More information on these parameters is provided in the **Ground Motion Parameters** section of this manual.

The mean period is commonly obtained using the Fourier amplitude spectrum. The method used in SHAKE2000 to compute the FFT is that summarized in Press et al. (1986). The FFT option only works for acceleration time histories, i.e. if necessary the data will be converted to g's before obtaining the FFT.

To obtain the parameters, first select one of the motions in the EDT file, use the **Quakes** command button to select a file from the database of ground motion files, or use the **Other** button to select other files and then click on the **GMP** button. After a few seconds the **Ground Motion Parameters** form is displayed to show the parameters. If the units for the motion file selected with the **Other** command button are either cm/sec^2, ft/sec^2 or m/sec^2 then the acceleration values will be converted to g's using the appropriate conversion factor before computing the Fourier spectrum. The Fourier spectrum can also be computed for velocity or displacement time histories, however, when the **Ground Motion Parameters** form is displayed, only the Fourier Spectrum options will be enabled. Other parameters will only be calculated and displayed for acceleration time histories.

Plot SPT & CPT Data



This form will display a series of graphs that summarize the SPT, CPT or V_s input data and the results of the liquefaction analysis. You can also display a graph of the soil column with soil type information.

Plot profile: This option allows you to display the soil column created with the **Soil Profile Information** form, which is displayed when you click on the **Profile** command button. In the **Soil Profile Information** form, you can enter data for the bottom elevation of the soil layer, and a description of the soil type. This option is enabled after you have entered the data for the soil layers. When the graphs are first displayed, the left most graph will show the soil layers as they were entered in either the Option 2 set of SHAKE91, or the **Simplified Cyclic Stress Ratio Analysis** form. In addition, the depth to the water table used for the CRR analysis will be shown as a triangle on the right side of the graph. When you select this option (i.e. an **x** is shown on the check box), the soil layers will be replaced by the soil column.

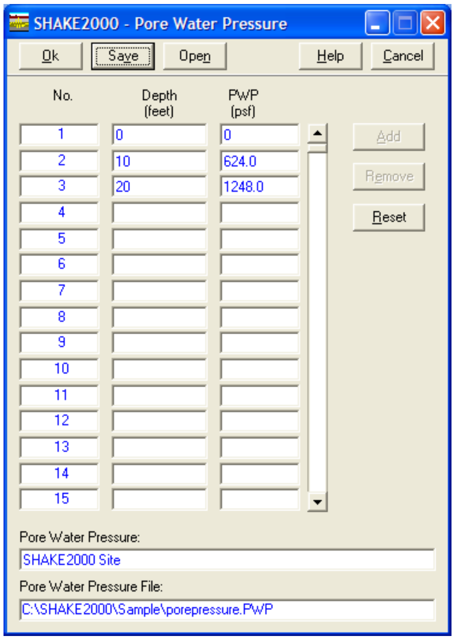
X Y coordinates: When you left-click on a symbol on any of the graphs, except the soil layers graph, the **X** and **Y** coordinates for that point will be displayed on the text boxes above the graphics window. Also, note that when you click on a graph, that graph will become the default graph when using the **Property** command button.

Settlement: This option allows you to plot the total settlement curve when using SPT, CPT or V_s data to conduct a liquefaction analysis. To plot the settlement curve, you need to first calculate settlement by using the settlement form, and then you can plot the curve using the **Report** command button of the SPT, CPT or V_s forms. Also, when using the probabilistic analysis, you have the option of either printing the probabilistic curve or the settlement curve.

Graph Properties: The properties of a graph (e.g. symbol color, axis values, etc.) can be modified using the property pages of the graphics server. To display the property pages for a graph, first left-click on any symbol of the graph to display its coordinates, and then click on the **Property** command button. To obtain more information about the different properties of the graph, click on the **Help** command button of the property pages.

Printing: To print the graphs, click on the **Print** command button to display the **Graphics Print Menu** form.

Pore Water Pressure



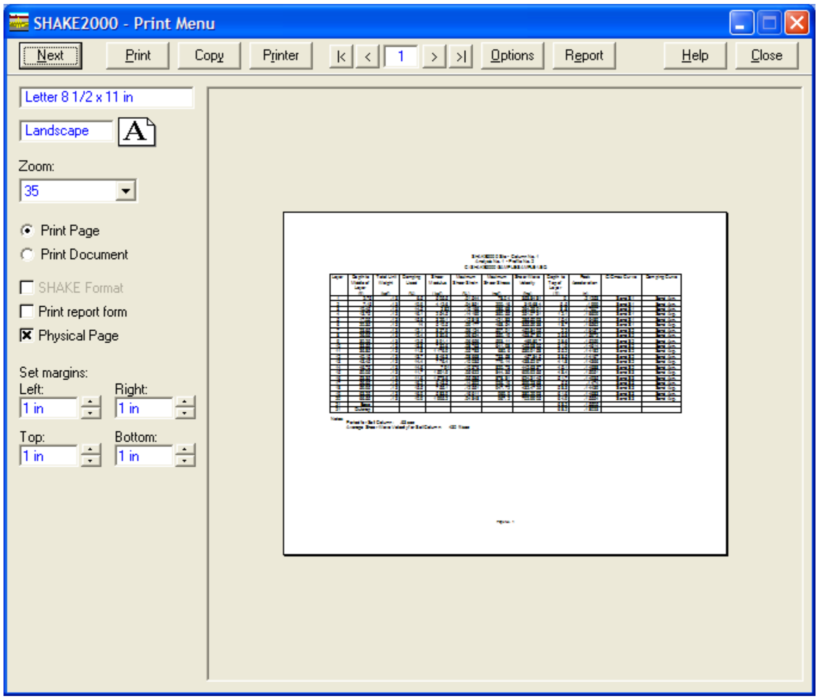
This form is used to enter the existing pore water pressure (pwp) values that can be used in the interpretation of CPT data. You need to enter a value for the depth (in feet or meters) and a value for pore pressure (in lb/ft^2 or kN/m^2).

To enter the data, first place the cursor on the text box for the **Depth** column and type in the value. Next, press the *Tab* key once to move the cursor to the text box for the **PWP** column and type in the value for the pore water pressure.

A description of the pwp regime can be entered in the text box below the **Pore Water Pressure** label. After you have entered the information for each depth-pwp pair, click on the **Ok** command button to return to the **Import data from CPT file** form.

Each time you place the cursor on either the **Depth** or **PWP** columns the **Add** and **Delete** command buttons are enabled. If you want to add data for a new depth-pwp pair, place the cursor on the depth where the new values will be located, and click on the **Add** button. A new depth-pwp pair will be created, and the values for the new pair will be the same as those for the pair immediately below. Now, you need to modify the information for the depth and pwp. The **Delete** button is used to delete a pair from the table. Place the cursor on the **Depth** or **PWP** column and then click on the **Delete** button. The data for the pair will be removed from the table, and the information for the other pairs updated accordingly. The **Reset** command button will delete all the information on the table. The **Save** command button is used to save the data in a text file for future use. These data can be retrieved using the **Open** command button.

Print Menu



The **Zoom** list can be used to select a magnification factor for the print viewing window. To open the zoom selection list, click on the arrow, and then click on one of the magnification factors.

SHAKE2000 uses the standard printer dialog form from Windows to select a printer and/or to change the properties of the printer and paper used to print the graph (e.g. paper size, orientation, etc.). This form can be displayed by clicking on the **Printer** command button.

To print the results for other analyses, use the **Next** command button to scroll through the different analyses available. This command button is disabled when printing the table of results from the cyclic ratio analyses. The **Options** button will display a form that can be used to change the title and subtitle for the analysis, and the font attributes such as bold face, italic, etc.; and to optionally add a header and/or footer to the page.

To print the table, click on the **Print** button. A message window is displayed indicating the default printer, and a **Cancel** button that can be used to stop printing.

When printing either the *.EDT or input file, the **Print Page** option is selected by default. When this option is selected, only the displayed page will be printed. If you would like to print the entire document, select the **Print Document** option. By default, the file will be printed using tables and descriptions for the different data. To print the document in SHAKE format, click on the **SHAKE Format** check box. Use the **Page** button to display the next page of data.

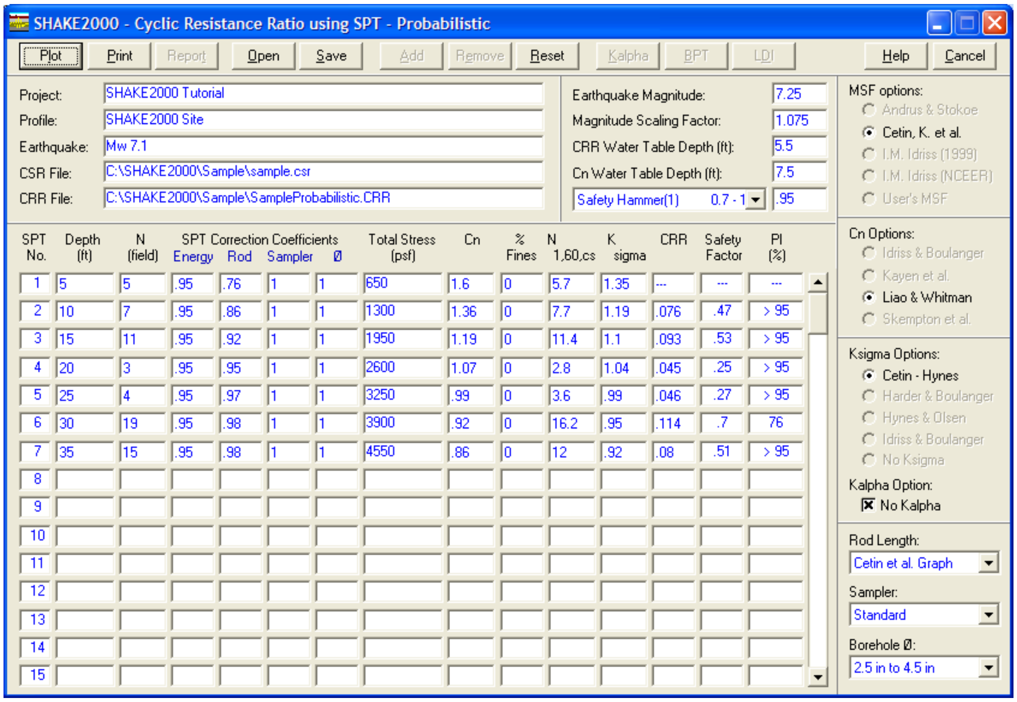
Print report form: Select this option to print a form on the same sheet of paper as the table of results. To create the form, click on the **Report** command button to display the **Company & Project Information** form, and then on the **Form** command button to display the **Report Form Development** form.

Physical page: This option determines whether the logical page used by the printer control should correspond to the entire physical page or only to its printable area. Most printers have a "logical" paper size that corresponds to the printer's printable area, and a "physical" paper size that corresponds to the actual page size. The physical paper size is always a little larger than the logical paper size. If this option is selected (an **x** is shown on the check box), the program will print to the physical page. This option only works when the **Print report form** option is selected.

New margins for the paper sheet can be entered in the **Set margins** text boxes, or by clicking on the respective arrow buttons. Please note that the table of results has a specific size and changing the default margin settings may prevent the table from being printed in its entirety.

To return to the previous form, click on the **Close** button.

Probabilistic and Deterministic Liquefaction Analysis using SPT Data



The procedure followed to conduct a liquefaction analysis using the recently published probabilistic approach is similar to that described in the **Cyclic Resistance Ratio using SPT** form of this manual. In this section, we will only cover those options that are different from the traditional analysis using SPT.

The methodology followed in this analysis is explained in Cetin et al. (1999), Seed et al. (2001), and Cetin et al. (2004, 2006). Between these references there are some differences in the graphs and equations presented. However, the software follows the more updated version described in Cetin et al. (2004, 2006).

Values of magnitude scaling factor (MSF) are obtained from Figure 10(a) of Cetin et al. (2004), and automatically defined by setting the **Cetin et al.** option of the MSF options as default. As with the C_n, K_σ, and K_α options, there is only one setting available for the corresponding parameter. This is to conform to the methodology used to develop the probabilistic liquefaction curves.

The list of energy ratios for SPT has been updated to reflect the information provided by Cetin et al. (2004). However, you could also enter a different value by choosing the **Other energy ratio** option from the list, and then entering the value in the text box.

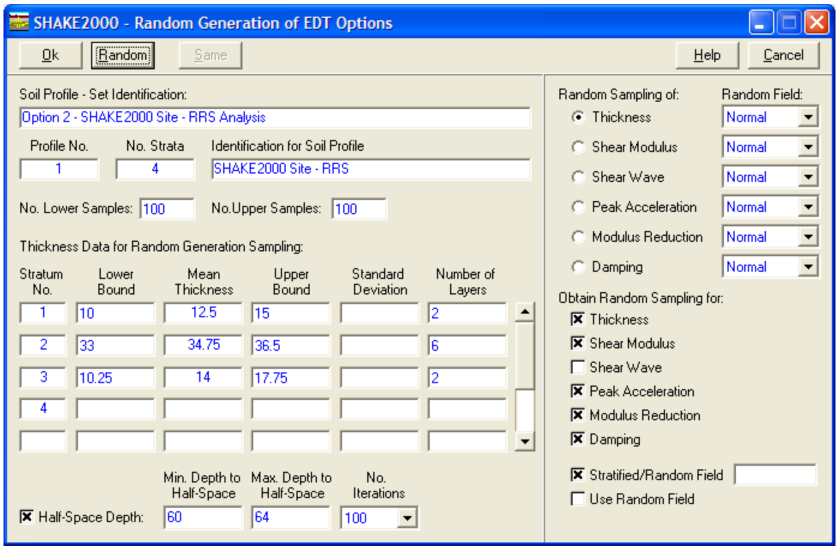
There are two other correction factors that apply to the SPT. These are shown on the lower right corner of the form. The **Rod Length** lists correction factors for different lengths of the drill rods and shows the **Cetin et al. Graph** as the only option available. Figure 7 of Cetin et al. (2004) corresponds to the graph used in this option. The **Sampler** list shows correction factors for the case when the sampler is used without liners, as recommended by Seed et al. (1985) and Seed et al. (2004). Every time you select a different energy correction factor, sampler, or rod length option, the correction factors will be automatically updated and displayed in the respective data columns.

To correct for fines content, FC, the SPT determined for silty sands are corrected to equivalent clean sand penetration resistance, using the equation developed by Cetin et al. (2004).

The depth to the water table cannot be changed in this form. In order to use a common depth to the water table when conducting different analyses simultaneously (i.e. SPT, CPT, V_s and CSR), the depth to water table can only be changed either on the **Simplified Cyclic Stress Ratio Analysis** form or the **Calculated Results Plot Menu** form. After you have entered the basic information, the "deterministic" value of cyclic stress ratio (CSR) to trigger liquefaction will be displayed on the CRR column. This value is obtained from Figure 14(a) of Cetin et al. (2004) and corresponds to approximately 20% probability of liquefaction. The probability of liquefaction value will be shown on the P_L column.

The cyclic resistance ratio can be entered manually. To do this, place the cursor on the **CRR** column, and enter the value. Alternatively, you can delete the computed value. Please note that although the values of CSR and FSL will be plotted, settlement and probability of liquefaction for the respective layers will not be computed. This option allows you to modify the CSR value, or delete it, in the event there are layers in the soil profile that do not liquefy, or for which the procedure described herein does not apply.

Random Generation of EDT Options



This form is used to randomly generate sets of options 1, 2 and 3 based on lower and upper bound, mean and standard deviation values for modulus reduction and damping curves; thickness, G_{max} and/or shear wave velocity; and peak acceleration. Please note that the approach used in SHAKE2000 should not be considered a formal, scientifically based approach (e.g. Monte Carlo Simulation) to account for the effects of uncertainty on the site response analysis. It should be considered more like a "crude sensitivity analysis" to evaluate the effect of the variability of the input data on the results of a site response analysis.

This form is called from the **Earthquake Response Analysis** form using the **Random** command button after selecting the **Random generation of EDT data** option.

There are three approaches to generating the data:

1. The simplified random generation process used in SHAKE2000 consists of dividing the range of data (e.g. the range between the lower bound and mean values) in intervals, and then randomly selecting a sample from each interval. For this method, the number of samples is not necessarily the same for each parameter; i.e., the number of intervals for thickness could be different from the number of intervals for peak acceleration.

   For example, assume that a soil profile was developed based on a series of soil borings. In addition, the variability of some of the material properties has also been determined from experience, laboratory results, etc.. For the first stratum, the thickness was found to range between 10 feet to 17 feet, with a mean value of 14.0 feet. In SHAKE2000 this range is first divided into a lower bound range, i.e. between 10 feet to 14.0 feet; and, on an upper range, i.e. between 14.0 feet to 17.0 feet. The next step is to subdivide both the lower and upper ranges into intervals, e.g. the lower bound range could be subdivided into 2 intervals, i.e. from 10 feet to 12.0 and from 12.0 feet to 14.0 feet. Similarly, the upper bound range could be subdivided into 3 intervals, i.e. 14.0' to 15.0', 15.0' to 16.0' and 16.0' to 17.0'. Once the number of intervals has been defined, SHAKE2000 will randomly pick a value from each interval, e.g. 10.95, 13.27, 14.21, 15.74 and 16.42. Each stratum can also be divided in layers, e.g. for the first stratum when using the thickness of 10.95 feet, if the user selects to subdivide the stratum into 2 layers, then each layer will have a thickness of 10.95/2 or approximately 5.47 feet. This process will be repeated for each stratum of the soil profile and a total of *lower interval + upper interval* soil profiles will be created.

   To prevent the creation of soil profiles that use only the lowest value of the randomly generated values for each stratum, or profiles formed by the highest values, the random thicknesses for each layer are randomly ordered. For example, if we consider that there were two other soil strata on the above soil profile, the randomly generated thicknesses for each could look like:

Stratum	Thickness				
1	10.95	13.27	14.21	15.74	16.42
2	30.51	35.24	38.13	40.64	44.56
3	12.05	14.23	16.87	17.11	18.55

A soil profile could be created by using the first randomly generated thickness for each stratum, e.g. 10.95, 30.51 and 12.05. The approach used in SHAKE2000 is to randomly select a value from the group of random values. For example, a randomly ordered soil profile would be formed by 14.21, 30.51 and 17.11. The values selected will not be used again, i.e. additional profiles will be formed by randomly selecting from the remaining random values. This procedure is also used when selecting values from the random group of G_{max}, V_s, G/G_{max} and damping curves, and peak acceleration if these were generated.

In this method, the number of SHAKE columns generated will depend on the number of intervals and number of Option 3 sets used. For example, assume that there are 2 sets of option 3 used for the analysis, and for each option and set the following number of intervals were used in the random generation of data:

Option	No. Intervals			Subtotal
	Lower Bound	Upper Bound		
1	2	2		4
2	5	5		10
3 (set 1)	3	3		6
3 (set 2)	3	3		6
			Total:	4 x 10 x (6 + 6) = 480

For the above case, 480 different SHAKE columns would be generated, i.e. this is similar to creating 480 different input files for SHAKE.

2. The **Stratified/Random Field** option is used to create SHAKE columns by choosing a value from each interval, for every parameter selected (e.g. Thickness, peak acceleration, etc.). The number of samples will be the same for all of the parameters with this method. The values for every parameter are randomly ordered first. Then, a SHAKE column is created by choosing the first randomized value for every parameter selected, then the second randomized value, and so on until a number of SHAKE columns equal to the *lower+upper* intervals have been created. For example, if both the lower and upper intervals for thickness, peak acceleration, and dynamic soil properties are set to 200 each; and, there are three different sets of Option 3; the program will generate 400 sets of Options 1 and 2, and 400 sets for each Option 3 for a combined total of 1200 different sets of Option 3. When creating the input data for SHAKE, these sets will be randomly ordered to prevent selection of the first value (i.e. the value for the lowest segment of the first interval) for each Option. However, because there are 3 sets of Option 3, each of the sets generated for Options 1 and 2 will be used 3 different times, hence a total of 1200 different SHAKE columns are generated. In other words, this is similar to creating 1200 different input files for SHAKE, and executing the program 1200 times. The number of intervals for thickness, shear modulus, shear wave, peak acceleration and dynamic material properties should be the same when using the **Stratified/Random Field** option.

3. When using the **Use Random Field** option in conjunction with the **Stratified/Random Field** option, the random numbers will be normally distributed between 0 and 1, then normalized, and used with the random field distribution selected from the **Random Field** list for each parameter. A more detailed description of this procedure is provided by Jones et al. (2002) and Fenton (1997). For each parameter two random numbers, r_1 and r_2, are generated, then a normalized number, N, is obtained as suggested by Box and Muller (1958):

$$N = \left(\sqrt{-2\ln(r_1)}\right) \quad \sin(2\pi r_2)$$

A new value for each parameter, P, is then computed based on the mean, μ, and standard deviation, σ, values according to the random field distribution selected:

$P = \mu + N\sigma$	Normal random field distribution, i.e. **Normal** option
$P = \exp^{(\ln(\mu) + N\sigma)}$	Natural logarithm random field distribution, i.e. **Ln Normal** option
$P = 10^{(\log(\mu) + N\sigma)}$	Common logarithm random field distribution, i.e. **Log Normal** option

The new value, P, should be within the limits entered as **Lower Bound** and **Upper Bound** values. If P is outside the limits, a new value of N will be computed.

For peak acceleration, if the standard deviation value is obtained from an attenuation relation that is based on the common logarithm (i.e. base 10), then the **Log Normal** option of the **Random Field** list should be used.

For the generation of the random field of samples, the number of samples generated is entered in the **No. Samples** text box. Further, it is assumed that the parameters are independent of each other, except for the shear modulus reduction vs. strain and damping ratio vs. strain curves (Darendeli, 2001). For these curves the same random number is used for both.

The difference on the data generated can be better explained by referring to the histograms below. Both histograms were created using data generated by assuming a lower bound value of 0.075, a mean value of 0.15, and an upper bound value of 0.3. For the Stratified Sampling with Random Field histogram (Figure 2), a standard deviation value of 0.22 and an **Ln Normal** option were used for the **Random Field** option.

