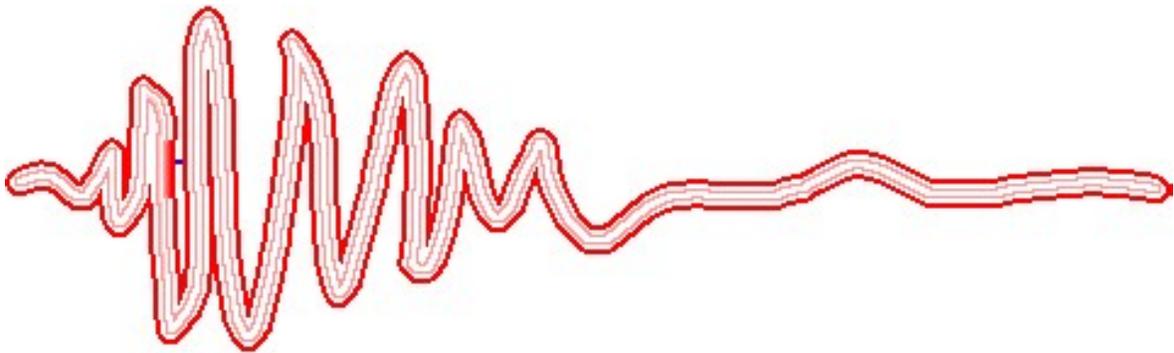


# ProShake

**Ground Response Analysis Program**

**Version 2.0**



**User's Manual**

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## INTRODUCTION

### PROSHAKE

ProShake is a powerful, user-friendly computer program for one-dimensional, equivalent linear ground response analysis. Written completely from scratch, ProShake includes numerous features to make data entry, analysis, viewing and documenting of results efficient and effective, including built-in modulus reduction and damping models, graphical display of soil profile and input motion parameters, graphical display of a wide variety of output parameters, and animation of ground response.

ProShake is organized into three "managers" - an Input Manager, a Solution Manager, and an Output Manager. The Input Manager allows entry of soil profile and input motion data. The Solution Manager performs iterative equivalent linear analyses while tracking the process of convergence toward strain-compatible soil properties. The Output Manager allows easy plotting of results in the form of time histories, response spectra, parameter profiles, and animations. A series of other parameters can also be computed.

ProShake also includes useful Report feature, as a file in Microsoft® Word® format, that automatically records the conditions of each analysis in tabular form. All ProShake plots can be copied to the Report and saved for subsequent editing in Word.

ProShake has been shown to produce results virtually identical to those produced by SHAKE91 and closed form solutions - but the process of entering data, running the analysis, and plotting the results is approximately 50 times faster with ProShake!

### WHAT'S NEW

ProShake 2.0 incorporates numerous enhancements over ProShake 1.12. This is only a short list of the enhancements:

- Completely redesigned user interface with extensive plotting options in the Input and Output Managers.
- Works on all new versions Microsoft® Windows® OS, Windows Vista® or higher.
- Uses Microsoft® Excel® and Word® format files for input data/results/output and report, respectively.
- Can analyze multiple soil profiles within the same project (analysis).
- Graphical display of profile and properties during data entry.
- New soil models with option for strength-compatible modulus reduction curves.
- Data filtering for efficient examination and plotting of analysis results.

- Exporting of ground motion animations as Flash files for stand-alone viewing or insertion into presentations.

## GETTING STARTED

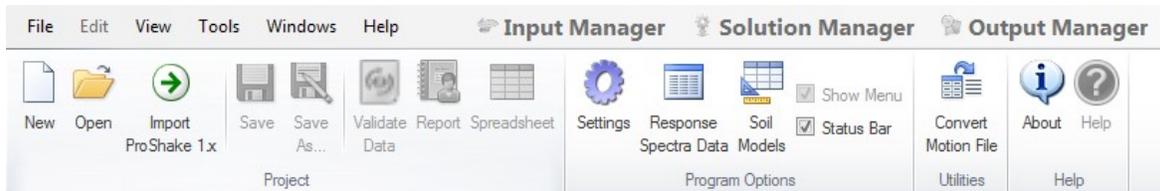
### SYSTEM REQUIREMENTS

#### HARDWARE AND SOFTWARE REQUIREMENTS

<b>Hardware Requirements</b>	
Machine	Minimum: 1.9GHz clock speed processor Recommended: dual processor
Memory	Minimum: 2GB of RAM Recommended: 4GB RAM or more
Display	Minimum: 1024 x 768 screen resolution; Recommended: 1600x1200
Hard Disk	Minimum: 500 MB free hard disk space Recommended: 5GB free hard disk space
NET version	NET 4.0 Client Profile required

## PROGRAM FUNCTIONS

Several functions are common to all three managers, and appear in a ribbon of graphical icons across the top of the ProShake form. Several of these, e.g., New, Open, Save, Save As, are common functions to all Windows programs and do not require explanation here.



Other functions are specific to ProShake 2.0 and allow various forms of data to be specified and preferences to be set. These functions are described below.

**Import ProShake 1.x:** The Import button allows users to open an existing ProShake 1.x file in ProShake 2.0. All of the appropriate ProShake 2.0 fields will be filled, and the file can then be modified at the user's option and then saved as a ProShake 2.0 file.

**Validate Data:** The Validate Data button will initiate a check of the input data in a project file. Any missing data will be flagged and noted in the Messages tab on the right side of the screen.

**Report:** The Report button opens the ProShake report, a Word format file that contains a tabular summary of all relevant input data (project data, profile data, ground motion data). The report with basic data is automatically generated, but all plots of input and output data can be added to it with a single click. More information on this file is presented on page 32.

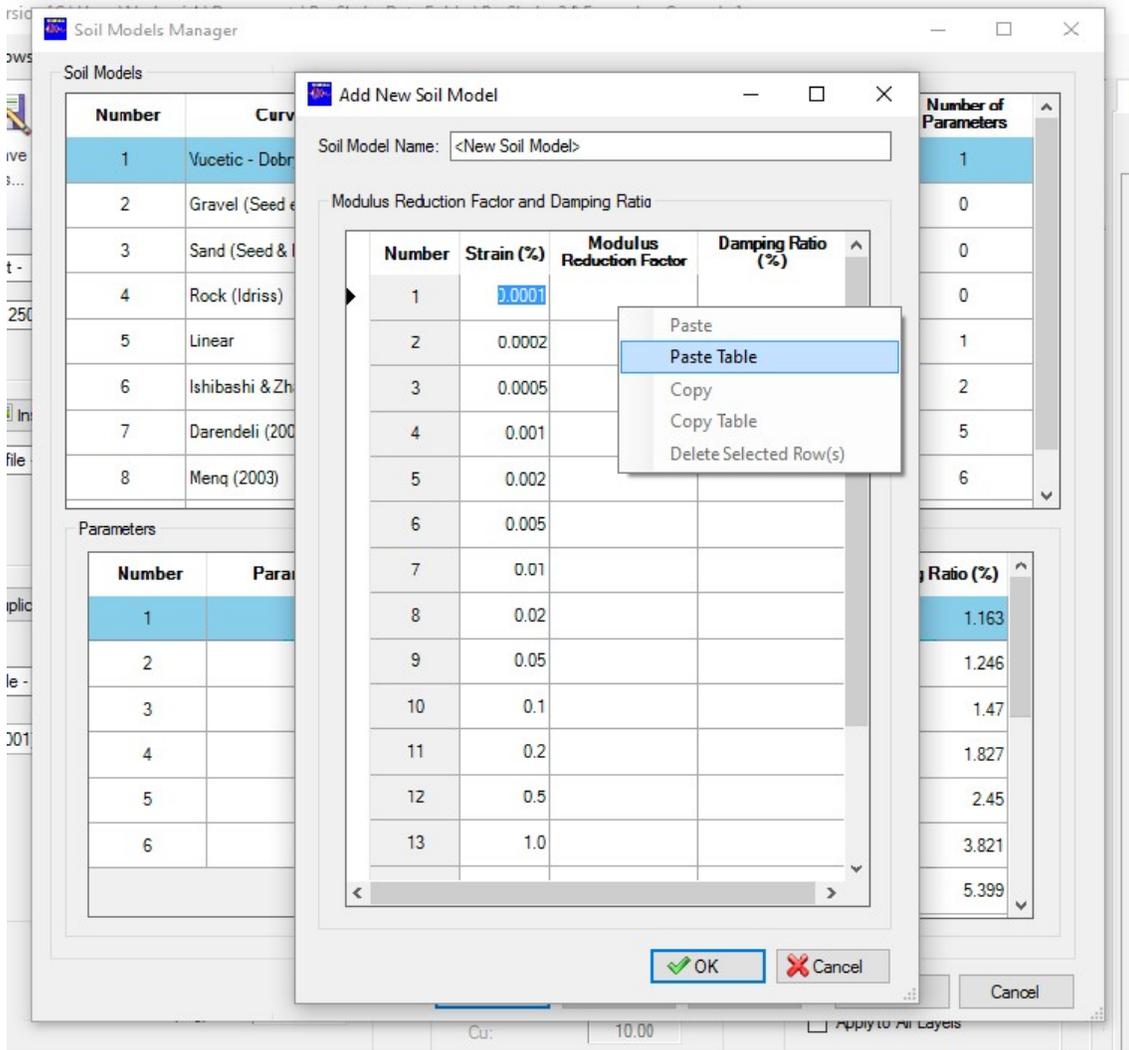
**Spreadsheet:** The Spreadsheet button opens the ProShake spreadsheet, an Excel format file that contains input and output data on a series of worksheets (Input Data, Exported Data, Exported Charts, User Worksheet, and a separate output worksheets for each soil profile). The spreadsheet contains all input data, and all data exported to the spreadsheet from the Input and Output Managers. More information on this file is presented on page 32.