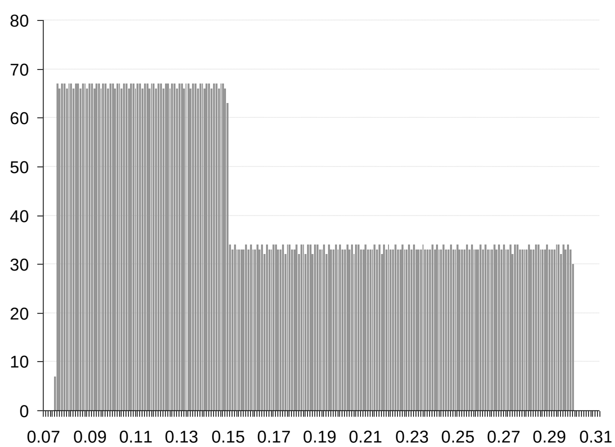


Figure 1: Stratified Sampling

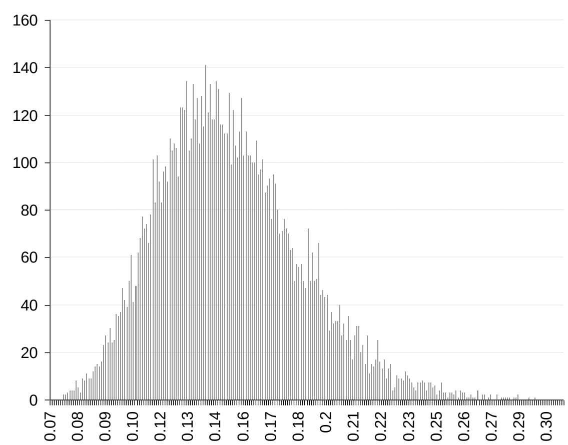


Figure 2: Stratified Sampling with Random Field

For the Stratified Sampling histogram (Figure 1), 5,000 samples were uniformly taken from the 0.075-0.15 interval and 5,000 samples taken from the 0.15-0.3 interval. In other words, the 0.075-0.15 interval was divided into 5000 intervals with a spacing of (0.15-0.075)/5000 = 0.000015 units each, and a sample randomly taken from each interval. Similarly, the 0.15-0.3 interval was subdivided into 5000 intervals of (0.3-0.15)/5000 = 0.00003 units spacing and a sample randomly taken from each interval. The Stratified Sampling with Random Field histogram (Figure 2) was created by randomly generating 10,000 values using an Ln Normal random field distribution with a mean of 0.15 and a standard deviation of 0.22.

For the shear modulus reduction and damping ratio curves, only one value of standard deviation is required; i.e., even if there are 15 values of G/G_{max} vs. strain in the curve, enter a value of standard deviation for only one of the G/G_{max}-strain pairs. The random number for this pair will be used to proportionally compute the random G/G_{max} value for the other strain values. This way, the shape of the curve will be preserved (Silva, 1992).

To use this form, first select one of the **Random Sampling of** options. The configuration of the form will change depending on the option selected. Next, enter the number of intervals for each range in the **No. Lower Intervals** and **No. Upper Intervals** text boxes. Move the cursor to the first text box of the **Lower Bound** column and enter the lower bound value. Press the Tab key or place the cursor on the text box of the **Upper Bound** column and enter the value. If working with the data for Option 2, i.e. soil profile, you also need to enter a value for **Number of Layers**. It is not necessary to enter values for each of the parameters, e.g. only the variation of thickness could be used when generating the data. The value for standard deviation when using the **Random Field** options should be entered in the **Standard Deviation** text box.

For Option 1, i.e. G/G_{max} vs. strain and damping vs. strain curves, lower and upper bound values should be entered for each point of the curve. The strain values are shown for reference. When not using the **Random Field** option, the same shape for the G/G_{max} vs. strain and damping vs. strain curves will be preserved by using the same random number when selecting from each strain-G/G_{max} or strain-damping pair. The **Same** command button is used to use the mean values as upper and lower bounds. This way, if you are not normalizing a curve, you can click on this button to copy the mean values instead of entering them manually.

After the limiting data have been entered, it is necessary to select which parameters will be used for the random generation of the options. From the list of **Obtain Random Sampling for** options, select those parameters used in the random generation of the options by clicking on their check boxes.

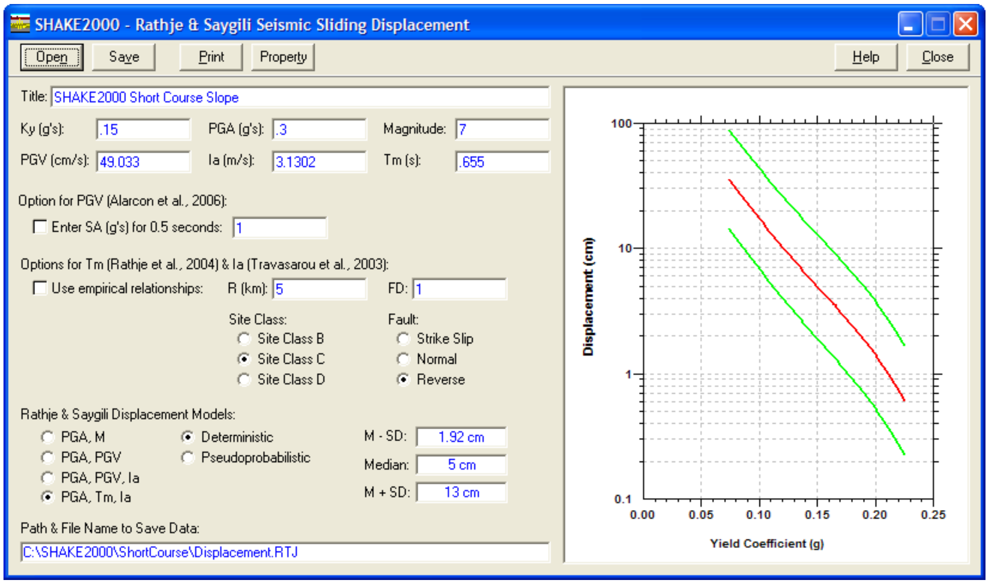
To generate the data, click on the **Random** command button. After a couple of seconds, the data are created and saved in text files for use when returning to the **Earthquake Response Analysis** form to create the input data for SHAKE. These files are named ***mcopt1.mcs***, ***mcopt2.mcs*** and ***mcopt3.mcs*** for Options 1, 2 and 3 respectively. The files are saved in the directory of output files selected in the **Earthquake Response Analysis** form. The random results are also stored in other text files in the same output directory. These files, ????-RandomOption1.txt, ????-Opt1Rndm.txt, ????-Opt2Rndm.txt, and ????-Opt3Rndm.txt are text files that can be opened with other software applications for further processing. The ???? is the same name displayed in the **Name of Plot Files** text box of the **Earthquake Response Analysis** form.

The total depth variation of the soil column can be constrained to fit within the half-space depth variation. To enter the minimum depth of the soil column to the half-space layer, place the cursor on the text box below the **Min. Depth to Half-Space** label. The maximum depth to the half-space layer can be entered in the text box below the **Max. Depth to Half-Space** label. To enable this feature, click on the check box for the **Half-Space Depth** option to select it. When this option is selected, the program will check that the depth of each column generated is within the limits set for the depth to the half-space layer. The **No. Iterations** list is used to change the number of iterations that are used to obtain the soil columns that satisfy the limits set for the depth to the half-space layer. If the soil columns cannot be generated using the interval settings, then a second iteration is conducted to determine if the columns can be generated ignoring the interval settings. If necessary, a third iteration is conducted to determine if the columns can be generated by adjusting the thickness of a randomly selected stratum. A message is displayed indicating which method was used.

The mean and median data for peak acceleration, strain, etc. are automatically saved in a file with the same name as the *.GRF file, but with the "-RNDM" characters attached to it, and saved in the same directory where all of the data files where saved. This is also done for the response spectrum data.

Use the **Ok** command button to return to the **Earthquake Response Analysis** form and to create the input file. The **Cancel** command button is used to return to the analysis form without creating the input file.

Rathje & Saygili Seismic Sliding Displacement



This form is used to input the data necessary to conduct a deterministic or pseudoprobabilistic seismic sliding displacement using the simplified methods developed by Rathje & Saygili (2011).

The parameters for the model are entered in the respective text boxes. For more detailed information on the method and the parameters used, please refer to Alarcon et al. (2006), Rathje and Saygili (2011), Rathje et al. (2004), Saygili and Rathje (2008), and Travasarou and Bray (2003).

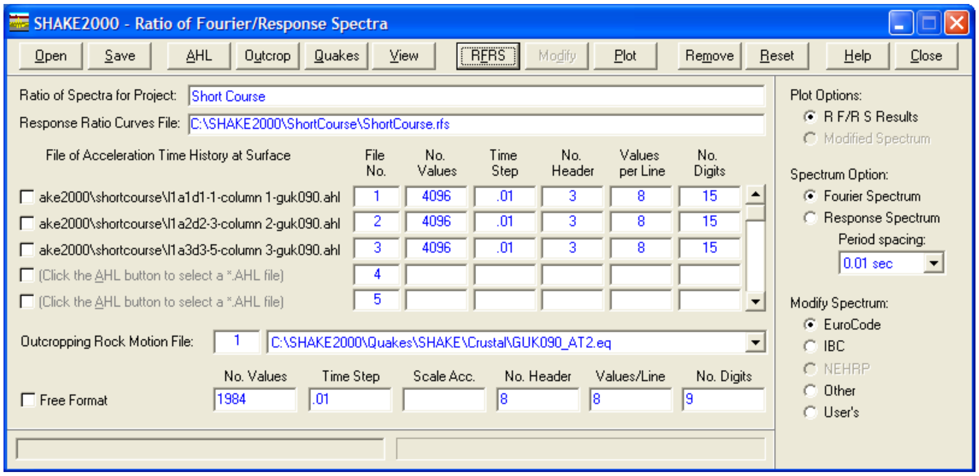
Values for PGV can be entered manually in the **PGV** text box, or can be estimated using the spectral acceleration at a period of 0.5 seconds using the relationship proposed by Alarcon et al. (2006). To use this relationship, click on the **Enter SA (g's) for 0.5 seconds** check box to select it and then enter the value for $S_{A,0.5\ sec}$ in the text box.

Similarly, values for T_m and I_A can be manually entered in their respective text boxes, or estimated using the empirical relationships developed by Rathje et al. (2004) and Travasarou and Bray (2003), respectively. To do this, first, click on the **Use empirical relationships** check box to select it and then enter the closest distance to the rupture plane in the **R (km)** text box, the forward directivity coefficient in the **FD** text box and select a **Site Class** and **Fault** option.

To print a copy of the graph, a summary of the input data and results or to copy the results to the Windows Clipboard for use by other applications, click on the **Print** command button to display the **Print Menu** form.

The **Save** command button is used to save the data in a text file for future use. These data can be retrieved using the **Open** command button.

Ratio of Fourier/Response Spectra



This form is used to input the data necessary to conduct a ratio of response spectra, RRS (Dobry et al., 2000; Martirosyan et al., 2002), or Fourier spectra, RFS, analysis of the ground surface motions to the input outcropping rock motions.

The results of the RRS analysis can be used to obtain a soil response spectrum by multiplying either the mean or the median curve of the resultant RRS curves by a rock response spectrum. A likely application of this method would be to obtain a response spectrum for Site Class F soils as explained in the NEHRP Commentary (Building Seismic Safety Council, 2004b).

If the information for the acceleration time histories at the surface and the information about the outcropping motions were collected during processing of the SHAKE output files, the data will be automatically displayed on the form upon loading.

If the file information was not collected during processing of the SHAKE output files, first select the file for the outcropping ground motion. Click on the **Outcrop** command button to display the **Outcropping Rock Motion** dialog form. Switch to the appropriate folder, select the outcrop ground motion file and click on the **Open** command button. The file name and path will be displayed on the list shown next to the **Outcropping Rock Motion File** label. In order to read and use the data saved in the file you need to enter:

1. the total number of acceleration values that form the object motion file in the **No. Values** text box;
2. the time interval between each acceleration value in the **Time step** text box;
3. if the motion will be scaled to a different peak acceleration value, then enter the maximum value of acceleration to be used, in g’s, in the **Scale Acc.** text box;
4. the number of lines at the beginning of the file that are used to describe the object motion in the **No. Header** text box; and,
5. the number of acceleration values on each line in the **Values/Line** text box; and, the number of digits that form an acceleration value in the **No. Digits** text box.

If you select the **Free Format** option, then the data from the file are read “free format”, i.e. no consideration is given to the number of digits in each column, or to the number of columns in a row. When you select this option (an **x** is shown on the check box), you only need to provide the **No. Values**, **Scale Acc.**, **Time Step** and **No. Header** values. To be “free format” the data in the file have to be separated by at least one blank space, a comma, a tab, or be in different lines. More detailed information about these values is provided in the **Plot Object Motion** or **Response Spectra for Ground Motion** sections of this manual.

Additional outcrop motions can be selected by clicking on the **Outcrop** command button. Each new motion will be added to the list of outcrop motions. To switch between motions, click on the down-arrow to display the list, scroll down if necessary and click on the motion that you would like to be the current motion. You can now add or delete surface motion files related to this outcropping motion, delete the outcrop motion and its respective surface motions, etc.

You can also select an outcrop motion saved in the ground motion database by clicking on the **Quakes** button to display a listing of the files saved in the **SHAKEY2K.EQ** file. Once the list is displayed, you can choose a record by highlighting it and clicking on the **Ok** button, or by double clicking on it. The data for the ground motion will be added to the outcropping motion list and shown on the appropriate text boxes.

After selecting the outcrop motion file, you need to select the different surface motion files that will be used with the outcrop motion to obtain the RF/RS. You can select an unlimited number of surface motion files. In this way you may be able, for example, to account for the variability in soil properties, etc. Processing of the second output file generated by a SHAKE analysis creates the files for the ground motions at the surface layer that can be used in the RRS analysis. These files are identified with the extension *.AHL (or acceleration history at layer) and are created from the acceleration time histories requested in Option 6. The files are given a name such as **L##A#D#-##.AHL**, where **L** means layer and is followed by one or two numbers which are the layer number, and for the RF/RS analysis this number will be usually **1** for the surface layer; **A** stands for analysis, and the number following it is the analysis number; and, **D** is for soil deposit and the number is the number of the soil deposit as defined in option 2. The numbers after the "-" show the position of this time history in the second output file. For example, the very first time history in the second output file will have "-1" after the deposit number. To select the surface ground motion files, click on the **AHL** command button to display the **Acceleration Time History File** dialog form. Switch to the appropriate folder, select the file and then click on **Open**. The file name and path will be displayed in the first available row below the **File of Acceleration Time History at Surface** label. Other information necessary to read the file will be shown on the text boxes.

For calculation of the response spectrum, select the spacing between the period values by clicking on the down-arrow for the **Period spacing** list. A spacing of 0.01 seconds creates a spectrum with 1000 points starting with 0.01 seconds and ending at 10 seconds, while a spacing of 0.001 seconds will create a spectrum with 10,000 points starting at 0.001 seconds. Please note that using a smaller value for spacing will lengthen the time needed for computation and for plotting of the spectrum. The **NEHRP** option of the list is used when working with the NEHRP spectra. For this option, the periods will start at 0.01 seconds, use a spacing of 0.01 seconds, and end at a period of 20 seconds. This will allow computation of the spectra for periods greater than the Long-period transition period, or T_L.

Once you have selected the outcrop and surface motion files, select either the **Fourier Spectrum** or **Response Spectrum** option and then click on the **RFRS** command button to perform the RRS or RFS analysis. In SHAKE2000, the RRS analysis consists of obtaining the 5% damping pseudo-acceleration response spectrum for the surface and outcrop motions, and then dividing the surface spectrum by the outcrop spectrum for each period value. Similarly, for the RFS analysis, the Fourier spectrum is computed for the surface and outcrop motions and the ratio obtained by dividing the surface spectrum by the outcrop spectrum. This process is repeated for every surface-outcrop motion pair.

To plot the results of the RF/RS analysis, click on the **R F/R S Results** option to select it, and then on the **Plot** command button.

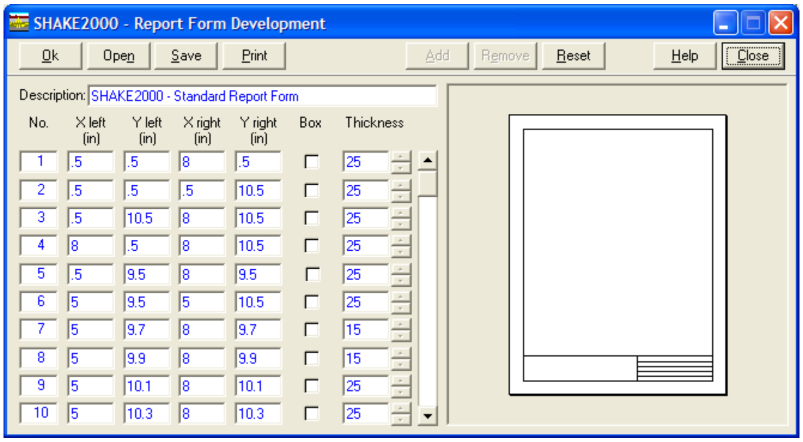
As noted before, the RRS analysis can be used to obtain a soil response spectrum for a specific site. In this case, the mean or median RRS curve will be multiplied by a rock response spectrum to obtain the soil spectrum. There are five options used to select the rock spectrum: **EuroCode**, **IBC**, **NEHRP**, **Other** and **User's**. Select one of these options and then click the **Modify** command button to display the respective form. Further information for the first three options is provided in the respective sections of this manual. The **Other** option will display the **Response Spectra for Ground Motion** form. This form can be used to compute the response spectrum using the data saved in a ground motion file if one is available for the rock motion for your site. If you would like to manually enter the values for period and spectral acceleration, select the **User's** option. This option will display the **User Defined Response Spectrum** form. In this form, you can enter values of period and spectra for a user defined response spectrum that will be used to compute the modified spectrum using the results of the RRS analysis. A similar option is provided when using the **IBC** and **NEHRP** options. In this way, you can enter a user-defined spectrum and select the IBC or NEHRP 80%-design spectrum to be plotted on the same graph with the modified spectrum.

After the rock spectrum is computed, the **Modified Spectrum** options will be enabled when returning to this form. Select the **Modified Spectrum** option to plot the soil response spectrum.

To delete a surface motion from the list of motions, click on the surface motion to highlight it and then on the **Remove** command button. A similar procedure is followed to delete an outcrop motion. However, if you delete an outcrop motion, the surface motions related to this motion will also be deleted.

The input and output data can be saved to a text file using the **Save** command button. In the RRS file, the input RRS curves, Mean and Median RRS curves, source and modified spectra, and spectrum for each ground motion file will be stored for future use. The data can be retrieved from the file using the **Open** command button. This file is an ASCII text file, thus, it can be open with other software applications for other purposes by the user.

Report Form Development



This form is used to create a form that can be printed together with your graphs. The process of creating a form consists of entering the coordinates of the end points and the thickness for each line on the form. You can then use the **Company & Project Information** form to enter textual information that is printed as part of the form.

The origin of coordinates (i.e. x = 0 & y = 0) is the top left corner of the paper sheet; and, the dimensions are those set for the paper (e.g. for the standard letter size of 8.5" by 11", the dimensions are in inches). Also, remember that the **Physical page** option of the **Graphics Print Menu** form may affect the way your form fits on the paper. This option determines whether the logical page used by the printer control should correspond to the entire physical page or only to its printable area. Most printers have a "logical" paper size that corresponds to the printer's printable area, and a "physical" paper size that corresponds to the actual page size. The physical paper size is always a little larger than the logical paper size. If this option is selected (an **x** is shown on the check box), the program will print to the physical page.

To better understand how to create a form, open the standard form included with SHAKE2000 and then modify it as explained in the following. The example described in the following paragraph is for a letter size paper (8.5" x 11") and portrait orientation. To change paper type or orientation, click on the **Printer** command button to display the printer dialog window. For our example, first click on the **Open** command button to display the file dialog form. If necessary, change to the directory where SHAKE2000 is installed, and select the shakey2k.frm file in the **Sample** folder. Now, click on **Open**. You will return to this screen, and the form will be displayed on the graphics window, and the information about each line shown on the text boxes. For each line, the coordinates of its end points and thickness are shown on the text boxes.

To complete this form, enter the following lines: First, place the cursor on the **X left** text box for line No. 4 and type in **6.** Press the *Tab* key to move the cursor to the text box on the **Y left** column. Enter **9.7**. These are the coordinates for the left end point of the line. Now, press the *Tab* key to move the cursor to the text box on the **X right** column and enter **8**. Place the cursor on the text box for the **Y right** column, and enter **9.7**. By default, a line thickness of **25** pixels is shown when entering data for a new line. We will reduce the thickness to 15 by clicking on the down arrow key next to the text box on the **Thickness** column until 15 is shown in it. A new line has been added to the form on the bottom right corner. To magnify the form, double-click on the graphics window with the left-button of the mouse. Double clicking with the right button reduces the size of the drawing.

Repeat the above procedure for the following lines:

X left	Y left	X right	Y right	Thickness
6	9.9	8	9.9	15
6	10.1	8	10.1	15
6	10.3	8	10.3	15

If you select the **Box** option (an **x** is shown on the check box) then the coordinates entered will be taken as the upper-left and bottom-right corners, respectively, of a rectangle.

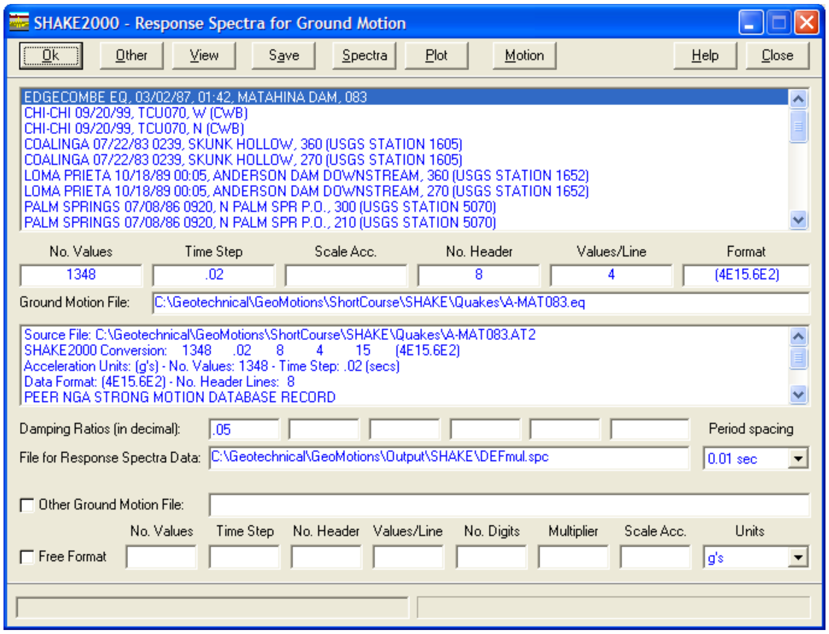
To save the information for the form, click on the **Save** command button to display the file dialog form, and then click on **Save** to save the data. You can enter a different file name to save each form you create to a new file.

When you create your own forms, you can enter a description for the form on the text box next to the **Description** label. This description can be up to 80 characters long, and will not be shown on the form.

Each time you place the cursor on either the **X left**, **Y left**, **X right**, or **Y right** columns the **Add** and **Delete** command buttons are enabled. If you want to add data for a new line, place the cursor on the line where the new line will be located, and click on the **Add** button. A new line will be created, and the coordinates and thickness for the new line will be the same as those for the line immediately below. Now, you need to modify the information for the coordinates and thickness for the new line. The **Delete** button is used to delete a line from the form. Place the cursor on either the **X left**, **Y left**, **X right** or **Y right** columns and then click on the **Delete** button. The data for the line will be removed from the form, and the information for the other lines updated accordingly. The **Reset** command button will delete the information for all of the lines.

After you have created the form, click on the **Ok** command button to return to the **Company & Project Information** form.

Response Spectra for Ground Motion



This form is used to compute the response spectra for a ground motion. The routine used by SHAKE2000 is based on the SPECTR computer program (Donovan, 1972).

To compute the response spectra, first select a ground motion file. There are two ways you can select a ground motion file. First, you can use the information stored in the SHAKEY2K.EQ file; or second, by using the **Other** command button to select a file and then entering the information necessary to read the data.

1. **Ground Motion Files defined in SHAKEY2K.EQ:** Included with SHAKE2000 is a series of ground motion files that can be used for seismic analysis with SHAKE. Basic information for each record is saved in the **SHAKEY2K.EQ** data base file located in the same directory where SHAKE2000 is installed. This file is an ASCII text file that can be modified to include new information about new records. However, the formatting in the file should not be modified. To select an earthquake record, click on it to highlight it. The information stored in shakey2k.eq for this file will be displayed on the corresponding cells. If you wish to scale the ground motion to a different value of peak acceleration, enter the new peak value in the **Scale Acc.** text box. Each acceleration value will be scaled proportionally to the ratio of the specified scale acceleration to the maximum acceleration of the time history.

2. **Using an object motion file not included in the SHAKEY2K.EQ file**: If you want to use the data saved in a file that is not included in SHAKEY2K.EQ, use the **Other** command button to display the **Open Object Motion File** dialog box to select the file that you want to plot. The name of the file will be displayed next to the option button on the bottom section of the form. Now you need to enter the following information on the data cells below the file name. First, you need to select the file by clicking on the check box next to the **Other Ground Motion File** cell (an **x** is shown on the check box). This will enable (i.e. the mouse cursor changes to the I-beam appearance when placed on the cells) the data cells to enter the data. We'll use the following example to explain the information necessary to plot the object motion.

   Example:

```
SHAKE2000 Sample Object Motion
Time Period = 0.01   Number of Points = 2000
  .024455  .000868 -.019352 -.012488  .003331  .030202  .021586 -.022183        1
 -.050340 -.025930  .000123  .020366 -.000176 -.008401 -.013457 -.014927        2
```

No. Values: This is the total number of acceleration values that form the object motion file. For the above example, there are 2000 points in the file, thus, you will enter 2000 in this cell.

Time step: Enter the time interval between each acceleration value. For this example, it is 0.01 seconds.

Scale Acc.: Maximum acceleration to be used, in g's; each acceleration value will be scaled proportionally to the ratio of the specified scale acceleration to the maximum acceleration of the time history.

No. Header (or Number of header lines): Enter the number of lines at the beginning of the file that are used to describe the object motion. In the above example, the first two lines are the header lines. Thus, you will enter a 2 in this data cell.

Values/Line (or Number of values per line): Enter the number of acceleration values on each line. For the above example, there are 8 values on each line. The last number (e.g. 1) only identifies the row number. Thus, you would enter an 8 in this cell for this specific example.

No. Digits (or Number of digits per value): Enter the number of digits that form an acceleration value. In the above example, each value is defined by 9 digits, including the spaces. Therefore, you would enter a 9 for this specific example.

Units: For the computation of response spectra, the values of acceleration are in **g's**. If the values saved in the file are in other units (e.g. ft/sec^2, cm/sec^2, or mm/sec^2), then select the appropriate units by clicking on the up or down arrows to scroll through the different options. This way, the data will be converted from these units to **g's**. For example, if the data in the file are in ft/sec^2, then you scroll down until **ft/sec/sec** is shown on the **Units** box. Then, the values will be divided by 32.2 to transform them to g's.

Free format: The data from the file are read "free format", i.e. no consideration is given to the number of digits in each column, or to the number of columns in a row. When you select this option (an **x** is shown on the check box), you only need to provide the **No. Values**, **Scale Acc.**, **Time Step** and **No. Header** values, and then select the units of acceleration by clicking on the up or down arrow keys next to the **Units** text box. To be "free format" the data in the file have to be separated by at least one blank space, a comma, a tab, or be in different lines.

Period spacing: This list is used to select the spacing between the period values used to compute the response spectrum. Click on the down arrow list to select a different value. A spacing of 0.01 seconds creates a spectrum with 1000 points starting with 0.01 seconds, while a spacing of 0.001 seconds will create a spectrum with 10,000 points starting at 0.001 seconds. Please note that using a smaller value for spacing will lengthen the time needed for computation and for plotting of the spectrum.

Once you have selected a ground motion file, you need to enter the values of damping ratio used for the computation of the response spectra. To add a new ratio, place the cursor on the first blank cell next to the **Damping Ratios (in decimal)** label and enter the value in decimal (e.g., 5% damping is entered as 0.05). The number of damping ratios will be increased automatically. To delete a ratio, place the cursor on the corresponding cell, and use the *Delete* key. Then press the *Tab* key to move the cursor to a different cell. The number of damping ratios will be decreased, and the ratios will move to occupy the empty cells.

After you have entered at least one value of damping ratio, the **Spectra** command button will be enabled. Click on this button to compute the response spectra for the ground motion. The results will be automatically saved in the file shown on the text box next to the **File for Response Spectra Data** label. To select a different file to save the data in, click on the **Save** command button and select, or enter the name for, a new file.

The results can be plotted by clicking on the **Plot** command button. By default, the Relative Displacement spectrum is plotted. If you want to plot other spectra (e.g. relative velocity, absolute acceleration, etc.), click on the **Graph** command button to display the **Response Spectrum Plot Menu.** In this form, you will be able to select other computed spectra, and other spectra from codes and ground motion prediction equations.

The **View** command button can be used to view the contents of a ground motion file. This will help you to collect the information needed to define the formatting of the file if necessary. To do this, first select a file using the **Other** button to select other files.

The first 60 lines of the file will be displayed on a form, with the first characters displayed in red representing the numbers of each row of data in the file followed by a "|". These characters are not part of the source file and are only shown to number the rows. After the row numbers, the alphanumeric characters that constitute the information saved in the file for each row are shown. Note that the characters are displayed as blue on a white background, and that every tenth character is displayed in red. However, if the tenth character is a "blank space" then the character is not shown. This is done to guide the user when defining the order of the data in the file.

The ground motion can be plotted by clicking on the **Motion** command button.

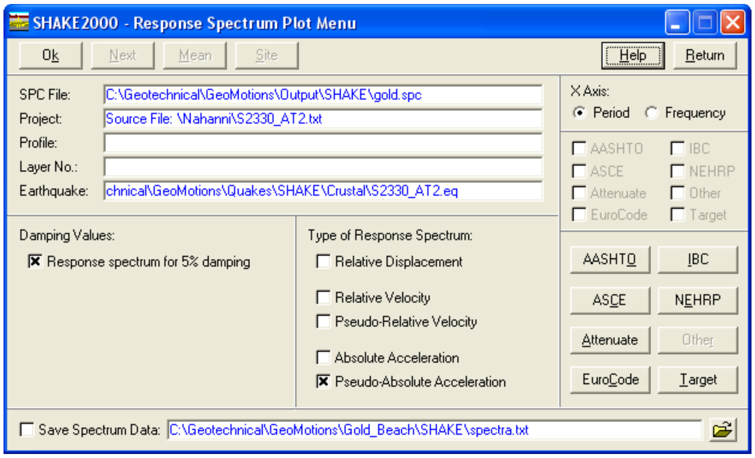
The **Import** command button is only enabled when this form is called from the **Makdisi & Seed (1977) Simplified Displacement Analysis** form. This button is used to import a series of user specified response spectra, saved in a text file, for use in the Makdisi-Seed displacement analysis. The data in the file should be saved using the following format:

```
STATION:  2701 ADN* ADAK, NAVAL BASE
C:\SHAKE2000\QUAKES\124c08AD_N0a.eq
151  6  .025    .05     .1    .15     .2    .25
 .01     .25828     .25819     .25804    .25781     .25767    .25758
 .02      .2583     .25828     .25826    .25819     .25809    .25798
 .03      .2599     .25988     .25984     .2597     .25951    .25926
 .04     .26219     .26217      .2621    .26188     .26153    .26106
```

First line:	Identification for the spectra, up to 80 characters
Second Line:	Earthquake record used to generate the spectra or any other information, up to 80 characters
Third line:	Number of periods (for above example, 151) Number of damping values (for above example, 6) Damping values in decimal (for above example, .025 .05 .1 .15 .2 .25)
Fourth to end of file:	Period, in seconds, followed by spectral acceleration values, in g's, for each damping value

When this form is called from the **Ratio of Response Spectra** form, the damping ratio text boxes and the list of period values will be disabled, i.e. the user will not be able to modify these values. The **Ok** command button will be enabled after the spectrum has been computed for the respective motion using the **Spectra** command button.

Response Spectrum Plot Menu



This form is used to select the response spectra to be plotted. The values for these plots are stored in the *.SPC file.

To display the spectrum for a damping value, place the cursor on the damping check box and then click the left button on the mouse. An **x** will appear in the check box to indicate your selection. To choose a **Type of Response Spectrum**, click on the appropriate check box, then, click on the **Ok** button to display the graph. To cancel a selection, click on the box again to remove the **x**.

There are three possible combinations for displaying the response spectrum:

- Select one damping value and one type of response spectrum.
- Select one damping value and two types of response. The two types of response spectrum are either Relative Velocity & Pseudo-Relative Velocity, or Absolute Acceleration & Pseudo-Absolute Acceleration.
- Select as many damping values as desired, up to the total shown, and only one type of spectrum.

If enabled, you can also select the average response spectrum options (with the **Mean** command button). However, these options work only with one type of response spectrum and one value of damping.

Other options and/or features available are:

- **Period:** Select this option to use the period (sec) scale in the **X**-axis.
- **Frequency:** Select this option to use the frequency (Hz) scale in the **X**-axis.
- **Normalized:** Use this option to plot the normalized response spectrum. This option only works when plotting S_a or PSA spectra.
- **Relative Displacement:** Plot the Relative Displacement (Sd) spectrum.
- **Relative Velocity:** Plot the Relative Velocity (Sv) spectrum.
- **Pseudo-Relative Velocity:** Plot the Pseudo-Relative Velocity (PSV) spectrum.
- **Absolute Acceleration:** Plot the Absolute Acceleration (Sa) spectrum.
- **Pseudo-Absolute Acceleration:** Plot the Pseudo-Absolute Acceleration (PSA) spectrum.

To plot average spectra: For a specific layer, you can obtain average response spectra from the results of several different analyses ***using the same soil profile (i.e. a profile with the same number of layers and thickness)***. For example, using the data provided in the sample files that came with SHAKE2000, say that you want to obtain average response spectra for layer 1 using profile number 1 that is formed by 29 layers. The input file will look like this for the first analysis:

1 Option 1: Modulus reduction and damping curves
2 Option 2: Profile No. 1
3 Option 3: SAMPLE1.EQ
4 Option 4: Object motion on layer 29
5 Option 5: 10 iterations, 0.65 strain ratio
6 Option 6
7 Option 7
8 Option 9: Spectra for 1%, 2.5%, 5%, 10%, 15%, 20% damping.
9 Option 10
10 Option 11

To obtain average results, you need to conduct a second analysis. Say that the second time you would like to use a different object motion that is saved as SAMPLE2.EQ. Then your input file, after including the options for the second analysis will look like:

1 Option 1: Modulus reduction and damping curves
2 Option 2: Profile No. 1
3 Option 3: SAMPLE1.EQ
4 Option 4: Object motion on layer 29
5 Option 5: 10 iterations, 0.65 strain ratio
6 Option 6
7 Option 7
8 Option 9: Layer 1 - Spectra for 1%, 2.5%, 5%, 10%, 15%, 20% damping.
9 Option 10:
10 Option 11:
11 Option 2: Profile No.1
12 Option 3: **SAMPLE2.EQ**
13 Option 4: Object motion on layer 29
14 Option 5: 10 iterations, 0.65 strain ratio
15 Option 6
16 Option 7
17 Option 9: Layer 1 - Spectra for 1%, 2.5%, 5%, 10%, 15%, 20% damping.
18 Option 10:
19 Option 11:

After executing SHAKE and processing the first output file, the *.SPC file will contain the response spectra data for layer 1 obtained from the two analyses. To plot the average response spectrum for layer 1, first you need to select both a type of response spectrum and a damping ratio. Once you do this, the **Ok**, **Mean** and **Site** command buttons will be enabled. Click on the **Mean** button to display the **Average Response Spectrum** form.

To plot the response spectrum of different layers in a soil profile: For a specific soil profile, you can plot the response spectrum of different layers at the same time. For example, using the data provided in the sample files that came with SHAKE2000, say that you want to plot the response spectrum for 5% damping for layers 1, 5, 10, 17, 23 and 29 of profile number 1, to determine the influence of soil conditions on the ground motion. The input file will look like this for the first analysis:

1 Option 1
2 Option 2: Profile No. 1
3 Option 3: SAMPLE.EQ
4 Option 4: Object motion on layer 29
5 Option 5: 10 iterations, 0.65 strain ratio
6 Option 6
7 Option 7
8 Option 9: Layer 1 - Spectra for 1%, 2.5%, 5%, 10%, 15%, 20% damping.
9 Option 9: Layer 5 - Spectra for 1%, 2.5%, 5%, 10%, 15%, 20% damping.
10 Option 9: Layer 10 - Spectra for 1%, 2.5%, 5%, 10%, 15%, 20% damping.

11 Option 9: Layer 17 - Spectra for 1%, 2.5%, 5%, 10%, 15%, 20% damping.
12 Option 9: Layer 23 - Spectra for 1%, 2.5%, 5%, 10%, 15%, 20% damping.
13 Option 9: Layer 29 - Spectra for 1%, 2.5%, 5%, 10%, 15%, 20% damping.
14 Option 10
15 Option 11

After executing SHAKE and processing the first output file, the *.SPC file will contain the response spectra data for the different layers. To plot the response spectrum for 5% damping for layers 1, 5, 10, 17, 23 and 29, first select a type of response spectrum and the 5% damping ratio option. Once you do this, the **Ok**, **Mean** and **Site** command buttons will be enabled. Click on the **Site** button to display the **Response Spectra - Site Effects Menu** form.

AASHTO: This option allows you to plot the AASHTO response spectra based on the approach outlined in the AASHTO Guide Specifications for LRFD Seismic Bridge Design (FHWA, 2011). This option can only be used with the **Acceleration** response spectra and **5% damping**. You can use this option together with the **Mean**, **Site**, **Attenuate** or **NEHRP** options. After clicking on the **AASHTO** button, the **AASHTO Response Spectrum** form will be displayed.

ASCE: Use this command button to plot a design response spectrum based on the 2010 ASCE method. After clicking on the **ASCE** button, the **ASCE Response Spectrum** form will be displayed.

Attenuate: This option allows you to plot pseudo absolute acceleration or pseudo relative velocity spectra, predicted using published ground motion prediction equations. This option can only be used with either the **Acceleration** or **Velocity** response spectra, and **5% damping**. You can use this option together with the **Mean**, **Site** or **NEHRP** options. After clicking on the **Attenuate** button, the **Ground Motion Prediction Equations** form will be displayed.

EuroCode: This button is used to select the options and/or enter the data necessary to plot a design response spectrum in accordance with Part 1 of the Eurocode 8 (European Committee for Standardization, 2000).

IBC: Use this command button to plot a design response spectrum using the procedure set forth in the International Building Code (International Code Council, 2003, 2012). This button will display the **IBC Design Response Spectrum** form that can be used to select the appropriate spectrum.

NEHRP Provisions - Site-Specific Response Spectra: This option allows you to plot up to two site-specific response spectra; constructed using the procedures outlined in the NEHRP Provisions (Building Seismic Safety Council, 2004a & 2004b, 2009). This option can only be used with either the **Absolute Acceleration** or **Pseudo-Absolute Acceleration** response spectra, and **5% damping**. You can use this option together with the **Mean** or **Site** options, but first you need to select the NEHRP spectra.

Target: Click on this button to display the **Target Response Spectrum** form. In this form, you can enter values of period and spectra for a target response spectrum that will be plotted together with the other spectra.

For the **AASHTO**, **ASCE** and **NEHRP** spectra, the program can use the data provided by the USGS website at:

http://earthquake.usgs.gov/hazards/designmaps/usdesign.php

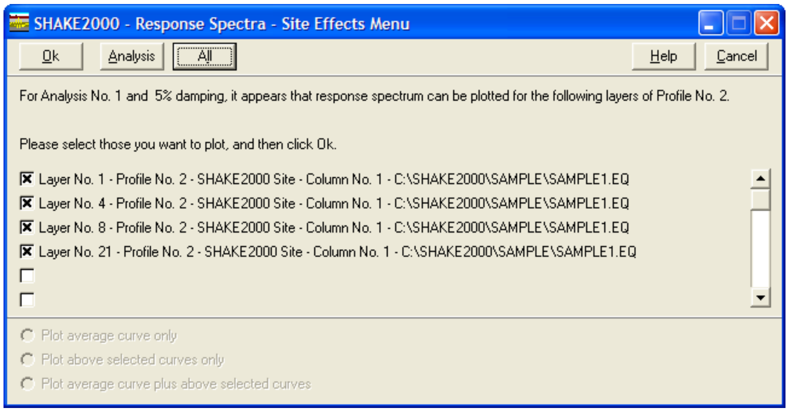
For these spectra, you can obtain the most-up-to-date parameters using the on-line application at:

http://earthquake.usgs.gov/designmaps/us/application.php

Check to plot: Once you have selected a response spectra option (AASHTO, ASCE, Attenuate, IBC, NEHRP, or Target), the corresponding option will be enabled (i.e., will not be grayed out). The purpose of this option is to allow the user to switch on and off the plotting of the response spectra. For example, if you have selected the NEHRP spectra and entered the coefficients, an **x** will appear in the check box next to the NEHRP label. This means that every time that you click on the **Plot** command button, these spectra will be plotted together with any other spectra selected. If you click on the check box, the **x** will be removed, and when you click on the **Plot** button, the NEHRP spectra will not be plotted. To plot them again, just click on the check box again. You don't need to re-enter the coefficients.

The response spectra data can be saved to a text file by selecting the **Save Spectrum Data** option. This text file can then be open with other applications, e.g. Excel, for further use. The path and name of the text file can be changed by clicking on the command button with the folder icon next to the text box.

Response Spectra - Site Effects Menu

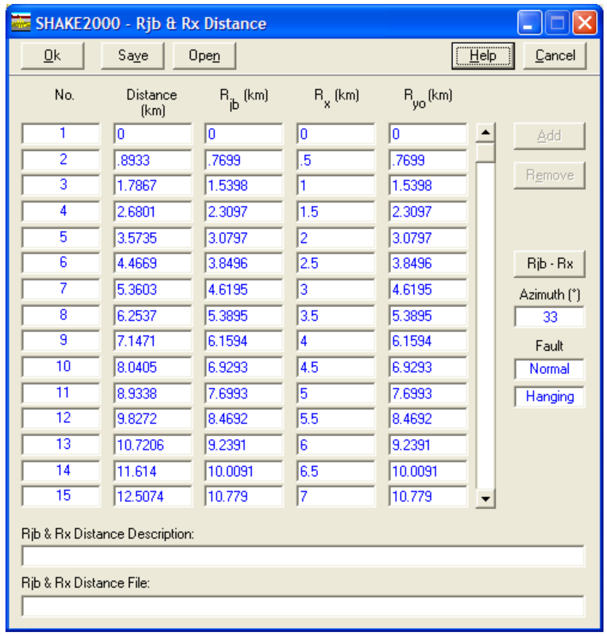


This form will display a list of layers that have response spectrum for the selected damping ratio. To plot a spectrum, click on the check box to select it. Then click on **Ok** to return to the spectrum plot menu form.

When the **Analysis** command button is enabled, it can be used to display a summary list of the different options that form each analysis group. The results contained in the first and second output files generated from the execution of SHAKE are grouped in sets, or analyses, depending on the order of the different options.

The **All** command button will select all of the spectra available for plotting.

R_{jb} & R_x Distance



This form is used to enter R_{jb}, or the closest distance to the surface projection of fault rupture used by the Akkar & Bommer (2007) – Europe/Middle East; Campbell & Bozorgnia (2003); Campbell & Bozorgnia (2008) – NGA; Boore, D. & Atkinson, G. (2008) – NGA; Chiou, B. & Youngs, R. (2008) – NGA; and, the R_x and R_{yo} distances used by the NGA and NGA-West2 distance used by the NGA ground motion prediction equations.

Note that the program will plot the PHA vs. Distance, where for the NGA equations the distance is R_{rup} and for Campbell & Bozorgnia (2003) it is R_{seis}. Accordingly, for the NGA relations R_{jb} and R_x should be computed and entered in the R_{jb} and R_x columns of the **R_{jb} and R_x Distance** form.

Similarly, for the Boore & Atkinson NGA relation, the program will also plot the PHA vs. Distance wherein distance is assumed to be R_{rup}, but the program will use R_{jb} entered in the respective column of the **R_{jb} and R_x Distance** form for the computations. For further information on these distances, please refer to the respective reference for each relation.

To enter the data, place the cursor on the text box for **R_{jb}** column and type in the values in kilometers. Please note that the default values shown on the R_{jb} and R_x columns are not representative of any particular field situation. Also enter values for Distance based on the attenuation relation being used. For example, for the Campbell & Bozorgnia NGA the values on the Distance column will correspond to the values for R_{rup}. When computing the attenuation values, the program will linearly interpolate between the values entered to obtain the corresponding R_{jb} and R_x when specific values for a distance are not entered. The program will only accept values greater than 1 for distance.