**Settings:** The Settings button exposes two tabs that allow specification of important information. The first, labeled Default Folders, allows the user to specify the paths to a required file – the Program Data File, which contains basic information common to all analyses – and the locations of two folders: the folder where input/output files are stored, and the folder where ground motions are stored. Upon installation, default locations for these folders will be established, but this tab allows those locations to be changed by the user. The second tab, labeled Chart Style, allows the user to control the visual appearance of the graphical plots in the Input and Output Managers. Two basic styles are available – one with a white background, and one with the traditional ProShake 1.x color scheme. Alternate background and line colors can be changed and saved by the user.

**Response Spectrum Data:** The Response Spectrum Data button displays three tabs that allow specification of the periods at which spectral ordinates are to be computed, specification of a target spectrum that can be displayed along with spectra from individual motions, and specification of damping ratios (default is 5%) for which spectral ordinates are to be computed. If the data in is Excel or tab separated columns, the user can copy and right-click in ProShake 2.0, and then select the "Paste Table" menu item to paste the data. The

copied range in Excel should have same number of columns as the input data items in ProShake 2.0, in that order.

**Soil Models:** The Soil Models button allows examination of modulus reduction and damping data for the built-in models that ProShake comes with, and allows the user to add new models to the suite of built-in models. Highlighting any of the models in the upper portion of the Soil Models form will display the discrete data points that define the modulus reduction and damping curves. Some models, such as Darendeli, are defined by algebraic equations so discrete data points are not displayed. The Add button at the bottom of the Soil Models form allows the user to define a new soil model that will subsequently appear with the other soil models in a drop-down list in the Input Manager. The user must provide a name for the new model and a series of discrete modulus reduction ratio and damping ratio points at a user-specified number of strain levels. When adding new models, if the data is in Excel or tab separated columns, the user can copy and right-click in ProShake 2.0 and select the "Paste Table" menu item to paste the data. The copied range in Excel should have 3 columns - strain (in percent), modulus reduction ratio, and damping ratio (in percent), in that order.