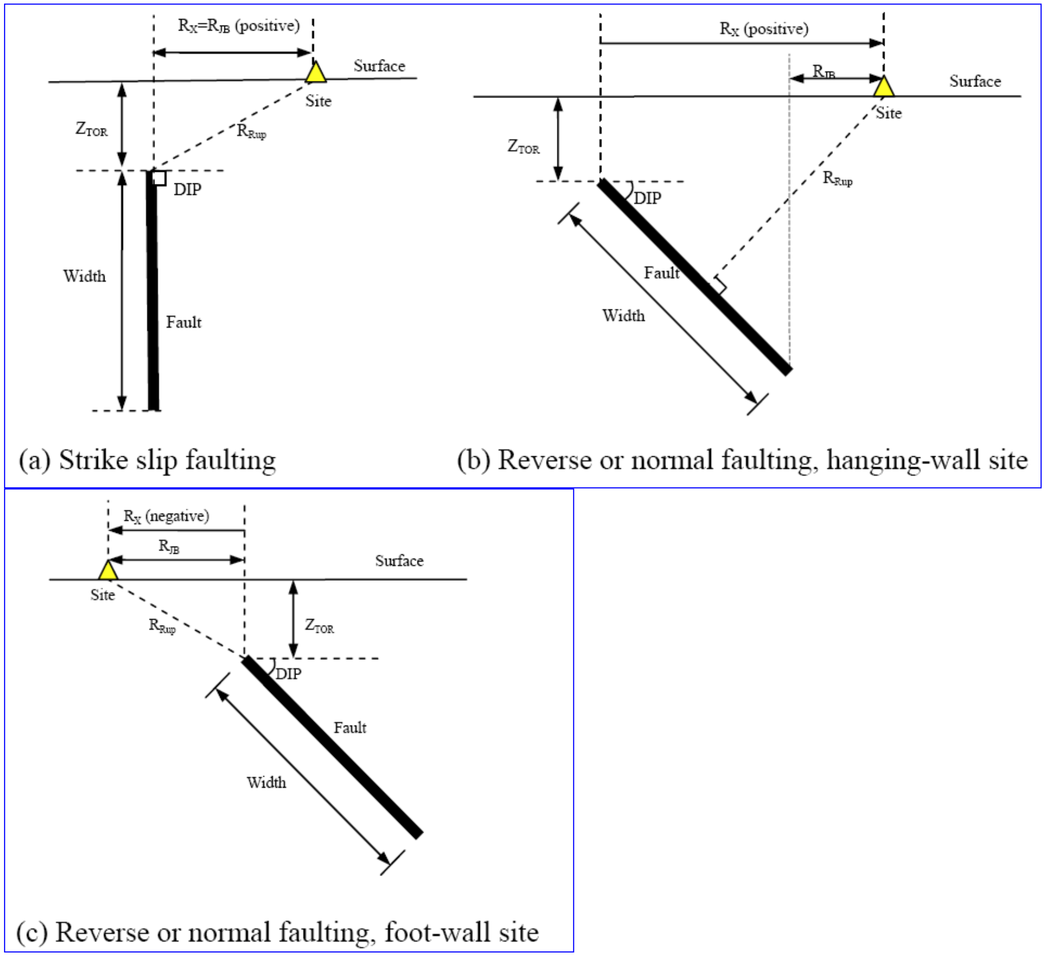
After you have entered the information for each R_{jb} and R_x, click on the **Ok** command button to return to the **Ground Motion Prediction Equations** form.

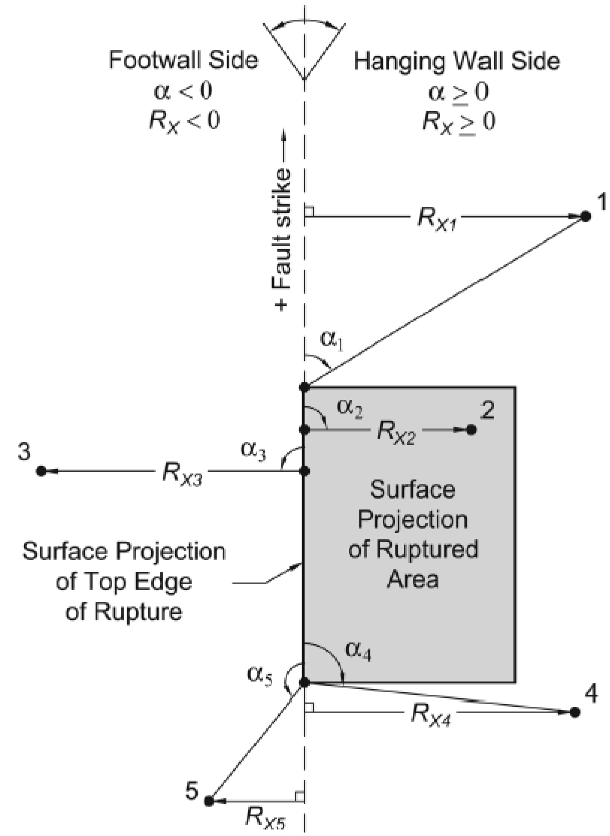
Each time you place the cursor on the Distance, R_{jb} or R_x columns the **Add** and **Delete** command buttons are enabled. If you want to add data for a new Distance, place the cursor on the distance where the new values will be located, and click on the **Add** button. New values will be created, and the values will be the same as those for the Distance immediately below. The **Delete** button is used to delete the data for a Distance from the table. Place the cursor on the Distance, R_{jb} or R_x value column and then click on the **Delete** button. The data for the Distance will be removed from the table, and the information for the other Distances updated accordingly. The **Reset** command button will delete all the information on the table and display the default values. The **Save** command button is used to save the data in a text file for future use. These data can be retrieved using the **Open** command button.

The **Rjb – Rx** command button can be used to compute values of R_{jb} and R_x for the distances shown on the **Distance** column (or R_{rup} on the figure). The computation of the distance is based on the geometries shown on the following figures (a), (b) and (c) included in the PEER NGA Excel spreadsheet.

For the computation of the R_{jb} and R_{Rup} distances, the program will first assume default values of either R_{jb} or R_x and then use the equations presented by Kaklamanos et al. (2011) to compute R_{Rup}. For these equations, the value of the *source-to-site azimuth* can be entered in the **Azimuth (◦)** text box. The definitions for the parameters used in the equations are shown on the following page.

The information and data used for the computation, i.e., dip, style of faulting, Z_{TOR}, and width; are entered in the **Ground Motion Prediction Equations** form.

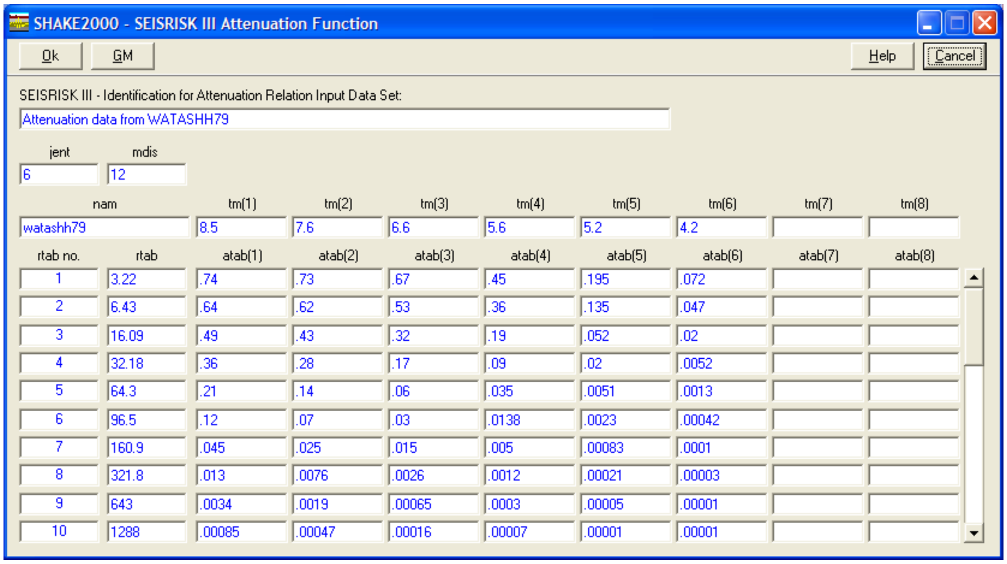




Distance Definitions in PEER NGA Excel Spreadsheet

Definition of source-to-site-azimuth and site coordinates when using Kaklamanos et al. (2010) equations (figure extracted from Kaklamanos et al. (2010).

SEISRISK III Attenuation Function



This form is used to enter the attenuation data as a function of magnitude and distance for SEISRISK III. It is recommended that you review the SEISRISK III User's Manual (Bender & Perkins, 1987) for more information on this program.

For convenience, the data in this form have been labeled according to the variable names used by SEISRISK III. To enter the values, place the cursor on the respective text box for the parameter and type in the data. To delete a value, place the cursor on the corresponding cell, and use the *Delete* key. Then press the *Tab* key to move the cursor to a different cell.

Further information for each parameter required in the analysis is given below (this information has been literally taken from the SEISRISK III User's Manual, pp. 24-25):

The attenuation values can also be estimated using the ground motion prediction equations included with SHAKE2000. To do this, first enter the values for magnitude and distance in this form and then click on the **GM** command button to display the **Ground Motion Prediction Equations** form. Select an attenuation relation and other options for the attenuation relation, and then click on the **Plot** command button of the form to display the attenuation curves. Click on the **Close** command button to return to the **Ground motion Prediction Equations** form, and then on **Ok** to return to this form. The attenuation values will be displayed in the text boxes.

SEISRISK III – Identification for Input Data Set: A description of this data set can be entered in this text box. This is the code that SHAKE2000 will use to identify this data set as input data option for subsequent operations, such as creating an input file. This information is not used by SEISRISK III.

Line 9:
jent, mdis

jent = number of magnitudes for which acceleration is tabulated as a function of distance (maximum 8).
mdis = number of distances in attenuation table (maximum 20)

Line 10:
nam, tm (jent values of tm)

nam = identifier up to 10 characters – for example 'schn-seed'
identifies attenuation curve used (when using the **GM** command button, an identifier is created automatically)

tm = magnitude for which table of distance versus acceleration (or other ground motion parameter) values follows
**** magnitudes must be in descending order ****

Line 11:

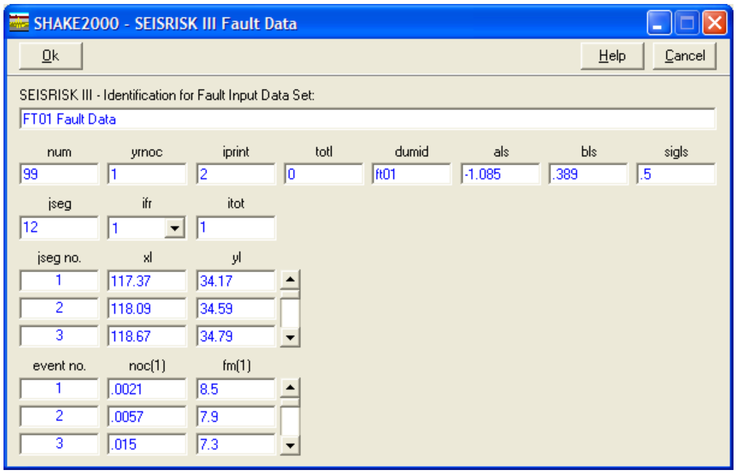
rtab(i), (atab(i, j), j=1,jent) (mdis lines, i=1,mdis)

rtab(i) = i^{th} tabular distance in kilometers from earthquake source

atab(i,j) = mean peak acceleration (or other ground motion parameter) at i^{th} distance for j^{th} magnitude.

After entering the data, click on the **Ok** command button to return to the SEISRISK III pre & postprocessor form. To return to the pre & postprocessor form without accepting the changes made to the data in this form, click on the **Cancel** command button.

SEISRISK III Fault Data



This form is used to enter the fault data for use in SEISRISK III. It is recommended that you review the SEISRISK III User's Manual (Bender & Perkins, 1987) for more information on this program.

For convenience, the data in this form have been labeled according to the variable names used by SEISRISK III. To enter the values, place the cursor on the respective text box for the parameter and type in the data. To delete a value, place the cursor on the corresponding cell, and use the *Delete* key. Then press the *Tab* key to move the cursor to a different cell. Further information for each parameter required in the analysis is given below (this information has been literally taken from the SEISRISK III User's Manual, pp. 24-25):

There are a few "rules" that should be followed when entering the values for longitude and latitude:

1. Longitudes in the Western Hemisphere should be entered as positive values.
2. Longitudes in the Eastern Hemisphere should be entered as negative values.
3. Latitudes north of the Equator should be positive.
4. Latitudes south of the Equator should be negative.
5. Values should be entered left to right, i.e. greater values are on the left side.

SHAKE2000 will assume that any positive value for longitude is *West*, and any negative value is *East*. Similarly, positive latitudes are *North* and negative latitudes are *South*.

SEISRISK III – Identification for Input Data Set: A description of this data set can be entered in this text box. This is the code that SHAKE2000 will use to identify this data set as input data option for subsequent operations, such as creating an input file. This information is not used by SEISRISK III.

Line 1f:
num, yrnoc, iprint, totl, dumid, als, bls, sigls

num = 99 for first fault
num = 0 for all fault sets after 1st
= 99 at the end of computation
yrnoc = number of years over which the earthquake occurrences take place
irpint = -1 no statistics for this (intermediate) set of occurrences
= 1 statistical calculations and printout
= 2 same as 1 plus summary file for plot, etc.
= 3 omit printout; do summary file for plot
totl = distance between faults if this set of faults is a set of "dummy" faults used to approximate a uniform field of faults.
totl = 0 if individual fault or a number of well defined faults are used.

totl determines whether ground motions for a site are to be smoothed in distance or smoothed in magnitude
(smoothed in magnitude if *totl* = 0)
(smoothed in distance if *totl* is nonzero).

dumid = four character identifier for fault

als, bls, sigls rupture length parameters
if als, bls non zero:
length = 10**(als + bls * m + fr * sigl)
where m = magnitude; sigl = standard deviation (in log length)
fr = (normally) 5 values in range (-2, +2) if *sigl* non zero
fr = 0 (1 value) – mean rupture length only if sigl = 0
if als, bls, sigls = 0 (or blank) previous values are used
if no previous values input, default values are used:
als = -1.085 bls = 0.389 sigls = 0.52

Line 2f:
jseg, ifr, itot

jseg = number of fault segment end points to be connected into single fault (*jseg*-1 segments)
ifr = set number (ifr = 1,2 …. *itot* in sequence)
itot = 10 max; total quad pairs for *itot* sources maximum 50

Line 3f:
(xl(i, i(fr), yl(i,i(fr), i =1, jseg)

xl = long yl = lat (degrees) (ifr = fault number)
jseg = 24 max
itot = 26 max

Line 4f:
noc(l) l = 1, lev (lev = 12 maximum)
number of events expected in *yrnoc* years in each magnitude interval for earthquake occurrences

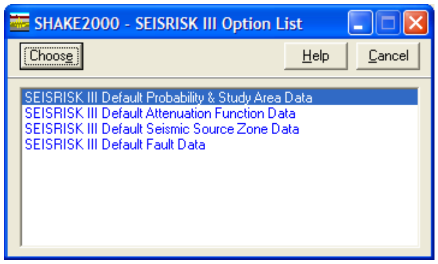
Line 5f:
fm(l) l = 1, lev
fm(l) = center of magnitude interval for which *noc(l)* occur

Repeat *2f*, *3f* for *itot* faults
Repeat *1f* thru *5f* for remaining faults

End with *num* = 99 (omit other inputs on line)

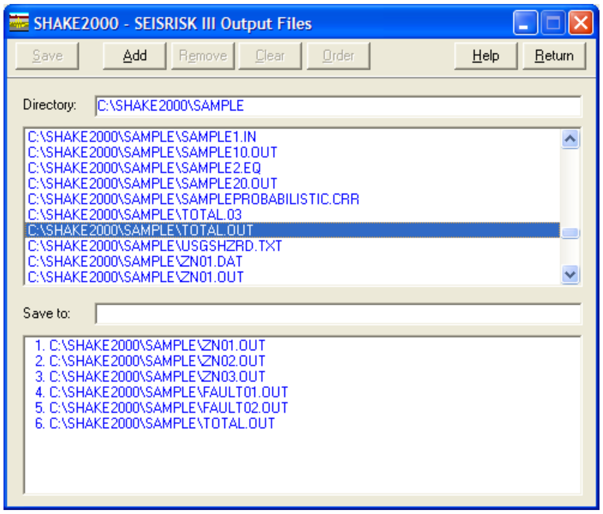
After entering the data, click on the **Ok** command button to return to the SEISRISK III pre & postprocessor form. To return to the pre & postprocessor form without accepting the changes made to the data in this form, click on the **Cancel** command button.

SEISRISK III Option List



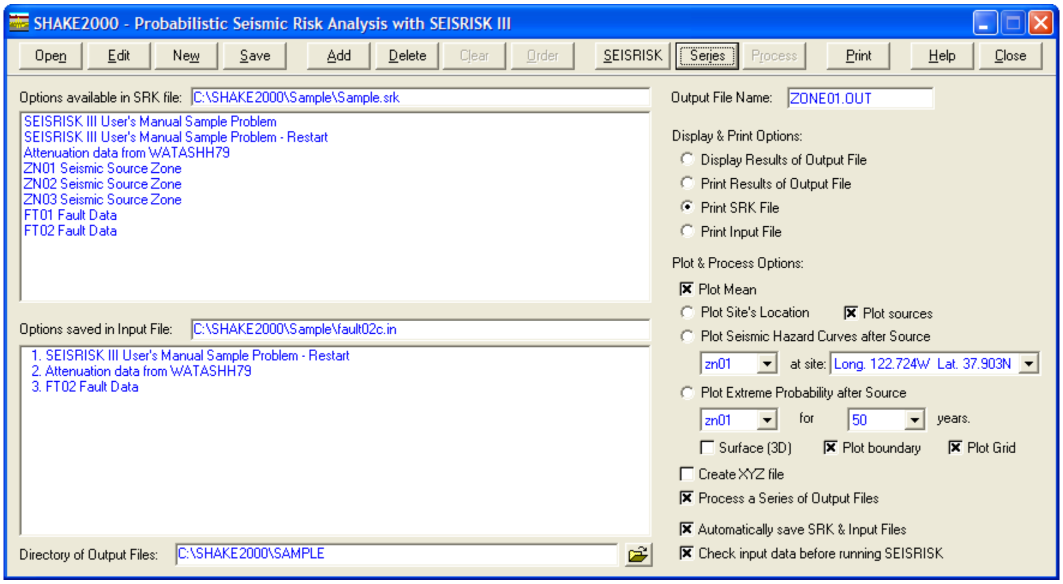
This form is used to select SEISRISK III options that are not already included in the *.SRK file, or to create new sets of an option. Default values will be given to the option. To select an option, click on the option to highlight it and then click on the **Choose** button to return to the **SEISRISK III Pre & Postprocessor** form. The new option will be shown on the option list. You can also double click on the option to select it.

SEISRISK III Output Files



When selecting different output files for SEISRISK III, the files available will be displayed in the top list box. The directory where these files are saved is shown in the text box next to the **Directory** label. To select a file, highlight it, and then click on the **Add** command button. This will display the file in the bottom list box. Alternatively, double click on the file to add it to the bottom list box. Once you have selected all the files that should be included in the analysis, click on the **Return** command button to return to the **SEISRISK III Pre & Postprocessor** form.

SEISRISK III Pre & Postprocessor



This option of SHAKE2000 is used to create an input file for, and to process the output file created with SEISRISK III (Bender and Perkins, 1987). More information about SEISRISK III can also be found at:

http://eqhazmaps.usgs.gov/html/swmain.html

An executable version of SEISRISK III is included with SHAKE2000.

1. SRK File:

An *.SRK file is an ASCII file that contains data for the different options used by SEISRISK III. The data are in a format that is not compatible with SEISRISK III; accordingly, the *.SRK file may not be used as an input file for SEISRISK III. However, SHAKE2000 uses this file as a database to create an input file. In other words, the *.SRK file can contain sets for each option used by SEISRISK III (e.g. different sets of the attenuation function). Thus, when the file is saved, the options will be saved in numeric order, and all the sets for each option will be grouped together. As similarly done for SHAKE, SHAKE2000 separates the data used in SEISRISK into “options”. These options are defined by the type of data in the input file: 1) Option 1 is formed by the information about the probabilities and the area of study, i.e. between the title line and before the attenuation data; 2) Option 2 is formed the attenuation data; 3) Option 3 is formed by the seismic source zone data; and, 4) Option 4 is formed by the fault data.

Options available in SRK file: Use the **Open** command button to load and edit an existing *.SRK file. After the data in the file are read, the list box will show the options that are included in the *.SRK file, and the first option will be selected. Further, if the *.SRK file also includes information about the options included in the input file, these options will be shown on the bottom list box, i.e. the Input list box. The SRK list box is used to select the options that the user can edit and options to be included in the input file. The vertical scroll bars on the right side of the list box can be used to scroll between the options. To edit an option, click on it to highlight it and then click on the **Edit** button. You can also double click on the option to edit it. If you want to remove an option from the *.SRK file, highlight it and then click on the **Delete** button. The option cannot be un-erased. To create a specific option that is not included in the *.SRK file, or to create a new set of an existent option, click on the **New** button. The button will display the **SEISRISK III Option List** form to select new options.

To save the *.SRK and Input files, click on the **Save** button. The files can be saved automatically after you edit an option, or before you execute SEISRISK, by selecting the **Automatically save SRK & Input Files** check box.

To print the SRK file, first click on the **Print SRK File** option to select it, and then click on the **Print** command button. This will display the **Print Menu** form.

When the **Automatically save SRK & Input Files** option is selected (an **x** is shown on the check box) the SRK and Input files will be automatically saved every time you return from editing an option (using the **Edit** command button), or before SEISRISK III is executed (with the **SEISRISK** command button).

The **Check input data before running SEISRISK** option is selected by default. When this option is selected, the data in the different options that form the input data will be checked to determine if there are any errors that may cause problems during the execution of SEISRISK. If you are sure that your data are correct and do not wish to check the data before execution of SEISRISK starts, click on the check box to de-select this option.

2. Input File:

The top list box will show the options that are included in the *.SRK file. This list is used to select the options that will be included in the SEISRISK III input file. To include one of these options in the input file, first select the option by clicking on it to highlight it, and then click on the **Add** button. The **Order**, **Remove** and **Clear** buttons are not enabled, i.e. they are grayed out. These buttons are enabled when an option from the input file's option list is selected.

Input File's Option List: This list box will show the options that will be included in the SEISRISK III input file. If no options have been selected before this form is displayed, then this list box will be empty. Once you have selected the options, you can reorganize them with the **Order** button, remove any with the **Remove** button, delete all the options from this list box with the **Clear** button, and create the input file with the **Save** button.

To create an input file for SEISRISK III, select the options you want to include from the top list (i.e. SRK File's Option List) in the order they will be executed by SEISRISK III. The options selected will be shown on the bottom list box (**Input File's Option List**) with the order number next to them. Then, use the **Save** command button to store these options in the input file. A file dialog form will be displayed requesting you to enter the name for the file. Alternatively, you can select to overwrite an existing file by selecting it.

To print the input file, first click on the **Print Input File** option to select it, and then click on the **Print** command button. This will display the **Print Menu** form.

3. Execute SEISRISK III:

After you have created an input file, you will perform the seismic hazard analysis using SEISRISK III.

Before you execute SEISRISK III, you need to enter the name of the output file and select a directory path where the file will be saved. Place the cursor on the text box next to the **Output File Name** label and type in the name for the output file, followed by a period and the extension (e.g. OUT). SHAKE2000 will not add an extension to the end of the file if it is not entered. Also, you will need to type the same name when requested by SEISRISK III. You can enter up to 32 characters. Blank spaces are not allowed. The file will be saved to the folder shown on the text box next to the **Directory of Output Files** label. To change the location of the output directory, there is a command button located next to the text box (i.e. the button with the open folder icon). Click on this button to display the **Choose Output Directory** form, select a different folder by double clicking on it, and then click on the **Ok** button to return to this form.