**Show Menu:** Toggles display of the menu (commands at very top of form) on and off.

**Show Status Bar:** Toggles display of the status bar (displayed at very bottom of form) on and off.

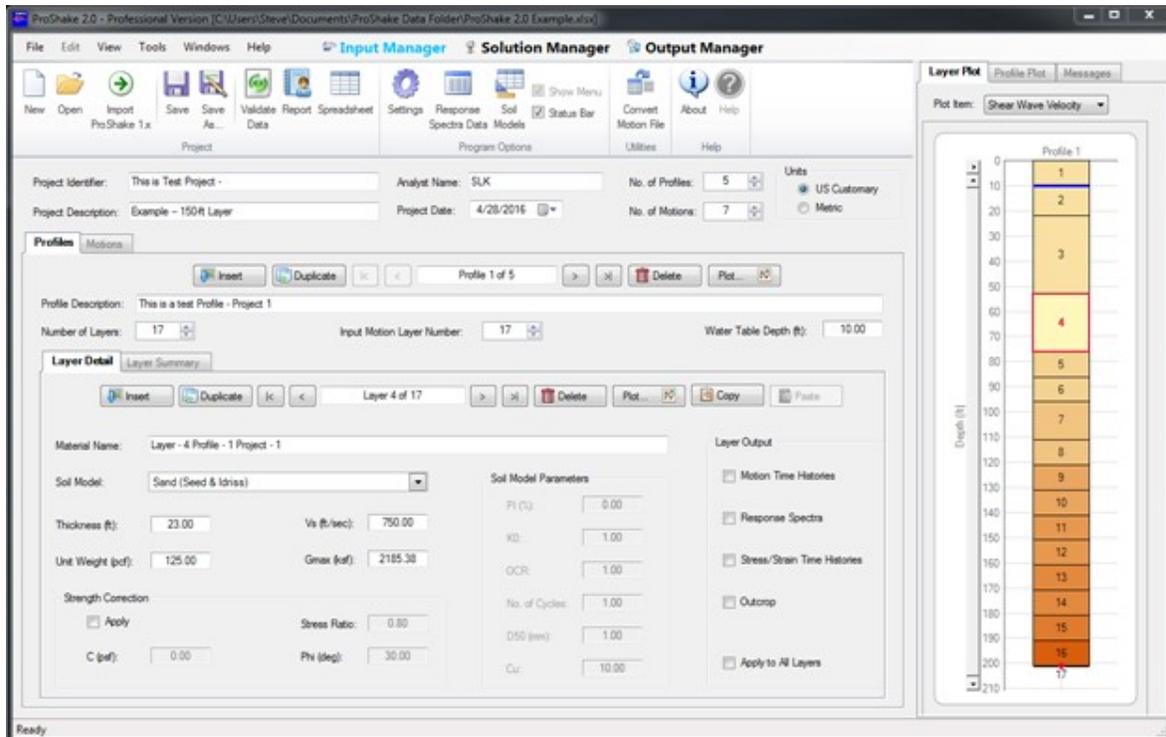
**Convert Motion File:** ProShake 2.0 will automatically accept ProShake 1.x ground motion files and the \*.at2 format used in the PEER NGA ground motion database. For motions with other formats, the Convert Motion File button allows the user to convert the motion to ProShake format. Conversion requires the user to provide the following information about the motion to be converted: filename, number of header lines, number of acceleration values, time step (sec), and units of acceleration. If the file is in two-column format with the first column containing time values, a check box can be used to avoid having to reformat the file before conversion.

**About:** Displays basic program information

**Help:** Provides information about basic function of different controls within ProShake; information is essentially equivalent to that found in this user's manual.

## INPUT MANAGER

The Input Manager organizes the input data in the form of a Project, which can include multiple soil profiles. Each project will have Soil Profile Data and Ground Motion Data. A new project will open in the Input Manager as shown below. Project-level data is entered in the upper portion of the form, profile-level data and input motion data are entered on tabs immediately below that, and layer-level data is entered on a tab in the lower portion of the form. As layer data is entered, the profile is illustrated graphically on the Layer Plot tab on the right side of the form.



## PROJECT DATA

The upper portion of the Input Manager screen allows the user to input project-level data. The project-level data applies to all soil profiles and all input motions.

**Project Identifier:** A short written text (maximum 255 characters) that identifies the project. The Project Identifier will be shown on subsequent forms to remind the user which project is being analyzed.

**Project Description:** The project description text box allows a longer (maximum 32627 characters) and more complete description of the project, analysis assumptions and other information can be entered to document the analysis.

**Analyst Name:** The name or initials of the person performing the analyses can be entered.

**Project Date:** The date on which the project was initialized or saved, as the user desires. Clicking on the caret to the right of the displayed date brings up a calendar that can be used to select a different date if desired.