Now, to execute SEISRISK III click on the **SEISRISK** command button. This will open a DOS window. At the prompt, type SEISRISK. You will be requested to provide the name of the input, output and auxiliary files. After execution of SEISRISK III terminates, type **exit** to close the DOS window and return to SHAKE2000.

4. Data Processing and Plotting:

After you have executed SEISRISK III, you need to process the output file created. SHAKE2000 will read the output file and extract the information that is most useful to the user. To process the output file, click on the **Process** command button. After a few seconds, information will be displayed on the lists next to the **Plot Seismic Hazard Curves** and **Plot Extreme Probability** options. If there were any errors during the execution of SEISRISK III, then an error message will likely be displayed during the processing of the output file. In this case, it is recommended to use the **Display Results of Output File** option to display the output file and proceed to the option that may have caused the error, usually the last option saved in the output file. Then, review the information provided in the output file and review the input data for this option to determine the reason for the error.

Process a Series of Output Files: If you have different seismic sources or faults, you can perform an individual analysis and create an output file for each source. You can also perform successive runs, accumulating the results for each source or fault, and then save the final results in the last output file created. This option will allow you to combine both output files, the individuals and the total, so that you can view the influence of each source on the total result. For example, using the sample problem in the SEISRISK III user's manual which includes three source zones, ZN01, ZN02 and ZN03; and, two faults, FT01 and FT02. For your first analysis, you create an input file for each source and fault using a code of zero, "0", for new run for the *isw* variable. Execute SEISRISK III using each file and name each output file using the same name as the input file, but with an extension of ".out" (i.e., ZN01.OUT, ZN02.OUT, ZN03.OUT, FT01.OUT and FT02.OUT). For the first run, i.e. ZN01, use the ***total.03*** name when asked about the 03 file. This file is used in the second series of runs. For the second part of the analysis, first, change the value of the *isw* variable to one, "1", for restart or continue from previous run for the ZN02, ZN03, FT01 and FT02 files. The value of the *isw* variable in the ZN01 file remains the same as zero because there are no previous runs conducted before. Next, do a separate analysis using each input file, but this time give a different name to each output file (e.g., ZN01TOT.OUT, ZN02TOT.OUT, ZN03TOT.OUT and FT01TOT.OUT); and, for the output file for FT02 use TOTAL.OUT. When restarting or continuing from a previous analysis, you need to use the same auxiliary file "03" for each run; i.e., when executing SEISRISK using these latest input files and you are requested to "*Enter auxiliary file name 03*", enter the name ***total.03*** each time. To process the files, first click on the **Process a Series of Output Files** check box to select it. This will enable the **Series** command button. If necessary, use the folder icon to display the **Choose Output Directory** form. Select the directory where the above output files are stored, and click on **Ok** to return to the SEISRISK III options form. Click the **Series** command button to display the **SEISRISK III - Output Files** form. A listing of the available output files will be displayed in the top list box. Select the output files in the same order that the sources are defined in the input file for the total analysis, i.e., select first **zn01.out**, **zn02.out, zn03.out**, **ft01.out**, and **ft02.out**. Then select the **total.out** file. Click on the **Return** command button. After a few seconds, information will be displayed on the lists next to the **Plot Seismic Hazard Curves** and **Plot Extreme Probability** options.

Plot Site's Location: Use this option to plot the grid used in the SEISRISK III analysis. Information that will be displayed includes the points on the grid for which the analysis is being conducted, points on a line, and points that represent the boundaries of the seismic sources and faults.

Plot Seismic Hazard Curves after Source: at Site: This option allows you to plot the yearly exceedance rate curve at a point on the grid. To select a source, click on the down arrow to display the list of available sources or faults, and click on the one you want to use. Next, click on the down arrow key of the list box next to the **Site** label to display the list of points. Click on a point to select it, then on **Ok** to display the curve. When processing a series of output files, the results from the file that contains the total or accumulated results will be identified with the **Total** label on the list of available sources. Selecting the **Total** option will also display the individual results for each fault or zone.

Plot Extreme Probability after Source: for years: This option will create a two dimensional (2D) contour plot, or three dimensional (3D) surface plot of the results on the grid of points analyzed. To select a source, click on the down arrow to display the list of available sources or faults, and click on the one you want to use. Click on the down arrow key of the list box next to the **year** label to display the list of years, and click on a year to select it. Next, click on **Ok** to display the curve. When processing a series of output files, the results from the file that contains the total or accumulated results will be identified with the **Total** label on the list of available sources. To plot the data as a 3D surface plot, click on the **Surface (3D)** check box to select this option.

Plot Mean: Click on this option to plot the mean curves or zero attenuation variability. If this option is not selected, then the results calculated considering the attenuation variability will be plotted.

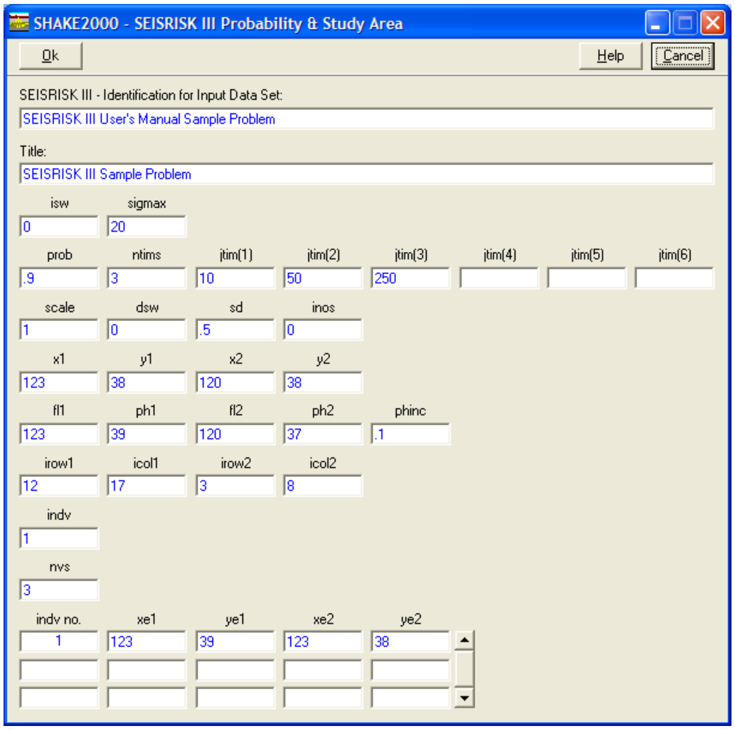
Plot boundary: This option is used with the 3D surface plot. When this option is on (an **x** is shown in the check box), boundary lines that define the grid are shown on the graph.

Plot grid: This option is used with the 3D surface or scatter plots. When this option is on (an **x** is shown in the check box), the background grid lines are shown on the walls of graph.

Plot sources: This option is used with the **Plot Site's Location** option. When this option is on (an **x** is shown in the check box), the seismic sources are displayed on the graph.

Create XYZ File: This option is used with the 2D contour or 3D surface and scatter plots. When this option is on (an **x** is shown in the check box), a text file is created that saves the different values used in creating the plots. This text file is formed by three columns. The first column corresponds to the longitude values, the second column to the latitude values, and the third column is the yearly exceedance rate value. This file can be used with other commercial software (e.g. Surfer, etc.) to create other graphs. By default this file will be given the **PSHA.TXT** name and will be saved to the folder shown on the text box next to the **Directory of Output Files** label. The file will be created by clicking on the **Plot** command button used to display the plot.

SEISRISK III Probability & Study Area



This form is used to enter the probability and study area data used by SEISRISK III. It is recommended that you review the SEISRISK III User's Manual (Bender & Perkins, 1987) for more information on this program.

For convenience, the data in this form have been labeled according to the variable names used by SEISRISK III. To enter the values, place the cursor on the respective text box for the parameter and type in the data. To delete a value, place the cursor on the corresponding cell, and use the *Delete* key. Then press the *Tab* key to move the cursor to a different cell. Further information for each parameter required in the analysis is given below (this information has been literally taken from the SEISRISK III User's Manual, pp. 24-25):

There are a few "rules" that should be followed when entering the values for longitude and latitude:

1. Longitudes in the Western Hemisphere should be entered as positive values.
2. Longitudes in the Eastern Hemisphere should be entered as negative values.
3. Latitudes north of the Equator should be positive.
4. Latitudes south of the Equator should be negative.
5. Values should be entered left to right, i.e. greater values are on the left side.

SHAKE2000 will assume that any positive value for longitude is *West*, and any negative value is *East*. Similarly, positive latitudes are *North* and negative latitudes are *South*.

SEISRISK III – Identification for Input Data Set: A description of this data set can be entered in this text box. This is the code that SHAKE2000 will use to identify this data set as input data option for subsequent operations, such as creating an input file. This information is not used by SEISRISK III.

Line 1:
title
Enter a description for the analysis, up to 80 characters long.

Line 2:

isw, sigmax

isw = 0 new run (usual case)
isw = 1 restart or continue from previous run
sigmax = maximum standard deviation (km) for earthquake location variability in seismic source zones for this run.

Line 3:

prob, ntims, jtim(1), jtim(2) …….. jtim(ntims)

acceleration is sought for which there is probability *prob* of not being exceeded in *jtim(1), jtim(2), ….. jtim(ntim)* years.
prob = extreme probability in decimal
ntims = number of times for which calculation is done
jtim(1) = durations (years) for which extreme motions are to be calculated at the *prob* probability level, $1 \leq i \leq ntims$

Line 4:

scale, dsw, sd, inos

scale = scaling factor for ground motion boxes
scale = 1 for for motions 0.02 to 1.0 – scale accordingly
dsw = 1 if inputs are degrees and minutes
= 0 if inputs are decimal degrees
sd = standard deviation in log acceleration for acceleration variability around mean value
inos = 1: divide magnitude interval in half and do calculations at twice as many magnitudes (assumes Gutenberg-Richter b-value is same for all intervals).
inos = any number other than 1: do calculations for original magnitude intervals.

Line 5:

x1, y1, x2 , y2

(long, lat) in decimal degrees
transform great circle thru (x1, y1), (x2, y2), (0, 0) to equator for new coordinate system.

Line 6:

fl1, ph1, fl2, ph2, phinc

(fl1, ph1) upper left (fl2, ph2) lower right (long, lat)
corners of seismic felt region for risk computation
rectangular region with sides parallel to arc of great circle thru (x1, y1), (x2, y2) (0, 0) – defined in Line 5.
other two sides perpendicular and thru given end points

```
     + (fl1,ph1)
    1     .
 (x1,y1) 1     .
.          1     .
    .          1     .
        .          1     .
            .      .    1
       (fl2,ph2)+      (x2,y2)
```

area within dots represents felt region
'1's represents line joining (x1, y1) (x2, y2)
phinc (long, lat) increment in degrees (in new coordinate system) for which risk is to be computed)

Line 7:

irow1, irow2, icol1, icol2

starting and ending rows and columns for this run accelerations computed for sites in these rows and columns – may be subset of seismic felt region defined in input 6. Also irow1 = irow2 = icol1 = icol2 = 0 permitted if only individual sites on lines (input 8) are selected

Line 8:

indv

number of line segments containing individual sites at which acceleration is to be computed; zero if only fixed grid is used.
If indv > 0 read next inputs, otherwise skip to input 9.

nvs

number of sites per line segment

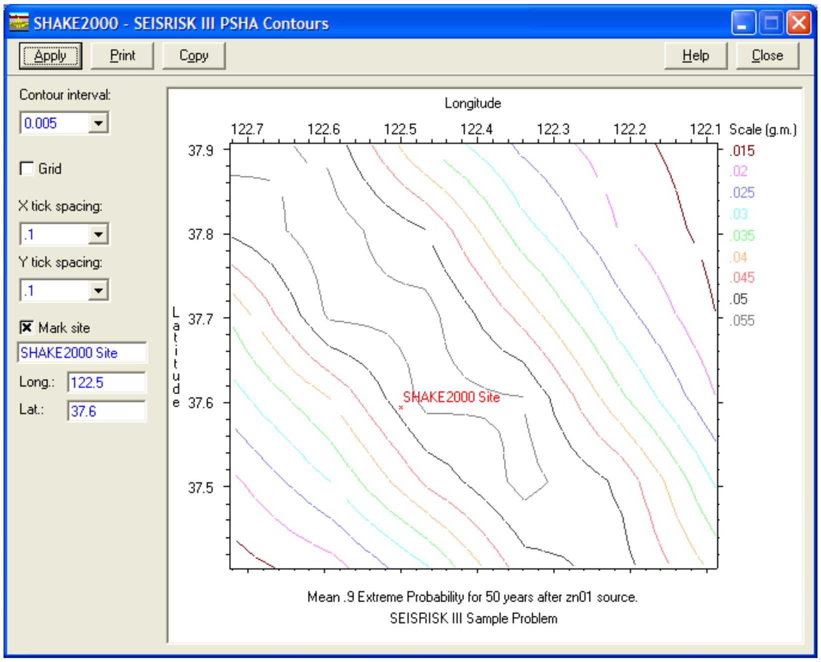
xe1, ye1, xe2, ye2

indv lines, one pair per line
end points (long, lat) of line segment: sites will be evenly spaced on line in new coordinate system
NOTE: NO SMOOTHING OF ACCELERATIONS AT SITES ON LINE FOR ACCELERATIONS FROM EARTHQUAKES WITHIN AREAL SOURCE ZONES. CALCULATIONS FOR UNIFORM SEISMICITY ONLY AT THESE SITES.

Lines 9, 10 & 11:
(see **SEISRISK III Attenuation Function** section of this manual).

After entering the data, click on the **Ok** command button to return to the SEISRISK III pre & postprocessor form. To return to the pre & postprocessor form without accepting the changes made to the data in this form, click on the **Cancel** command button.

SEISRISK III PSHA Contours



The PSHA (Probabilistic Seismic Hazard Assessment) Contours form is used to display the two-dimensional (2D) contour plot of the annual exceedance probability computed with SEISRISK III.

Contour Interval: To change the contour interval used in the plot, click on the down arrow to display the list of intervals available. Click on the interval that you want to use to highlight it, then on the **Apply** command button to redraw the graph using the new interval.

Grid: Select this option to display a grid on the plot. Grid lines will be drawn at each major tick mark. Click on the **Apply** command button to redraw the graph. An **x** is shown in the check box when this option is selected.

X tick spacing: To change the spacing of the major ticks on the longitude axis, click on the down arrow to display the list of available spacing values, and then select one. Click on the **Apply** command button to redraw the graph using the new tick spacing.

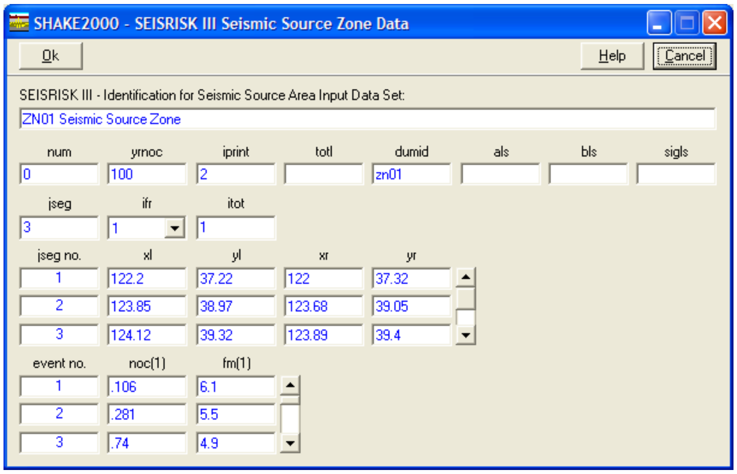
Y tick spacing: To change the spacing of the major ticks on the latitude axis, click on the down arrow to display the list of available spacing values, and then select one. Click on the **Apply** command button to redraw the graph using the new tick spacing.

Mark Site: Select this option to display a site location on the graph. An **x** is shown in the check box when this option is selected. Next, enter a label to identify the site by placing the cursor on the text box below the **Mark Site** label, and then enter up to 30 characters. Press the *Tab* key, or use the mouse, to place the cursor on the text box next to the **Long** label and enter the longitude value for the site in decimal form. Move the cursor to the text box next to the **Lat** label and enter the latitude value for the site in decimal form. Click on the **Apply** command button to redraw the graph and display the site location.

Use the **Copy** command button to copy the contour plot to the clipboard. You can use then the **Paste** or **Paste Special** commands on other Windows applications (i.e. Microsoft Word), to insert the graph into other documents.

The **Print** command button will display a printer dialog form that you can use to send a copy of the graph to the printer.

SEISRISK III Seismic Source Zone Data



This form is used to enter the seismic source zone data for use in SEISRISK III. It is recommended that you review the SEISRISK III User's Manual (Bender & Perkins, 1987) for more information on this program.

For convenience, the data in this form have been labeled according to the variable names used by SEISRISK III. To enter the values, place the cursor on the respective text box for the parameter and type in the data. To delete a value, place the cursor on the corresponding cell, and use the *Delete* key. Then press the *Tab* key to move the cursor to a different cell. Further information for each parameter required in the analysis is given below (this information has been literally taken from the SEISRISK III User's Manual, pp. 24-25):

There are a few "rules" that should be followed when entering the values for longitude and latitude:

1. Longitudes in the Western Hemisphere should be entered as positive values.
2. Longitudes in the Eastern Hemisphere should be entered as negative values.
3. Latitudes north of the Equator should be positive.
4. Latitudes south of the Equator should be negative.
5. Values should be entered left to right, i.e. greater values are on the left side.

SHAKE2000 will assume that any positive value for longitude is *West*, and any negative value is *East*. Similarly, positive latitudes are *North* and negative latitudes are *South*.

SEISRISK III – Identification for Input Data Set: A description of this data set can be entered in this text box. This is the code that SHAKE2000 will use to identify this data set as input data option for subsequent operations, such as creating an input file. This information is not used by SEISRISK III.

Line 1s:
num, yrnoc, iprint, totl, dumid, als, bls, sigls

num = 0 for seismic source areas if no averaging for earthquake location uncertainty is to be done at end of ground motion computations for this source zone
num = 98 for seismic source zones if averaging for earthquake location uncertainty is to be done at end of computations for this source zone.
yrnoc = number of years over which the earthquake occurrences take place
irpint = -1 no statistics for this (intermediate) set of occurrences
= 1 statistical calculations and printout
= 2 same as 1 plus summary file for plot, etc.
= 3 omit printout; do summary file for plot
totl ignored here but used for faults
dumid = four character identifier for source zone

als = earthquake location uncertainty standard deviation in km; current value of *als* is ignored when *num*=0
bls ignored here but used for faults
sigls ignored here but used for faults

Line 2s:
jseg, ifr, itot
jseg = number of pairs of quadrilateral corner points in this source set (*jseg*-1 quads). seismicity to be apportioned by fractional area among *itot* sources
ifr = set number (ifr = 1,2 …. *itot* in sequence)
itot = 10 max; total quad pairs for *itot* sources maximum 50

Line 3s:
jseg quadrilateral endpoint lines (two points per line): quad corner points (left long, left lat), (right long, right lat), in decimal degrees (if *dsw* = 0) or degrees, minutes (if *dsw* = 1)

```
x1,y1  __________   x2,y2
      1          1
      1          1
      1          1
      1          1
x3,y3  __________   x4,y4
      1          1
        1          1
          1          1
            1          1
              1_________1
        x5,y5                x6,y6
```

jseg = 3 in this example: quad endpoint pairs are:
(x1,y1) --- (x2,y2)
(x3,y3) --- (x4,y4)
(x5,y5) --- (x6,y6)

subregions of a set are defined as shown
subregions of one set are separate from those of other sets
repeat *2s*, *3s*, for *itot* sources

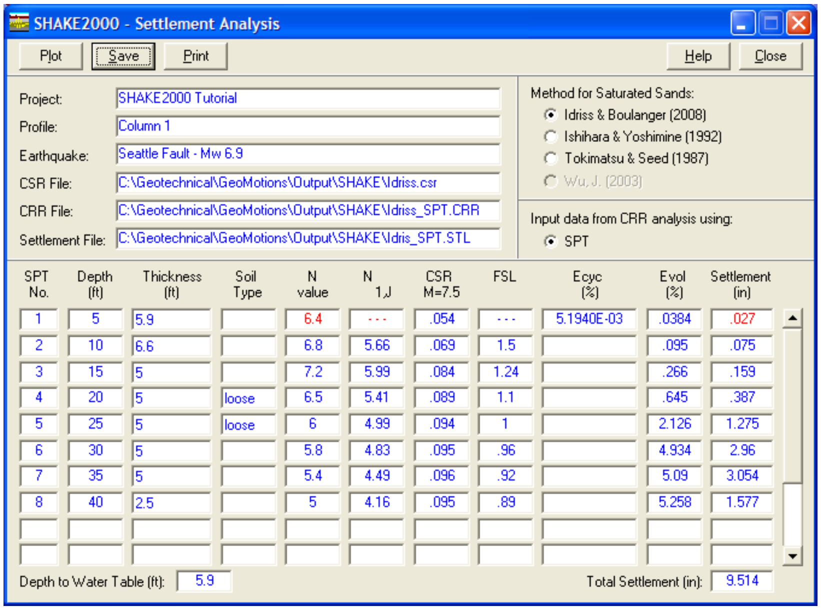
Line 4s:
noc(l) l = 1, lev (lev = 12 maximum)
number of events expected in *yrnoc* years in each magnitude interval for earthquake occurrences

Line 5s:
fm(l) l = 1, lev
fm(l) = center of magnitude interval for which *noc(l)* occur

Repeat *1s* thru *5s* for remaining sources.

After entering the data, click on the **Ok** command button to return to the SEISRISK III pre & postprocessor form. To return to the pre & postprocessor form without accepting the changes made to the data in this form, click on the **Cancel** command button.

Settlement Analysis



This form is used to enter the data necessary to estimate the settlement in the soil column due to earthquake shaking. Before using this form, you should perform a liquefaction analysis for the same soil column with the **Cyclic Resistance Ratio using SPT** form. The input data used in the liquefaction analysis (i.e. $N_{1,60,cs}$, CSR) and the results (e.g. factor of safety against liquefaction) are used together with the equivalent uniform shear strain to do the settlement analysis.

The equivalent uniform shear strain is taken as 65% of the peak cyclic shear strain computed with SHAKE. When using the simplified equation by Seed & Idriss to compute the CSR, the shear strain developed by the ground motion is estimated using the procedure recommended by Tokimatsu and Seed (1987). In this case, G_{max} is approximated with Equation No. 6 described in the **Shear Moduli Equations** section of this manual, assuming a value of 0.5 for K_o.

Four options are given to estimate the settlement for saturated sands: **Idriss & Boulanger** (Idriss & Boulanger, 2008), **Ishihara & Yoshimine (1992)** (Kramer, 1996); **Tokimatsu & Seed (1987)** (Tokimatsu and Seed, 1987); and, **Wu, J. (2003)** (Seed et al., 2003). If the CSR analysis for the evaluation of liquefaction potential using SPT is conducted using the **Cetin & Seed (2000)** option for the calculation of the stress reduction factor, r_d, then the only option enabled to calculate settlement of saturated sands will be **Wu, J. (2003)**. When you select a different option, the settlement will be recalculated and the results shown in their respective text boxes. For dry sands, the method by Tokimatsu and Seed (1987) is used in SHAKE2000.