**No. of Profiles:** Each project can include an unlimited number of soil profiles – the user-selected number of profiles is entered here.

**No. of Motions:** All profiles are subjected to the same set of input motions, the number of which is unlimited. The number of input motions to be used in the analyses is entered here.

**Units:** The units to be used are selected by the user – choices are U.S. Customary or Metric. The choice can be toggled back and forth as desired.

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## SOIL PROFILE DATA

Data specific to each soil profile is entered on the Profile tab. The upper portion of the Profiles tab allows entry of data that applies to a specific soil profile.

**Profile Navigation:** Navigation controls are located at the top of the Profile tab. At the center is a text box indicating the active soil profile. Immediately to the left and right of the center text box are navigation buttons that use standard notation to take the user to the previous (<) or next (>) profile, or to the first (|<) or last (>|) profile.

**Insert button:** The Insert button will insert a new blank profile immediately before the active profile. The number of profiles will be increased by one.

**Duplicate button:** The Duplicate button will insert a duplicate of the active profile, including layer data, immediately after the active profile. The number of profiles will be increased by one. The duplication feature is handy for sensitivity analyses in which a single input parameter is varied – a profile can be specified, duplicated, and the duplicate edited as desired.

**Delete button:** The Delete button will delete the active profile. The number of profiles will be decreased by one.

**Plot button:** The Plot button will plot pertinent soil profile variables such as shear wave velocity, maximum shear modulus, and unit weight.

**Profile Description:** A short written text (maximum 255 characters) describing the soil profile.

**Number of Layers:** Number of layers in the active soil profile. Note that the halfspace counts as a layer.

**Input Motion Layer No.:** The layer number that the input motion is to be applied to. The motion is applied at the top of the specified layer. In most cases, the input motion will be applied at the top of the halfspace, i.e. the last layer, but it is not required to do so. Note that the input motion layer number will not change when soil layers are added or deleted (except when the selection was the last layer and layer is deleted – in such cases, the selection will be set to the new last layer), so it is important to check the input motion layer number when such changes have been made.

**Water Table Depth:** Depth of the water table, used to compute vertical effective stresses.

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## LAYER DETAIL DATA

The Layer Detail tab is where the geometry and properties of each soil layer are defined. The user will likely spend more time entering data in this tab than anywhere else in the Input Manager.

**Layer Navigation:** Navigation controls are located at the top of the Layer Detail tab. At the center is a text box indicating the active soil layer. Immediately to the left and right of the center text box are navigation buttons that use standard notation to take the user to the previous (<) or next (>) layer, or to the first (|<) or last (>|) layer.

**Insert button:** The Insert button will insert a new blank layer immediately before the active layer. The number of layers will be increased by one.

**Duplicate button:** The Duplicate button will insert a duplicate of the active layer immediately after the active layer. The number of layers will be increased by one. The duplication feature can be handy for building a profile, particularly when multiple layers have the same properties.

**Delete button:** The Delete button will delete the active layer. The number of layers will be decreased by one.

**Plot button:** The Plot button will plot modulus reduction and damping curves, and the corresponding backbone (stress-strain) curve. The basic backbone curve is defined by  $\tau = G_{max}(G/G_{max})\gamma$  so its basic shape is controlled by the modulus reduction curve. Users should note that the large-strain portion of the modulus reduction curve, which is usually obtained as an extrapolation of resonant column data usually limited to shear strains less than about 1%, controls the apparent shear strength of the soil, and that extrapolated strength may not be realistic. If the user specifies strength parameters, the modulus reduction curve will be modified so that the shear stress approaches that strength asymptotically; the modification to both curves will be shown on these plots. Note that the strain axes for both plots is the same, and both can be plotted linearly or logarithmically.

**Copy Button:** Creates a reference to the current layer for pasting its data to another layer using the Paste button.

**Paste Button:** Pastes layer data from the marked layer using the Copy button to the current layer. One can copy data for an active layer, move to a different position in the soil profile, and then paste the copied layer data to the new active layer.

**Material Name:** Descriptive name for the soil material (maximum 255 characters)

**Soil Model:** Selected modulus reduction and damping curve. The program comes with nine modulus reduction and damping models, and additional models can be entered using the Soil Models button in the ribbon at the top of the screen.