For the analysis, the soil column is divided in layers. Each layer is then represented by its depth, N value, and thickness. If the depth to the N value is less than the depth to the water table, the layer is assumed to be dry and the corresponding chart for dry sands (Figure 13 of Tokimatsu and Seed, 1987) is used to obtain the volumetric strain. The N value is shown in red for unsaturated soil layers.

If the soil layer depth is greater than the depth to the water table, the chart for saturated sands (Figure 9 of Tokimatsu and Seed, 1987) is used, and the N value is shown in blue. Further, for the Tokimatsu & Seed approach, if the factor of safety against liquefaction is greater than 1 but less than or equal to 1.22, the post-earthquake volumetric strains are estimated based on the normalized stress ratio (Figure 8 of Tokimatsu and Seed, 1987). In this case, the user needs to enter the type of soil as either loose or dense sand. By default, SHAKE2000 assumes that for $N_{1,60,cs}$ values greater than 15, the soil is dense, and loose otherwise. For unsaturated layers, values of equivalent cyclic shear strain are shown on the **Ecyc** column. For saturated layers, values of cyclic shear stress ratio are shown on the **CSR** column, and the **Ecyc** column is left blank.

By default, SHAKE2000 will estimate the thickness of the layers based on the position of the test values. A layer interface will be set at the midpoint between two test values. Another layer interface will also be set at the depth of the ground water table. The thickness for these layers will be different than the ones set for in the simplified cyclic stress ratio analysis form, or as read from Option 2 from the first SHAKE output file.

For unsaturated layers, the volumetric strains for earthquake magnitudes other than 7.5 are obtained by multiplying the strain by the correction factors recommended by Tokimatsu and Seed (Table 1 of Tokimatsu and Seed, 1987). This factor is automatically estimated by SHAKE2000 when the data for the liquefaction analysis are entered. Further, the volumetric strains are doubled to account for multidirectional shaking.

For saturated layers, the cyclic stress ratio for an earthquake magnitude of 7.5 is obtained by multiplying the CSR from the SHAKE, or simplified Seed & Idriss analysis, times the inverse of the magnitude scaling factor used in the liquefaction analysis. Then, the volumetric strain is obtained from the chart (Figure 13 of Tokimatsu and Seed (1987) or Figure 9.54 of Kramer (1996) for the Ishihara & Yoshimine approach), and shown on the **Evol** column.

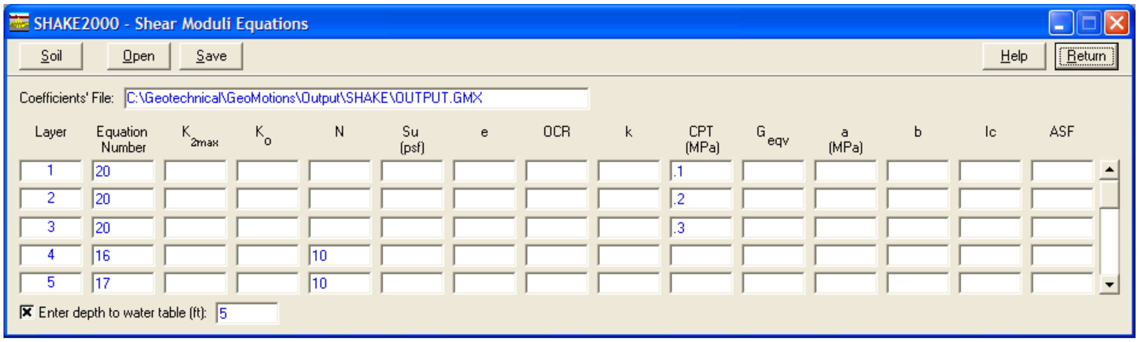
Finally, the settlement for each layer is obtained as the product of the volumetric strain and the thickness of the layer. The total settlement for the column is shown on the **Total Settlement** cell.

The results can be saved on an ASCII file using the **Save** command button. The file uses the *.STL extension by default. To plot the total settlement curve, click on the **Plot** command button. This button is enabled after thickness data for all of the layers are entered, and only when you are performing the settlement analysis using the Simplified Seed & Idriss approach for CRR. Use the **Print** button to send a copy of the table of results to the printer.

Notes:

- For some layers, the settlement is not calculated, and some other information is shown on the **Settlement** column. This information is either NFSL (meaning that a factor of safety against liquefaction could not be computed during the liquefaction analysis); or FSL > 1.22 (meaning that the factor of safety computed during liquefaction is greater than 1.22 and the post-earthquake volume changes are small).
- The procedure used by SHAKE2000 applies to either saturated or unsaturated sand deposits. For any other kind of soil types, the settlement of the corresponding layers should not be computed with this procedure. Accordingly, the CRR value in the CRR form should be deleted to indicate that the point should not be considered in the computation of settlement.
- You can also perform a settlement analysis for a soil column of unsaturated soil; however, you still need to use the **Cyclic Resistance Ratio** forms to enter the **SPT** data for the column, and make sure that the depth to the water table is greater than the depth to the bottom layer of the soil column.
- The depth to the water table is used as the boundary between saturated and unsaturated soils. Thus, it is recommended that this depth also correspond to the boundary between two soil layers.
- For the settlement analysis using the Tokimatsu & Seed method, the program uses the equivalent clean sand penetration resistance value, $N_{1,\,60cs}$, for saturated and dry sands.
- In the Ishihara & Yoshimine approach, the program uses an equivalent $N_{1,J}$ value that corresponds to an N_1 value obtained with standard Japanese SPT procedures. This $N_{1,J}$ value is obtained as the product of the $N_{1,60cs}$ times 0.833. This conversion is recommended due to "…*Japanese SPT procedures typically transmit 20% more energy to the SPT sampler, hence* $N_1 \approx 0.833(N_1)_{60}$" (Kramer, 1996).
- When the depth to the middle of the bottom layer is less than the depth to the groundwater, the **Ishihara & Yoshimine (1992)** option is disabled.

Shear Moduli Equations



This section presents a number of equations that can be used to estimate the maximum-dynamic shear modulus for a soil type, or a layer of the soil profile. The reference for each equation is given, and the user is solely responsible for verifying that the equations are appropriate for his/her particular problem, and that the coefficients required for each equation are entered in the appropriate units. For each equation, the dimensions of the G_{max} result will be transformed to **ksf** or **kN/m^2** for use in SHAKE2000.

To compute the shear modulus, select the equation number from the list in the following pages, and enter it in the **Eq. No.** text box next to the soil type or layer number. When computing the modulus, if an equation number was used for a specific soil layer, this has precedence over an equation number used for the layer's soil type. For example, soil layer 1 (usually the surface layer) has a soil type 3.

When setting the equation number, layer 1 is assigned an equation number of 1, and soil type 3 is assigned an equation number of 2. SHAKE2000 will use equation number 1 to compute the modulus for layer 1. You don't need to specify an equation number for each soil type and/or every soil layer. SHAKE2000 will not modify the shear moduli values you entered in the Option 2 edit form if an equation is not specified.

The coefficients for the equations used can be saved in an ASCII file by using the **Save** command button. The save file dialog box will be displayed, requesting that you enter the name of the file and the directory path where the file is to be stored. It is recommended that you use the *.GMX extension. The **Open** command button is used to open an existing file that stores the coefficients for the equations. Files of type *.GMX are automatically shown on the File Name section. To open a file, highlight the file's name and then click on the **Ok** button, or double click on the file's name.

The **Layers** command button is used to switch between soil type and profile layers. By default, every time this form is displayed, it is set to enter data for the soil types. This button changes to **Soil** when the form is set to accept data for the profile layers instead.

As required by SHAKE2000, the unit weights entered in Option 2 are total unit weights. Thus, to obtain the effective vertical stress we need total unit weights and the depth to the water table. To specify the depth to the water table from the surface of the ground, click on the check box next to the **Enter depth to water Table** label. Use the *Tab* key or the mouse to place the cursor on the text box next to this label, and enter the depth. If you click on the check box but do not enter a value, then a value of 0.0 feet or meters will be used for the depth, i.e. the water table is at the surface. If the water table check box is not selected, then SHAKE2000 assumes that a water table is not being used in the calculation of effective stresses, i.e. the soil column is unsaturated.

Once you have entered the coefficients for the equations, click on the **Return** command button to return to the Option 2 Edit form. To compute the shear moduli, click on the **Gmax** command button. The computed shear moduli will be displayed on the **Shear Moduli** column. Before computing the shear moduli, you need to enter all of the data used to define the soil profile, i.e., the soil type, thickness, unit weights, and shear wave velocity, if needed. SHAKE2000 will compute the effective vertical stress to the mid point of the soil layer, using the thickness, unit weights of the layers above each layer, and the depth to water table entered in the bottom frame of this form.

To display the rows for the following soil types, or layers, use the scroll bar. The bar is disabled when entering data in any of the text boxes, but it is enabled when the cursor is moved out of the box.

For example, to compute the maximum shear moduli for those layers having a soil type 2, use equation number 1; and for the half space layer, say layer no. 30, use equation number 2. Click on the **GmaxEq** button to open the **Shear Moduli Equations** form. Place the cursor on the **Eq. No.** column for soil no. 2. Type in a 1, and then use the *Tab* key to move to the $\mathbf{K_{2max}}$ column. Equation 1 uses as variables K_{2max}, the effective vertical stress, and K_o. Thus, you need to enter the values for K_{2max} and K_o. SHAKE2000 will calculate the vertical stress based on the unit weights and layer thickness entered in the form for Option 2. Enter the value for K_{2max}, and then use the *Tab* key again to move to the $\mathbf{K_o}$ column. Type in the value for K_o. Click on the **Layers** button to switch to the layer's form. Click on the **Next** command button until layer 30 is shown on the **Layers** column. Place the cursor on the **Eq. No.** column and type a 2. Click on the check box next to the **Enter depth to water Table** label, and then move the cursor to the text box next to it. Enter a value for the depth to the water table. To compute the maximum shear moduli, click on the **Return** button to return control to the Option 2 form. Click on the **Gmax** button. You will be asked if you wish to continue with the calculation of the maximum shear moduli. Click on **Yes**. The maximum shear moduli for those layers having a soil type no. 2 and for the half space layer will be computed and shown on the **Shear Moduli** column.

Please note that Equation 2 does not need any additional variables. It uses the shear wave velocity and unit weight that you should enter on the form for Option 2.

The equations available in SHAKE2000 to estimate G_{max} are:

Equation No. 1: $G_{max} = 1000\,K_{2\max}\left(\sigma_m\right)^{1/2}$

where:

G_{max}	=	maximum shear modulus
K_{2max}	=	maximum soil modulus coefficient
σ_m	=	effective mean principle stress
σ_m	=	$\left(\dfrac{1+2K_o}{3}\right)\sigma'_v$
K_o	=	at-rest earth pressure coefficient
σ'_v	=	effective vertical stress

Variables: K_{2max}, K_o, σ'_v

Reference: Seed, H.B.; Wong, R.T.; Idriss, I.M. and Tokimatsu, K. (1986).

Equation No. 2: $G_{max} = \left(\dfrac{\gamma}{g}\right)\left(V_s\right)^2$

where:

G_{max}	=	maximum shear modulus
γ	=	soil unit weight
g	=	acceleration of gravity
V_s	=	shear wave velocity

Variables: γ, V_s (data for these variables are entered in the Option 2 form).

Reference: Seed, H.B.; Wong, R.T.; Idriss, I.M. and Tokimatsu, K. (1986).

Equation No. 3: $G_{max} = 65\,N$

where:

G_{max}	=	maximum shear modulus
N	=	N-value measured in SPT test

Variables: N

Reference: Seed, H.B.; Idriss, I.M. and Arango, I. (1983).

Equation No. 4: G_{max} = $$2000\,S_u$$

where: G_{max} = maximum shear modulus

S_u = undrained shear strength

Variables: S_u **(in lb/ft^2 for English units; or, in kN/m^2 for SI units)**.

Reference: Seed, H.B. and Idriss, I.M. (1970); Egan, J.A. and Ebeling, R.M. (1985).

Equation No. 5: G_{max} = $$1000\left[35\left(N_{60}\right)^{0.34}\right]\left(\sigma_v^{'}\right)^{0.4}$$

where: G_{max} = maximum shear modulus

N_{60} = N-value measured in SPT test delivering 60% of the theoretical free fall energy of the drill rod

σ'_v = effective vertical stress

Variables: N_{60}, σ'_v

Reference: Seed, H.B.; Wong, R.T.; Idriss, I.M. and Tokimatsu, K. (1986).

Equation No. 6: G_{max} = $$1000\left[20\left(N_{1,60}\right)^{1/3}\right]\left(\sigma_m\right)^{1/2}$$

where: G_{max} = maximum shear modulus

$N_{1,60}$ = N-value measured in SPT test delivering 60% of the theoretical free fall energy of the drill rod, and corrected for an effective overburden pressure of 1 ton/square foot

σ_m = effective mean principle stress

$$\sigma_m = \left(\frac{1+2K_o}{3}\right)\sigma_v^{'}$$

K_o = at-rest earth pressure coefficient

σ'_v = effective vertical stress

Variables: $N_{1,\,60}$, K_o, σ'_v

Reference: Seed, H.B.; Wong, R.T.; Idriss, I.M. and Tokimatsu, K. (1986).

Equation No. 7: G_{max} = $$\left[\frac{2630}{1+e}\right]\left(2.17-e\right)^2\left(\sigma_m\right)^{1/2}$$

where: G_{max} = maximum shear modulus for round-grained sands

e = void ratio

σ_m = average effective confining pressure

$$\sigma_m = \left(\frac{1+2K_o}{3}\right)\sigma_v^{'}$$

K_o = at-rest earth pressure coefficient

σ'_v = effective vertical stress

Variables: e, K_o, σ'_v

Reference: Das, B.M. (1993).

Equation No. 8: G_{max} = $$\left[\frac{1230}{1+e}\right]\left(2.97-e\right)^2\left(\sigma_m\right)^{1/2}$$

where: G_{max} = maximum shear modulus, for angular-grained sands

e = void ratio

σ_m = average effective confining pressure

	σ_m	=	$\left(\frac{1+2K_o}{3}\right)\sigma_v^{'}$
	K_o	=	at-rest earth pressure coefficient
	σ'_v	=	effective vertical stress
Variables:	e, K_o, σ'_v		
Reference:	Das, B.M. (1993).		

Equation No. 9: G_{max} = $$\left[\frac{1230}{1+e}\right](2.97-e)^2\,(OCR)^k\,(\sigma_m)^{1/2}$$

where:	G_{max}	=	maximum shear modulus for clays of moderate sensitivity
	e	=	void ratio
	OCR	=	overconsolidation ratio
	k	=	a parameter related to the plasticity index (PI)

PI (%)	k
0	0
20	0.18
40	0.30
60	0.41
80	0.48
100	0.5

	σ_m	=	average effective confining pressure
	σ_m	=	$\left(\frac{1+2K_o}{3}\right)\sigma_v^{'}$
	K_o	=	at-rest earth pressure coefficient
	σ'_v	=	effective vertical stress
Variables:	e, OCR, k, K_o, σ'_v		
Reference:	Das, B.M. (1993).		

Equation No. 10: G_{max} = $$1634(q_c)^{0.25}\left(\sigma_v^{'}\right)^{0.375}$$

where:	G_{max}	=	maximum shear modulus for quartz sand.
	q_c	=	CPT tip resistance
	σ'_v	=	effective vertical stress
Variables:	q_c, σ'_v (**q_c should be provided in MPa for either English or SI units**).		
Reference:	Kramer, S.L. (1996).		

Equation No. 11: G_{max} = $$406(q_c)^{0.695}\,e^{-1.13}$$

where:	G_{max}	=	maximum shear modulus for clay
	q_c	=	CPT tip resistance
	e	=	void ratio
Variables:	q_c, e (**q_c should be provided in MPa for either English or SI units**).		
Reference:	Kramer, S.L. (1996).		

Equation No. 12: G_{max} = $$\left[\frac{G_e(\gamma_e=0.5\%)}{\sigma}\right]\sigma_v$$

where: $\left[\frac{G_e(\gamma_e = 0.5\%)}{\sigma}\right]$ = Equivalent Shear Moduli for Geomembrane:

HDPE/clay (dry)	47
HDPE/clay (wet)	63
Textured HDPE/clay (dry)	58
HDPE/geogrid	43
HDPE/Gundseal	35
HDPE/geotextile	36
HDPE/Ottawa sand	52
PVC/Gundseal	58
PVC/geotextile	57

(Above values from Table 1 of Yegian et al., 1998). Enter the value for the Equivalent Shear Moduli in the **Geqv** column of the **Shear Moduli Equations** form. The Normalized Equivalent Shear Modulus and Equivalent Damping Ratio Curves for Geomembranes are included in the shakey2k.mat file.

σ_v = Overburden pressure at the elevation of the liner

Variables: σ_v, $\left[\frac{G_e(\gamma_e = 0.5\%)}{\sigma}\right]$

Reference: Yegian, M.K.; Harb, J.N. and Kadakal, U. (1998).

Equation No. 13: $G_{max} = 325(N_{60})^{0.68}$

where: G_{max} = maximum shear modulus

N_{60} = Measured N-value, corrected for hammer efficiency of 60%

Variables: N_{60}

Reference: Imai, T. and Tonouchi, K. (1982).

Equation No. 14: $G_{max} = a\,N^b$

where: G_{max} = maximum shear modulus

a, b = constants (**a is the constant for equation in MPa**). Values of a & b are provided in the reference by Anbazhagan et al. (2012).

N = N (Measured N-value); or, N_{60} (corrected for hammer efficiency of 60%); or, $N_{60,cs}$ (corrected for hammer efficiency of 60% and fines content).

Variables: a, b, N

Reference: Anbazhagan, P., Aditya Parihar, and H.N. Rashmi (2012)

Equation No. 15: $V_s = 30\,(N_{60})^{0.215}\,(\sigma'_v)^{0.275}\,ASF$

where: V_s = Shear wave velocity

$G_{max} = \left(\frac{\gamma}{g}\right)(V_s)^2$

G_{max} = maximum shear modulus

N_{60} = N-value measured in SPT test delivering 60% of the theoretical free fall energy of the drill rod

σ'_v = effective vertical stress

ASF = 0.87 (Holocene) or 1.13 (Pleistocene)
Variables: N_{60}, ASF (assumed equal to 1 if none entered)
Reference: All Soils - Wair et al. (2012).

Equation No. 16: V_s = $$26\,(N_{60})^{0.17}\,(\sigma'_v)^{0.32}\,ASF$$

where: V_s = Shear wave velocity

G_{max} = $\left(\frac{\gamma}{g}\right)(V_s)^2$

G_{max} = maximum shear modulus

N_{60} = N-value measured in SPT test delivering 60% of the theoretical free fall energy of the drill rod

σ'_v = effective vertical stress

ASF = 0.88 (Holocene) or 1.12 (Pleistocene)

Variables: N_{60}, ASF (assumed equal to 1 if none entered)

Reference: Clays & Silts - Wair et al. (2012).

Equation No. 17: V_s = $$30\,(N_{60})^{0.23}\,(\sigma'_v)^{0.23}\,ASF$$

where: V_s = Shear wave velocity

G_{max} = $\left(\frac{\gamma}{g}\right)(V_s)^2$

G_{max} = maximum shear modulus

N_{60} = N-value measured in SPT test delivering 60% of the theoretical free fall energy of the drill rod

σ'_v = effective vertical stress

ASF = 0.90 (Holocene) or 1.17 (Pleistocene)

Variables: N_{60}, ASF (assumed equal to 1 if none entered)
Reference: Sands - Wair et al. (2012).

Equation No. 18: V_s = $$53\,(N_{60})^{0.19}\,(\sigma'_v)^{0.18}$$

where: V_s = Shear wave velocity

G_{max} = $\left(\frac{\gamma}{g}\right)(V_s)^2$

G_{max} = maximum shear modulus

N_{60} = N-value measured in SPT test delivering 60% of the theoretical free fall energy of the drill rod

σ'_v = effective vertical stress

Variables: N_{60}
Reference: Gravels - Holocene - Wair et al. (2012).

Equation No. 19: V_s = $$115\,(N_{60})^{0.17}\,(\sigma'_v)^{0.12}$$

where: V_s = Shear wave velocity

G_{max} = $\left(\frac{\gamma}{g}\right)(V_s)^2$

G_{max} = maximum shear modulus

N_{60} = N-value measured in SPT test delivering 60% of the theoretical free fall energy of the drill rod

	σ'_v	=	effective vertical stress
Variables:	N_{60}		
Reference:	Gravels - Pleistocene - Wair et al. (2012).		

Equation No. 20: $V_s = \left[118.8\log\left(f_s\right)+18.5\right]ASF$

where:	V_s	=	Shear wave velocity
	G_{max}	=	$\left(\frac{\gamma}{g}\right)\left(V_s\right)^2$
	G_{max}	=	maximum shear modulus
	f_s	=	CPT sleeve friction resistance
	ASF	=	0.92 (Holocene) or 1.12 (Pleistocene)
Variables:	f_s (**f_s should be provided in MPa for either English or SI units**), ASF		
Reference:	Mayne (2006) as referenced in Wair et al. (2012).		

Equation No. 21: $V_s = \left[2.62\, q_t^{\,0.395}\, I_c^{\,0.912}\, D^{0.215}\right]ASF$

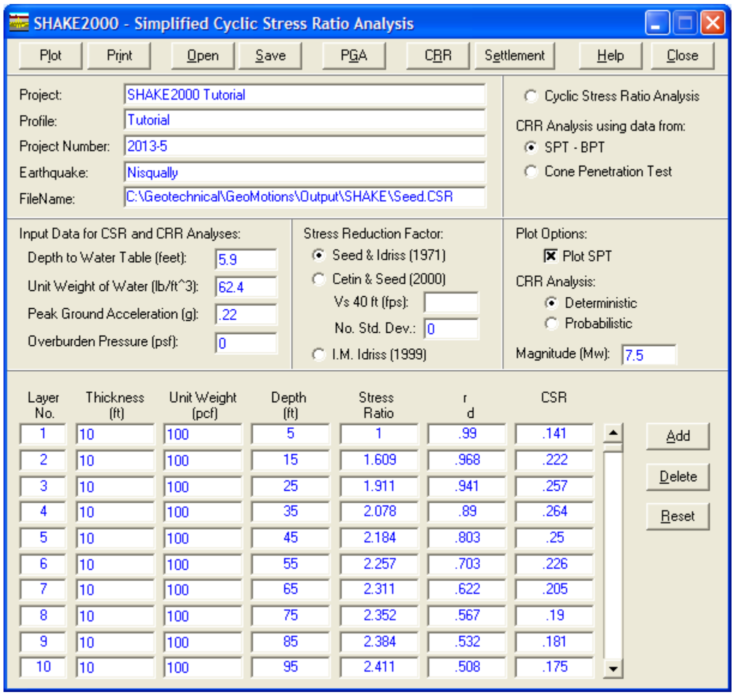
where:	V_s	=	Shear wave velocity
	G_{max}	=	$\left(\frac{\gamma}{g}\right)\left(V_s\right)^2$
	G_{max}	=	maximum shear modulus
	q_t	=	CPT total cone tip resistance
	I_c	=	Soil behavior type index
	D	=	Depth
	ASF	=	0.92 (Holocene) or 1.12 (Pleistocene)
Variables:	q_t (**q_t should be provided in MPa for either English or SI units**), I_c, ASF (assumed equal to 1 if none entered)		
Reference:	Andrus et al. (2007) as referenced in Wair et al. (2012).		

Equation No. 22: $V_s = \left[\left(10^{(0.55 I_c + 1.68)}\left(q_t - \sigma_v\right)/\,P_a\right)\right]^{0.5} ASF$

where:	V_s	=	Shear wave velocity
	G_{max}	=	$\left(\frac{\gamma}{g}\right)\left(V_s\right)^2$
	G_{max}	=	maximum shear modulus
	q_t	=	CPT total cone tip resistance
	I_c	=	Soil behavior type index
	σ_v	=	total vertical stress
	ASF	=	0.92 (Holocene) or 1.12 (Pleistocene)
Variables:	q_t (**q_t should be provided in MPa for either English or SI units**), I_c, ASF (assumed equal to 1 if none entered)		
Reference:	Robertson (2009) as referenced in Wair et al. (2012).		

In SHAKE2000, the input data for each equation is converted to the appropriate system of units, and the result for G_{max} is also converted if necessary. If you would like to use any of the above equations separately, please review the corresponding references for more detailed information on the data and units required for each equation.

Simplified Cyclic Stress Ratio Analysis



This form is used to evaluate the Cyclic Stress Ratio (CSR) induced by an earthquake, using the simplified equation proposed by Seed and Idriss (1971):

$$CSR = 0.65 a_{\max} \frac{\sigma_{vo}}{\sigma'_{o}} r_d$$

Where: a_{max} = peak horizontal acceleration at ground surface generated by the earthquake (in g's).
σ_{vo} = total vertical overburden stress.
σ'_o = effective vertical overburden stress.
r_d = stress reduction factor.

Four options to estimate the stress reduction factor are provided. The **Seed & Idriss (1971)** option uses the equation provided in Youd and Idriss (1997):

$$r_d = \frac{1 - 0.4113 z^{0.5} + 0.04052 z + 0.001753 z^{1.5}}{1 - 0.4177 z^{0.5} + 0.05729 z - 0.006205 z^{1.5} + 0.00121 z^{2}}$$

An improved graph of r_d vs. depth has been recently proposed by Cetin and Seed (2000, 2004) and can be selected by clicking on the **Cetin & Seed (2000)** option. This option uses the mean curve shown in Figure 3b of Cetin et al. (2004). The third option for r_d uses the equation provided by Cetin et al. (2004) for calculation of r_d as a function of depth, magnitude (M_w), peak ground surface acceleration (a_{max}), and the average shear wave velocity over the top 40 feet (or ≈12 meters) of a site ($V_{s,40'}$). To use this equation, first click on the **Cetin & Seed (2000)** radio button and enter a value for $V_{s,40'}$ in the **Vs top 40 feet (fps)** (or **12 m (m/s)**) text box, and a value for M_w in the **Magnitude (Mw)** text box. A value for standard deviation can be entered in the **No. Std. Dev.** Text box.

A fourth option for r_d, **Idriss (1999)**, uses the equations provided by Idriss, I.M. (Idriss, I.M., 1999; Idriss & Boulanger, 2004, 2006, 2008) based on moment magnitude. For this option, you need to enter a value for magnitude in the text box next to the **Magnitude** label. When using this r_d option, the earthquake magnitude entered in the **Magnitude** text box will be used in the CRR analysis using SPT, CPT or V_s data. Further, the user will not be able to change the magnitude value in the SPT, CPT or V_s forms.

For depths greater than 100 feet ($\approx$30.5 meters), the value of r_d will be set to 0.5 when using the Seed & Idriss option. To conform to the method applied in the computation of CRR, the r_d options are enabled/disabled based on the data used (i.e. SPT, CPT or V_s).

The analysis is performed for a soil column formed by layers. Each layer is represented by its thickness (in feet or meters), and the total unit weight of the soil (in lbs/ft^3 or kN/m^3). To perform the analysis, the user needs to enter values for a_{max}, depth to water table, and the thickness and unit weight for the different layers that form the soil column. SHAKE2000 will compute the CSR at the midpoint of the soil layer and show it on the **CSR** column.

A default value of 62.4 lb/ft^3 or 9.81 kN/m^3 for the unit weight of water is used. If you would like to use a different value, enter the new unit weight in the **Unit Weight of Water** text box.

First, enter information regarding the analysis you will be conducting. When first displaying the form, the cursor is placed on the **Project** text box. Enter a description for the project, up to 60 characters, and press the *Tab* key to move the cursor to the **Profile** text box. Type in a brief (up to 24 characters) description for the soil column. Press the *Tab* key or move the cursor to the **Project Number** text box and enter up to 24 characters for the number of your project, if any. Place the cursor on the **Earthquake** text box and type in a description of the earthquake record you are using for the analysis, if any. Some of this information is automatically entered by SHAKE2000 if you are using this form together with a SHAKE2000 analysis.

Place the cursor on the **Peak Ground Acceleration (g's)** text box and enter a value for the peak horizontal acceleration at ground surface generated by the earthquake (in g's; e.g. 0.25). This value can also be estimated using the ground motion prediction equations included with SHAKE2000. To do this, click on the **PGA** command button to display the **Ground Motion Prediction Equations** form. Select an attenuation relation, enter the values for magnitude, depth, and select other options for the attenuation relation. Then click on the **Plot** command button of the form to display the acceleration attenuation curve. Once the curve is plotted, click on the symbol for the distance of interest (or the closest distance value) to display the values in the X Y cells of the graphics window. Then click on the **Close** command button to return to the **Ground Motion Prediction Equations** form, and then on **Ok** to return to this form. The value for the peak ground acceleration will be displayed in the text box. Please note that this value of PGA may need to be corrected to represent the value at your site. For example, most ground motion prediction equations provide values of PGA for rock outcrops. Thus, it would be necessary to modify this value to obtain the PGA for a soil site.

When conducting analyses using SPT data, a surcharge or approach fill can be added on top of the soil column by entering its value in the **Overburden Pressure** text box. This overburden load will not be considered when conducting analyses using CPT data. The increase in overburden pressure will be accounted for in the computation of CSR and CRR. However, as recommended in the ATC/MCEER (2003) the normalization of the SPT data will be done considering only the effective stress profile that existed at the time the test was conducted. In other words, the increase in overburden pressure created by the fill will not be considered when normalizing the SPT data.

Next, press the *Tab* key to move the cursor to the **Depth to groundwater** text box, and enter the depth to the water table (in feet or meters). SHAKE2000 uses this depth to compute the effective vertical stress at the midpoint of the soil layer. In order to use a common depth to the water table when conducting different analyses simultaneously (e.g. SPT and CPT), the depth to water table can only be changed either on this form or on the **Calculated Results Plot Menu** form.

Move the cursor to the first blank cell of the **Thickness** column. As noted, the analysis is conducted for a soil column divided in layers. Enter the thickness (in feet or meters) for the layer and press the *Tab* key to move the cursor to the **Unit Weight** text box. Values of depth, stress radio, r_d, and CSR for a point at the middle of the soil layer will be computed and shown in their respective columns. The stress ratio value is the ratio of the total vertical overburden stress to the effective vertical overburden stress. Enter the value for the total unit weight for the soil in this layer. Although values of unit weight less than the unit weight of water are accepted by the program, the user should be aware that this may result in negative CSR values below the groundwater elevation which may not be realistic. The values for stress ratio and CSR will be recalculated and updated. After you have entered all the data necessary, click on the **Plot** command button to display the CSR curve.

Each time you place the cursor on either the **Thickness** or **Unit Weight** column the **Add** and **Delete** command buttons are enabled. If you want to add data for a layer, place the cursor on the layer where the new layer will be located, and click on the **Add** button. A new layer will be created, and the thickness and unit weight for the new layer will be the same as those for the layer immediately below. Values for depth, stress ratio, r_d, and CSR will be calculated and shown in their respective columns. Now, you need to modify the values for thickness and unit weight for the new layer. The **Delete** button is used to delete a layer from the soil column. Place the cursor on either the **Thickness** or **Unit Weight** column and then click on the **Delete** button. The data for the layer will be removed from the soil column, and the values for the other layers updated accordingly.

Cyclic resistance ratio (CRR) values, or the capacity of the soil to resist liquefaction, can be computed using standard penetration test (SPT), Becker penetration test (BPT), cone penetration test (CPT), or shear wave velocity (V_s) data.

To use SPT or BPT data, first click on the **SPT - BPT** option. Then click on the **CRR** command button to display the **Cyclic Resistance Ratio using SPT** form. Please refer to the **Cyclic Resistance Ratio using Standard Penetration Test (SPT) Data** section of this manual for further information. Updated correlations for the evaluation of liquefaction using SPT data have been recently presented by Cetin et al. (1999, 2004) and Seed et al. (2001, 2003). This updated approach also includes a probabilistic evaluation of liquefaction. This alternative approach can be used to evaluate liquefaction potential by first clicking on the **Probabilistic** check box to select it. Further information on this approach is included in the **Probabilistic and Deterministic Liquefaction Analysis Using SPT** section of this manual. Please note that when using this approach, the **Cetin & Seed (2000)** option for r_d is selected by default. This is to conform to the methodology presented in the references.

If a standard liquefaction analysis using SPT or BPT data has been conducted and if you select the probabilistic option, then the option to plot the results from the SPT/BPT analysis will be deselected. You will then need to conduct the SPT/BPT analysis again if you either plan to use the probabilistic approach or the more traditional method. For this reason, it is important that you save the data for the SPT/BPT analysis using the **Save** feature on the SPT form. Further, the **Idriss (1999)** option for calculation of r_d is disabled when conducting a CRR analysis. This is to conform to the methodology recommended in the references.

Selection of the **Cone Penetration Test** option will display the **Cyclic Resistance Ratio using CPT** form used to estimate the cyclic resistance ratio, or the capacity of the soil to resist liquefaction, based on cone penetration test data. Please refer to the **Cyclic Resistance Ratio using Cone Penetration Test (CPT) Data** section of this manual for further information. When using CPT data you may or may not enter data for the simplified CSR, i.e. the data in this form.

The **Plot Options** are enabled and automatically selected after their respective analyses have been conducted. If you don't want to plot the CRR curve together with the CSR curve, then deselect the corresponding option by clicking on the check box.

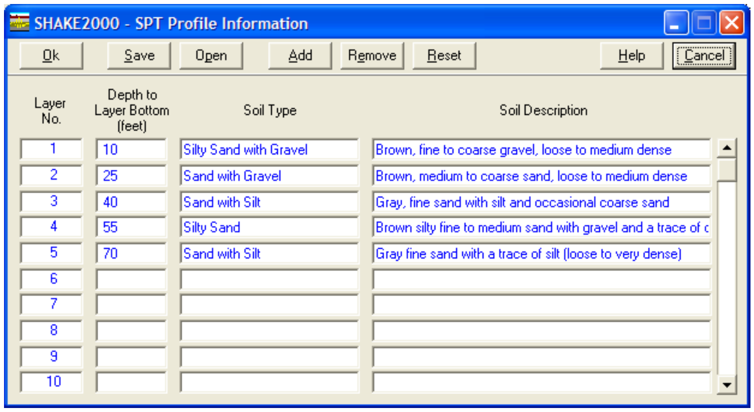
The **Settlement** command button is enabled after you have performed the CRR analysis with SPT-BPT data. This button will open the **Settlement Analysis** form used to enter the data necessary to estimate the settlement in the soil column due to earthquake shaking. The input data used in the liquefaction analysis (i.e. $N_{1,60}$, CSR) and the results (e.g. factor of safety against liquefaction) are used to do the settlement analysis. You can also perform a settlement analysis for a soil column of dry soil; however you still need to use the **Cyclic Resistance Ratio** forms to enter the SPT or BPT data for the column, and make sure that the depth to the water table is greater than the depth to the bottom layer of the soil column.

The **Print** command button is used to print the results of the cyclic stress ratio analysis as a table. When you click on the command button, the **Print Menu** form is displayed. For the different print options, see the **Print Menu** section of the User's Manual.

The results for the cyclic stress ratio analysis can be saved on an ASCII file using the **Save** command button. The file uses the *.CSR extension by default. The **Open** command button can be used to retrieve these data from the file.

A plot of CSR vs. depth can be obtained by clicking on the **Plot** command button. If any of the **Plot Options** is selected, then this curve will also be plotted. The curve of factor of safety vs. depth can be plotted by clicking on the **FSL** command button of the main graphics window.

Soil Profile Information



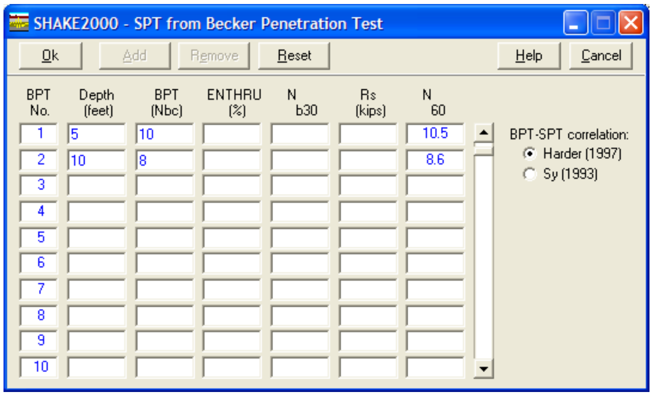
This form is used to enter information to create a soil column that will be displayed with the data input and the results of the liquefaction analysis using SPT, BPT, CPT or V_s data. The soil column is made up of layers, and for each layer, you need to enter the depth to the bottom of the layer and a description for the soil type on the layer. You can enter data for up to 50 different layers.

To enter the data, first place the cursor on the text box for the **Depth to Layer Bottom** column and type in the depth to the bottom of the layer (e.g. 10.5). Next, press the *Tab* key once to move the cursor to the text box for the **Soil Type** column and type in a short (up to 24 characters) description of the soil that forms the layer (e.g. Silty Sand with Gravel). Move the cursor to the text box for the **Soil Description** column and enter a longer description for the soil in the layer (e.g. Brown, loose to medium dense, wet, some organics, etc.). Depending on the space allowed for printing on each layer, SHAKE2000 will display first the information entered in the **Soil Type** column, and then display the information entered in the **Soil Description** column. If there is not enough space to display the information (i.e. the space is even smaller than the font size used for the text), then no information will be shown.

After you have entered the information for each layer, click on the **Save** command button to save the information on an ASCII text file. You can retrieve the information for future use with the **Open** command button. To return to the previous form, click on the **Ok** command button.

Each time you place the cursor on the **Depth**, **Soil Type** or **Soil Description** column the **Add** and **Delete** command buttons are enabled. If you want to add data for a layer, place the cursor on the layer where the new layer will be located, and click on the **Add** button. A new layer will be created, and the depth, type and description for the new layer will be the same as those for the layer immediately below. Now, you need to modify the information for the depth, type and description for the new layer. The **Delete** button is used to delete a layer from the soil column. Place the cursor on the **Depth**, **Soil Type** or **Soil Description** column and then click on the **Delete** button. The data for the layer will be removed from the soil column, and the information for the other layers updated accordingly. The **Reset** command button will delete the information for all of the soil layers.

SPT from Becker Penetration Test (BPT) Data



This form is used to estimate equivalent SPT N_{60} values given Becker Penetration Test (BPT) blow counts using either the correlation proposed by L. F. Harder (Youd et al., 1997, 2001) or by A. Sy and R.G. Campanella (Sy and Campanella, 1994). These data can then be used to conduct a liquefaction analysis based on SPT values as described in the **Cyclic Resistance Ration using Standard Penetration Test (SPT) Data** section of this manual.

To use this form, first select a correlation between SPT and BPT by clicking on one of the **BPT-SPT correlations** options. The **Harder (1997)** option uses the correlation originally developed by Harder and Seed (Harder and Seed, 1986) and later updated by Harder (Harder, L.F. as edited in Youd et al., 1997) with data from additional tests. This correlation uses Becker blow count corrected to a reference combustion condition, N_{BC}, obtained from the chart of measured BPT blow count vs. Bounce Chamber Pressure (see Figure 2 of Sy and Campanella, 1994; or, Figure 4, pp. 143 of Youd, et al., 1997). Accordingly, the BPT value used in this form for the **Harder (1997)** option is the corrected BPT blow count obtained from the field measured BPT and Bounce Chamber Pressure chart.

The second option, **Sy (1993)**, uses the correlation between BPT and SPT presented in Sy and Campanella (1994). This correlation is based on BPT blow counts normalized to a 30% reference energy level, N_{b30}, and total shaft resistance, R_s. The normalized blow count is obtained from:

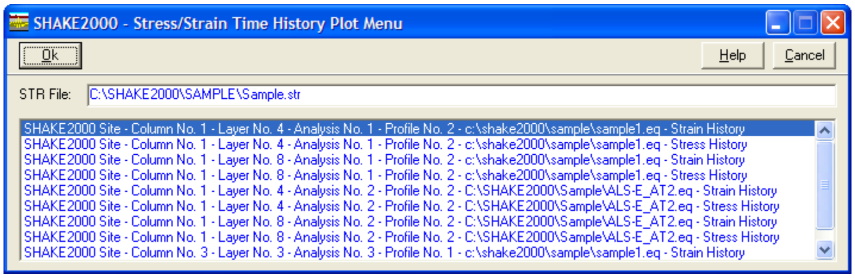
$$N_{b30} = N_b \frac{ENTHRU}{30}$$

Where, N_b = measured BPT blow count
ENTHRU = measured maximum transferred energy expressed as percentage of the rated hammer energy of 11.0 kJ.

After selecting a BPT-SPT correlation, place the cursor on the text box for the **Depth** column and enter the depth at which the BPT was measured (in feet or meters). Press the *Tab* key once and enter the blow count value in the **BPT** column. As noted before, the blow count value for the **Harder (1997)** option is the BPT blow count corrected to a reference combustion condition; and, for the **Sy (1993)** option, the value used is the measured BPT blow count, N_b. Press the *Tab* key to move the cursor to the next data column. If using the **Harder (1997)** option, the cursor will be placed on the next depth text box and the equivalent corrected SPT blow count value shown in the $\mathbf{N_{60}}$ text box. For the **Sy (1993)** option, the cursor will be placed on the **ENTHRU** text box. Enter the value for ENTHRU and press the *Tab* key to place the cursor on the $\mathbf{R_s}$ text box. In this box enter the value for the total shaft resistance in kips or kN, and press the *Tab* key to move the cursor to enter the data for the next BPT blow count.

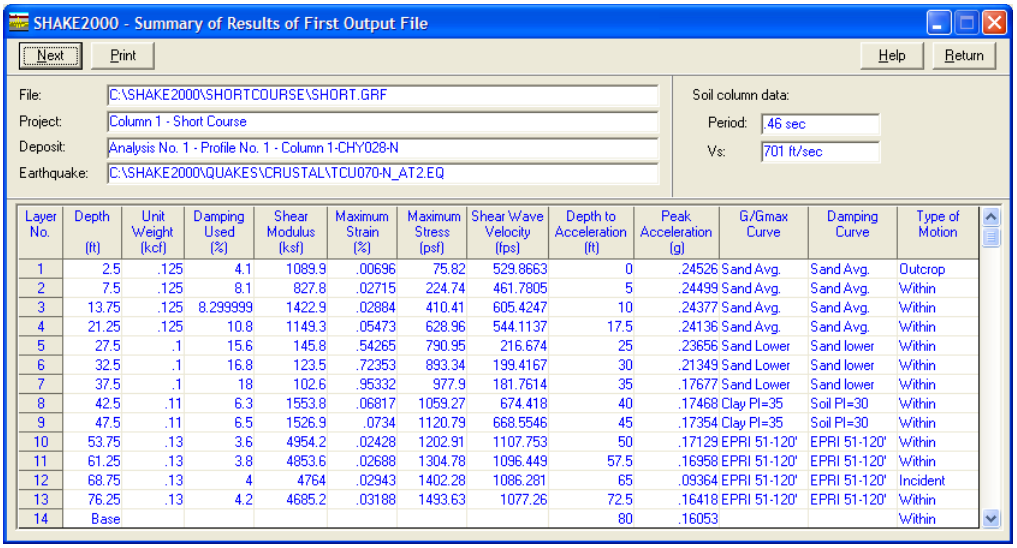
After entering the data for the BPT blow counts, click on the **Ok** command button to return to the **Cyclic Resistance Ration using Standard Penetration Test (SPT) Data** form.

Stress/Strain Time History Plot Menu



A list of the different plots is displayed on this window. To select a plot, click on it, and then click on the **Ok** button. Alternatively, you can double click on the plot. The **Cancel** button is used to return to the graph window without choosing a plot.