**Thickness:** Layer thickness. When the layer thickness is entered, a graphic illustration of the soil profile will be displayed on the Layer Plot tab on the far right side of the screen. The thicknesses of the various layers will be plotted to scale to allow profile visualization and error checking.

**Unit Weight:** Unit weight of soil layer. Total unit weight should be entered – dry unit weight for dry soil, moist unit weight for partially saturated soil, and saturated unit weight for saturated soil.

**Vs:** Shear wave velocity of soil layer (if Gmax value and unit weight are entered, shear wave velocity will be automatically calculated). By default, the colors of the soil layers shown on the Layer Plot tab will reflect the shear wave velocity of each layer to aid in profile visualization and error checking. The colors of soil layers can be assigned to other variables by the user.

**Gmax:** Low-strain shear modulus of soil layer (if Vs and unit weight are entered, Gmax will be automatically calculated).

**Strength Correction:** Check box to be selected if modulus reduction curve is to be modified for consistency with user-specified shear strength. If not selected, backbone curve will be inferred entirely from Gmax and modulus reduction curve with no guarantee that large strain shear stresses will be consistent with shear strength of soil.

**c:** Cohesive strength of soil – assumed to be independent of vertical stress.

**Phi:** Friction angle of soil.

**Stress Ratio:** Fraction of strength at which backbone curve transitions from being controlled by modulus reduction curve (at low strain levels) to hyperbolic form. Transition is smooth and continuous, and can be visualized and changed on the modulus reduction/damping/backbone curve plot form.

**Soil Model Parameters:** Some of the available soil models (e.g., Darendeli, Vucetic-Dobry, etc.) require additional parameters such as plasticity index, overconsolidation ratio, etc. When those models are selected, text boxes for entry of additional parameters will become active. When models that don't require those parameters are selected, the text boxes will be inactive, i.e., grayed out.

**Layer Output** – ProShake can generate a tremendous amount of data, and writing that data to output files can be time-consuming and result in very large files. To allow the user to avoid generating more data than necessary,

**Outcrop** – compute response as outcropping layer (i.e., as though all soil above active layer was removed). Note that first layer will automatically be an outcropping layer since there is no soil above it.

**Motion Time Histories** – compute acceleration, velocity, and displacement history at top of active layer.

**Stress-Strain Time Histories** – compute shear stress and shear strain at center of active layer.

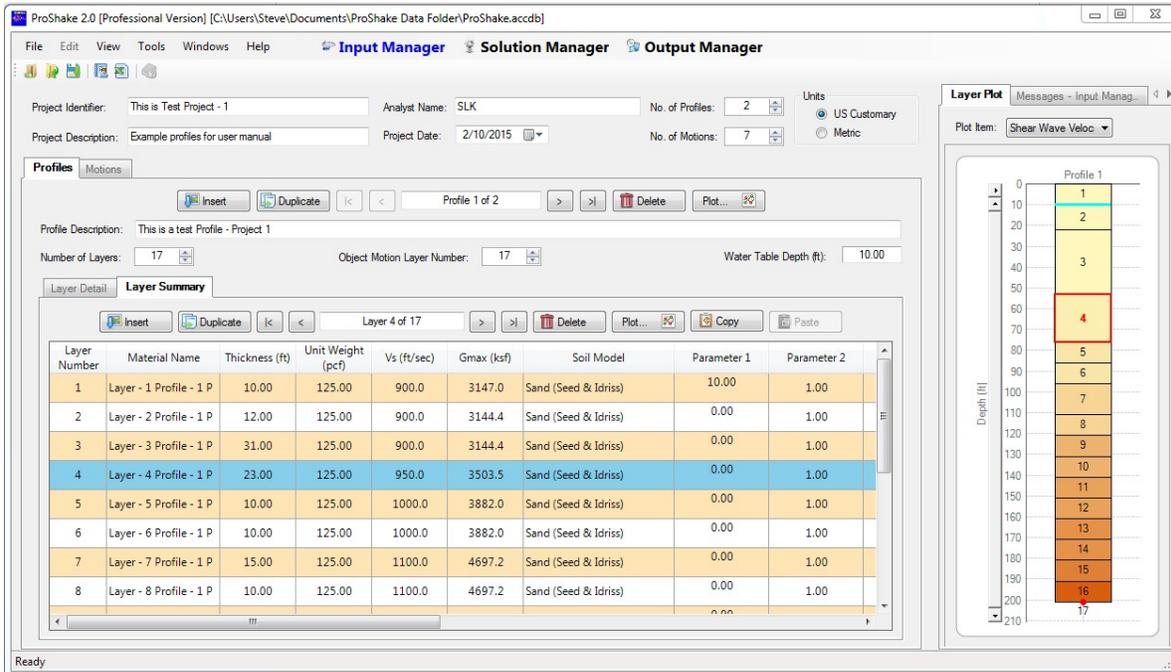
**Response Spectra** – compute response spectrum at top of active layer.