Summary of Results of First Output File



SHAKE2000 - Summary of Results of First Output File

Next Print Help Return

File: C:\SHAKE2000\SHORTCOURSE\SHORT.GRF
Project: Column 1 - Short Course
Deposit: Analysis No. 1 - Profile No. 1 - Column 1-CHY028-N
Earthquake: C:\SHAKE2000\QUAKES\CRUSTAL\TCU070-N_AT2.EQ

Soil column data:
Period: .46 sec
Vs: 701 ft/sec

Layer No.	Depth (ft)	Unit Weight (kcf)	Damping Used (%)	Shear Modulus (ksf)	Maximum Strain (%)	Maximum Stress (psf)	Shear Wave Velocity (fps)	Depth to Acceleration (ft)	Peak Acceleration (g)	G/Gmax Curve	Damping Curve	Type of Motion
1	2.5	.125	4.1	1089.9	.00696	75.82	529.8663	0	.24526	Sand Avg.	Sand Avg.	Outcrop
2	7.5	.125	8.1	827.8	.02715	224.74	461.7805	5	.24499	Sand Avg.	Sand Avg.	Within
3	13.75	.125	8.299999	1422.9	.02884	410.41	605.4247	10	.24377	Sand Avg.	Sand Avg.	Within
4	21.25	.125	10.8	1149.3	.05473	628.96	544.1137	17.5	.24136	Sand Avg.	Sand Avg.	Within
5	27.5	.1	15.6	145.8	.54265	790.95	216.674	25	.23656	Sand Lower	Sand lower	Within
6	32.5	.1	16.8	123.5	.72353	893.34	199.4167	30	.21349	Sand Lower	Sand lower	Within
7	37.5	.1	18	102.6	.95332	977.9	181.7614	35	.17677	Sand Lower	Sand lower	Within
8	42.5	.11	6.3	1553.8	.06817	1059.27	674.418	40	.17468	Clay PI=35	Soil PI=30	Within
9	47.5	.11	6.5	1526.9	.0734	1120.79	668.5546	45	.17354	Clay PI=35	Soil PI=30	Within
10	53.75	.13	3.6	4954.2	.02428	1202.91	1107.753	50	.17129	EPRI 51-120'	EPRI 51-120'	Within
11	61.25	.13	3.8	4853.6	.02688	1304.78	1096.449	57.5	.16958	EPRI 51-120'	EPRI 51-120'	Within
12	68.75	.13	4	4764	.02943	1402.28	1086.281	65	.09364	EPRI 51-120'	EPRI 51-120'	Incident
13	76.25	.13	4.2	4685.2	.03188	1493.63	1077.26	72.5	.16418	EPRI 51-120'	EPRI 51-120'	Within
14	Base							80	.16053			Within

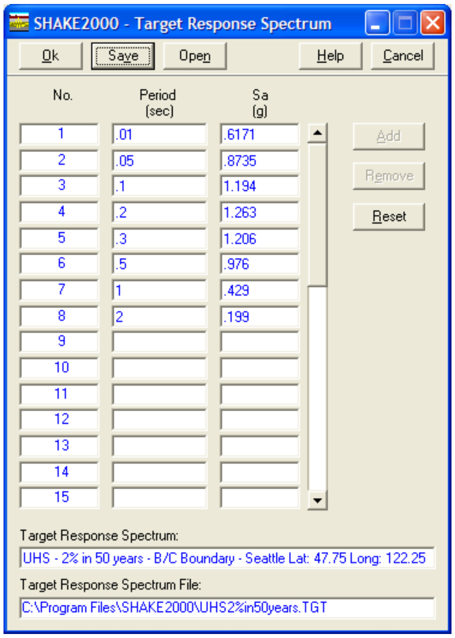
This form displays the main results obtained from processing the first output file generated by SHAKE. The results are stored in the *.GRF file in the output directory.

The results are grouped in sets called **Analysis**, and given a number according to the sequential order they had in the output file. Summary information on the different options that form each analysis group, is saved in an ASCII file identified with the *.ANZ extension, and saved in the same directory as the other output files.

If more than one analysis was conducted, then the **Next** button will be enabled. Click on this button to display the results of the following analyses.

The results can be sent to the printer by using the **Print** command button. The **Print Menu** form will be displayed.

Target/User Defined Response Spectrum



This form is used to enter either the target response spectrum values for a user-defined spectrum that can be plotted together with other spectra or spectra values used with the Ratio of Response Spectrum analysis. You need to enter a value for the period in seconds, and a value for the spectra values in the appropriate dimensions.

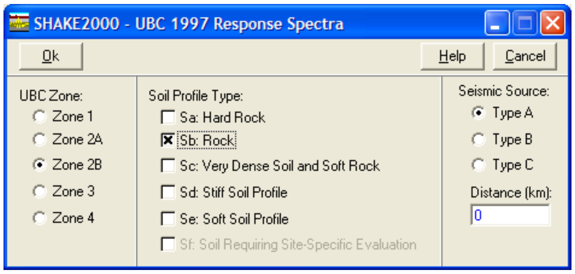
To enter the data, first place the cursor on the text box for the **Period** column and type in the value. Next, press the *Tab* key once to move the cursor to the text box for the **PSV**, **Sa** or **Spectral Value** column and type in the value for the spectra.

An alternative way of entering the data is to use one of the standard spectra available in SHAKE2000. The form used to define one of the standard spectra can be displayed by clicking on the **Attenuate**, **EuroCode**, **IBC**, or **NEHRP** command button. For example, clicking on the **Attenuate** command button will display the **Ground Motion Prediction Equations** form. In this form, select one attenuation relation, enter the parameters or select the options used by the attenuation relation, and then click on the **Plot** command button. You need to plot the spectra to calculate the values. This also helps you determine if the spectrum is the one you want to use.

After plotting the spectra, click on the **Ok** command button to return to this form. The periods and spectra values will be shown on the data cells of the form. A description of the spectrum will be shown on the text box below the **Target Response Spectrum** label. This description can be modified/entered manually by placing the cursor in the text box and typing in the desired information. After you have entered the information for each period-spectra pair, click on the **Ok** command button to return to the previous form.

Each time you place the cursor on either the period or spectral value columns the **Add** and **Delete** command buttons are enabled. If you want to add data for a new period-spectra pair, place the cursor on the period where the new values will be located, and click on the **Add** button. A new period-spectra pair will be created, and the values for the new pair will be the same as those for the pair immediately below. Now, you need to modify the information for the period and spectral value. The **Delete** button is used to delete a pair from the table. Place the cursor on the period or spectral value column and then click on the **Delete** button. The data for the pair will be removed from the table, and the information for the other pairs updated accordingly. The **Reset** command button will delete all the information on the table. The **Save** command button is used to save the data in a text file for future use. These data can be retrieved using the **Open** command button.

UBC 1997 Response Spectra

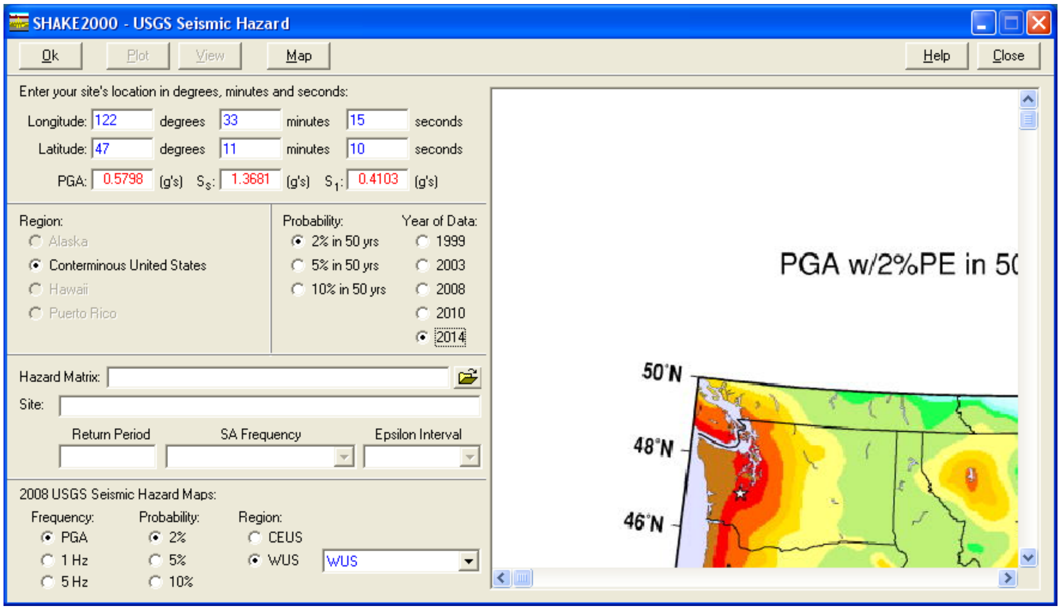


This form is used to select design spectra using the 1997 Uniform Building Code (UBC) method (ICBO, 1997).

To select a spectrum, first, select a zone from the **UBC Zone** options to determine the zone factor (Z). Next, select the spectra you would like to plot by clicking on the check boxes next to the different **Soil Profile Type** options. Note that the **Ok** button is enabled when at least one site type is checked. Then, click on the **Ok** button to return to the **Response Spectrum Plot Menu** form.

When you select the **UBC Zone 4** option, the spectra will be computed using the seismic source selected in the **Seismic Source** options, and the distance entered in the **Distance (km)** text box.

U.S. Geological Survey Seismic Hazard



This form is used to retrieve the Peak Ground Acceleration from the files of gridded points used to make the 1996/1999 USGS National Seismic Hazard Maps (Frankel et al., 1996), and for the updates of some of these maps in 2002-2003 and 2008 (Frankel et al., 2002; U.S. Geological Survey, 2003a and 2003b; 2008, 2014); and also, to plot the results of the seismic hazard deaggregation for a site in the Conterminous United States.

For more information, to view or to download these maps, visit the USGS web site at:

http://earthquake.usgs.gov/hazards/products/

The files used in SHAKE2000 are for PGA with 2%, 5%, or 10% probability of exceedance in 50 years for the Conterminous United States, Alaska, Hawaii and Puerto Rico. The original files are approximately 80 Mb in size. For SHAKE2000, the files have been reprocessed and reduced to a more manageable size, and are installed in the **USGSmaps** subdirectory. Please note that the program uses two sets of maps.

To obtain the PGA, enter the latitude and longitude of your site in degrees, minutes and seconds, and then select one of the **Region** options, and any of the **Probability of Exceedance** options. There is no need to enter a negative sign for the longitude. The values of PGA, S_s and S_1 for each of the four points that surround your site are retrieved from the files, and if necessary, the values interpolated between the four grid points. The values are displayed in the corresponding text boxes.

For the 2008 and 2014 options, the program uses the data files available at:

http://earthquake.usgs.gov/hazards/products/conterminous/2008/data/

http://earthquake.usgs.gov/hazards/products/conterminous/2014/data/

The USGS interactive deaggregation website is located at:
http://geohazards.usgs.gov/deaggint/2008/

On this web site the seismic hazard deaggregation for a site in the Conterminous United States can be conducted. The results of this analysis are provided graphically, and also as an ASCII file. The data on this text file are used by

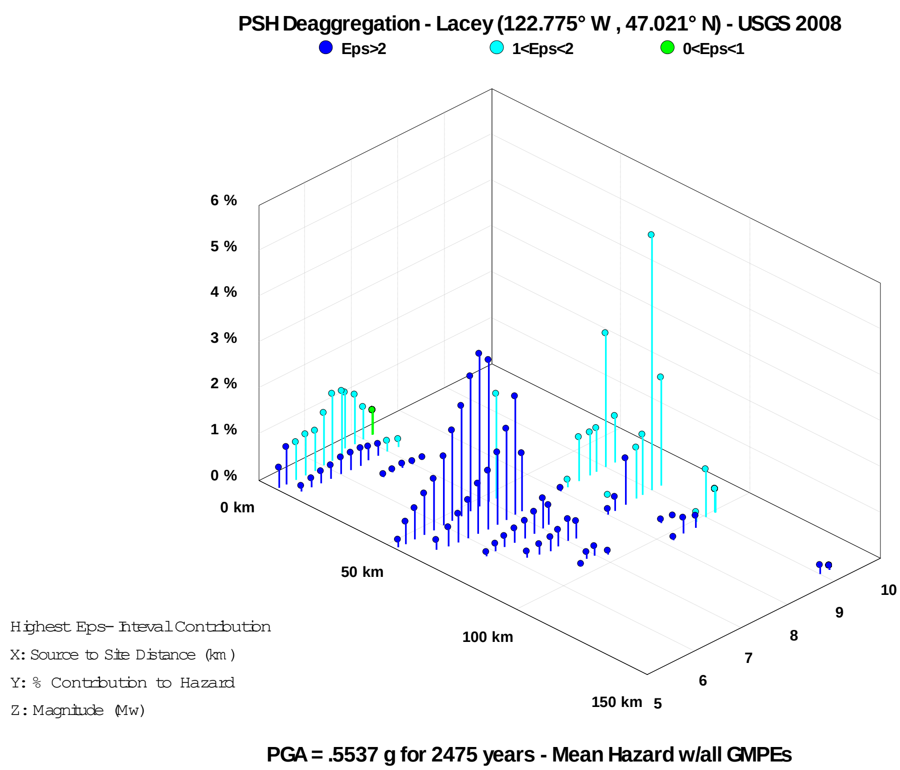
SHAKE2000 to obtain a plot of the deaggregated distance, magnitude and ground-motion uncertainty for the specified parameters.

Once the file is displayed, use the **Save As** command of the **File** menu option in your browser to save the file to your hard drive. The file should be saved as a text file, thus, the **Text File (*.txt)** option should be shown on the **Save as type** box of the file dialog form.

On the **USGS Seismic Hazard form** of SHAKE2000, click on the command button next to the **Hazard Matrix** text box to display the **USGS Hazard Matrix** file dialog form. Switch to the folder where the file is saved, click on the file to select it, and then click on the **Open** command button to retrieve the data.

After opening the file, some information about the site and the return period is shown on the respective text boxes. Data for several SA frequencies are included in this file. A list of the available SA frequencies in the file is shown by clicking on the down-arrow of the **SA Frequency** combo list; or, **PGA** list when using the 2008 deaggregation results. When using the 2008 deaggregation results, the list will show the list of ground motion prediction equations listed in the hazard matrix file. The options on the **Epsilon Interval** list are used to create plots for the different hazard columns at each distance-magnitude (R, M) bin location. Once you have selected a frequency and epsilon interval, click on the **Plot** command button to display the seismic hazard deaggregation graph.

For example, when using the **Highest Eps** option, the plot of the results from the 2008 deaggregation of PGA for all of the ground motion prediction equations is shown below.



Please note that different colors are used for the graph bars. These colors represent the interval of epsilon (from the hazard matrix file) that contributes the most to that pair. For example, a section of the results from the hazard matrix file for the above graph are shown below.

```
*** Deaggregation of Seismic Hazard at One Period of Spectral Accel. ***
*** Data from U.S.G.S. National Seismic Hazards Mapping Project, 2008 version ***
PSHA Deaggregation. %contributions. site: Lacey long: 122.775 W., lat: 47.021 N.
 Vs30(m/s)= 760.0 (some WUS atten. models use Site Class not Vs30).
NSHMP 2007-08  See USGS OFR 2008-1128. dM=0.2 below
```

```
Return period: 2475  yrs. Exceedance PGA =0.5537   g. Weight * Computed_Rate_Ex 0.403E-03
#Pr[at least one eq with median motion>=PGA in 50 yrs]=0.00011
#This deaggregation corresponds to Mean Hazard w/all GMPEs
DIST(KM) MAG(MW) ALL_EPS EPSILON>2  1<EPS<2 0<EPS<1 -1<EPS<0 -2<EPS<-1 EPS<-2
    7.3    5.05    0.631    0.437    0.194    0.000    0.000    0.000    0.000
   53.2    5.05    0.162    0.162    0.000    0.000    0.000    0.000    0.000
……
……
…..
…..
   62.4    9.00    4.569    0.733    2.918    0.918    0.000    0.000    0.000
   80.2    9.00    7.338    1.788    5.550    0.000    0.000    0.000    0.000
  101.0    9.00    1.663    0.628    1.036    0.000    0.000    0.000    0.000
  145.1    9.00    0.200    0.200    0.000    0.000    0.000    0.000    0.000
   62.4    9.20    1.791    0.245    1.003    0.543    0.000    0.000    0.000
   80.2    9.20    3.040    0.597    2.354    0.089    0.000    0.000    0.000
  101.0    9.20    0.738    0.228    0.510    0.000    0.000    0.000    0.000
  145.1    9.20    0.106    0.086    0.020    0.000    0.000    0.000    0.000

Summary statistics for above PSHA PGA  deaggregation, R=distance, e=epsilon:
Contribution from this GMPE(%):  100.0
 Mean src-site R=   52.4 km; M= 7.23; eps0=   1.52. Mean calculated for all sources.
Modal src-site R=   80.2 km; M= 9.00; eps0=   1.20 from peak (R,M) bin
 MODE R*=  80.2km; M*= 9.00; EPS.INTERVAL: 1 to 2 sigma  % CONTRIB.=  5.550
Modal-source dmetric: distance to rupture surface (Rrup or Rcd)

Principal sources (faults, subduction, random seismicity having > 3% contribution)
Source Category:                 % contr.  R(km)    M   epsilon0 (mean values).
Cascadia M8.3-M8.7 Floating         7.44    77.8   8.53    1.54
Cascadia Megathrust               23.04    77.8   9.02    1.15
WUS Compr crustal gridded         10.87     8.3   6.12    1.11
50-km Deep Intraplate             43.46    59.5   6.61    1.99
Puget Lowlands gridded            14.13     7.8   6.31    0.94
Individual fault hazard details if its contribution to mean hazard > 2%:
Fault ID                         % contr.   Rcd(km)  M   epsilon0 Site-to-src azimuth(d)
#*********End of deaggregation corresponding to Mean Hazard w/all GMPEs  *********#
```

For this example, the pair with the highest epsilon-interval contribution corresponds to an M_w 9.0 event at a distance of 80.2 km (highlighted in yellow). For this particular pair, the maximum contribution of 5.55 is for the 1<Eps<2 level (highlighted in light blue). Accordingly, for this pair a light blue color will be used when creating the graph.

The **View** command button can be used to view the contents of a hazard matrix file. The first lines of the file will be displayed on a form, with the first characters displayed in red representing the numbers of each row of data in the file followed by a "|". These characters are not part of the file and are only shown to number the rows.

The **Ok** button will return you to the **Main Menu** form.

If any of the options is disabled or results for any of the parameters are not shown on the respective text box, this is due to the maps for this option or for these parameters not being available from the USGS.

To display a USGS Seismic Hazard map, click on the appropriate frequency, probability or region option and then click on the **Map** command button.

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Conversion Factors

Length

To convert from	To	Multiply by
Inches (in)	Feet	0.083333
	Centimeters	2.54
	Meters	0.0254
Feet (ft)	Inches	12.0
	Centimeters	30.48
	Meters	0.3048
Meters (m)	inches	39.370079
	feet	3.2808399
	centimeters	100

Area

To convert from	To	Multiply by
Square meters (m^2)	Square feet	10.76387
	Square centimeters	10000
	Square inches	1550.0031
Square feet (ft^2)	Square meters	0.09290304
	Square centimeters	929.0304
	Square inches	144
Square centimeters (cm^2)	Square meters	0.0001
	Square feet	0.001076387
	Square inches	0.1550031
Square inches (in^2)	Square meters	0.00064516
	Square feet	0.0069444
	Square centimeters	6.4516

Volume

To convert from	To	Multiply by
Cubic centimeters (cm^3)	Cubic meters	1×10^{6}
	Cubic feet	3.5314667×10^{-5}
	Cubic inches	0.061023744
Cubic meters (m^3)	Cubic feet	35.314667
	Cubic centimeters	1000000
	Cubic inches	61023.74
Cubic inches (in^3)	Cubic meters	1.6387064×10^{-5}
	Cubic feet	5.787037×10^{-4}
	Cubic centimeters	16.387064
Cubic feet (ft^3)	Cubic meters	0.028316847
	Cubic centimeters	28316.847
	Cubic inches	1728

Force

To convert from	To	Multiply by
Pounds (lb)	grams	453.59243
	kilograms	0.45359243
	Tons (short)	5×10^{-4}
	kips	1×10^{-3}
	Newtons	4.44822
Kips	Pounds	1000
	Tons (short)	0.5
	kilograms	453.59243
Tons (short) (T)	kilograms	907.18474
	pounds	2000

Force (continues)

To convert from	To	Multiply by
Tons (short) (T)	Kips	2
Kilograms (kg)	grams	1000
	pounds	2.2046223
	Tons (short)	11.023113×10^{-4}
	kips	2.2046223×10^{-3}
	newtons	9.80665
Kilonewtons (kN)	pounds	224.81
	Tons (short)	0.1124
	kips	0.22481
	kilograms	101.97

Stress and Pressure

To convert from	To	Multiply by
Pounds/square foot (lb/ft^2)	Pounds/square inch	0.0069445
	Kips/square foot	1×10^{-3}
	Kilograms/square centimeter	0.000488243
	Tons/square meter	0.004882
	atmospheres	4.72541×10^{-4}
	Kilonewtons/square meter (kilopascals)	0.04788
Pounds/square inch (lb/in^2)	Pounds/square foot	144
	Kips/square foot	0.144
	Kilograms/square centimeter	0.070307
	Tons/square meter	0.70307
	atmospheres	0.068046
	Kilonewtons/square meter	95.76
Tons (short)/square foot (T/ft^2)	atmospheres	0.945082
	Kilograms/square meter	9764.86
	Pounds/square inch	13.8888
	Pounds/square foot	2000
	Kips/square foot	2.0
	Kilonewtons/square meter	95.76
Kips/square foot (ksf)	Pounds/square inch	6.94445
	Pounds/square foot	1000
	Tons (short)/square foot	0.5
	Kilograms/square centimeter	0.488244
	Kilonewtons/square meter	47.88
Kilograms/square centimeter (kg/cm^2)	Pounds/square inch	14.223
	Pounds square foot	2048.1614
	Feet of water (4^oC)	32.8093
	Kips/square foot	2.0481614
	Tons/square meter	10
	atmospheres	0.96784
	Kilonewtons/square meter	98.067
Atmospheres	bars	1.0133
	Kilograms/square centimeter	1.03323
	Grams/square centimeter	1033.23
	Kilograms/square meter	10332.3
	Pounds/square foot	2116.22
	Pounds/square inch	14.696
	Tons (short)/square foot	1.0581
	Kilonewtons/square meter	101.325

Stress and Pressure (continues)

To convert from	To	Multiply by
Kilonewtons/square meter (kPa)	Pounds/square foot	20.886
	Pounds/square inch	0.145
	Tons (short)/square foot	0.01044
	Meters of water	0.1020
	Kips/square foot	0.02089
	Kilograms/square centimeter	0.01020
	Bars	0.01
	MegaPascals	0.001
	atmospheres	0.00987

Unit Weight

To convert from	To	Multiply by
Grams/cubic centimeter (g/cm^3)	Kilograms/cubic meter	1000.0
	Pounds/cubic inch	0.036127292
	Pounds/cubic foot	62.427961
	Kilonewtons/cubic meter	9.8039
Kilograms/cubic meter (kg/m^3)	Grams/cubic centimeter	0.001
	Pounds/cubic inch	3.6127292×10^{-5}
	Pounds/cubic foot	0.062427961
	Kilonewtons/cubic meter	9.80584×10^{-3}
Pounds/cubic inch (lb/in^3)	Grams/cubic centimeter	27.679905
	Kilograms/cubic meter	27679.905
	Pounds/cubic foot	1728
	Kilonewtons/cubic meter	271.37
Pounds/cubic foot (lb/ft^3)	Grams/cubic centimeter	0.016018463
	Kilograms/cubic meter	16.018463
	Pounds/cubic inch	$5.78703704 \times 10^{-4}$
	Kilonewtons/cubic meter	0.157099
Kilonewtons/cubic meter (kN/m^3)	Grams/cubic centimeter	0.1020
	Kilograms/cubic meter	101.98
	Pounds/cubic inch	0.003685
	Pounds/cubic foot	6.3654

Velocity

To convert from	To	Multiply by
Centimeter/second (cm/sec)	Meters/second	0.01
	Feet/second	0.032808399
	Feet/minute	1.9685039
Feet/second (fps)	Meters/second	0.30479999
	Feet/minute	60.0
	Centimeters/second	30.48
Meters/second (m/sec)	Feet/second	3.2808399
	Feet/minute	196.850394
	Centimeters/second	100.0
Feet/minute	Centimeters/second	0.508001
	Meters/minute	0.3048