**Apply to All Layers** – allows above selections to be applied to all layers. Any selection/deselection made after when the Apply to All Layers is selected will apply to all layers.

**LAYER SUMMARY**

A more compact view of the soil layer data can be displayed on the Layer Summary tab. Input data can be entered, modified, and/or examined on this tab. An example of a completed profile is shown below. The Layer Plot on the right shows the thicknesses of the various soil layers – the groundwater level is shown by a blue line, the active layer is highlighted by a red box, and the colors assigned to the layers are keyed to the shear wave velocity.

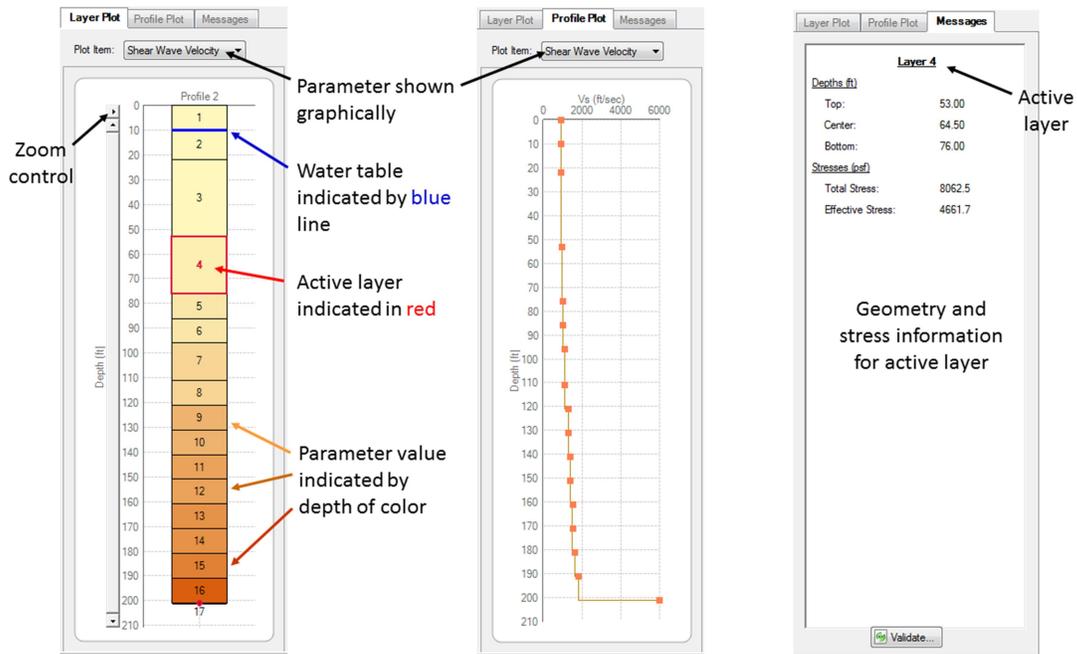
A helpful feature on the Layer Summary Data tab is the ability to drag-and-drop the properties of one layer to another. This is similar to the Copy and Paste feature available in the Layer Detail tab. To use this feature, left-click and hold on a layer whose properties have already been entered, drag the cursor down to the desired layer, and release the left-click button. The properties of the original layer will automatically be assigned to the desired layer. This feature can speed up the process of data entry considerably.



**LAYER PLOT / PROFILE PLOT / MESSAGES**

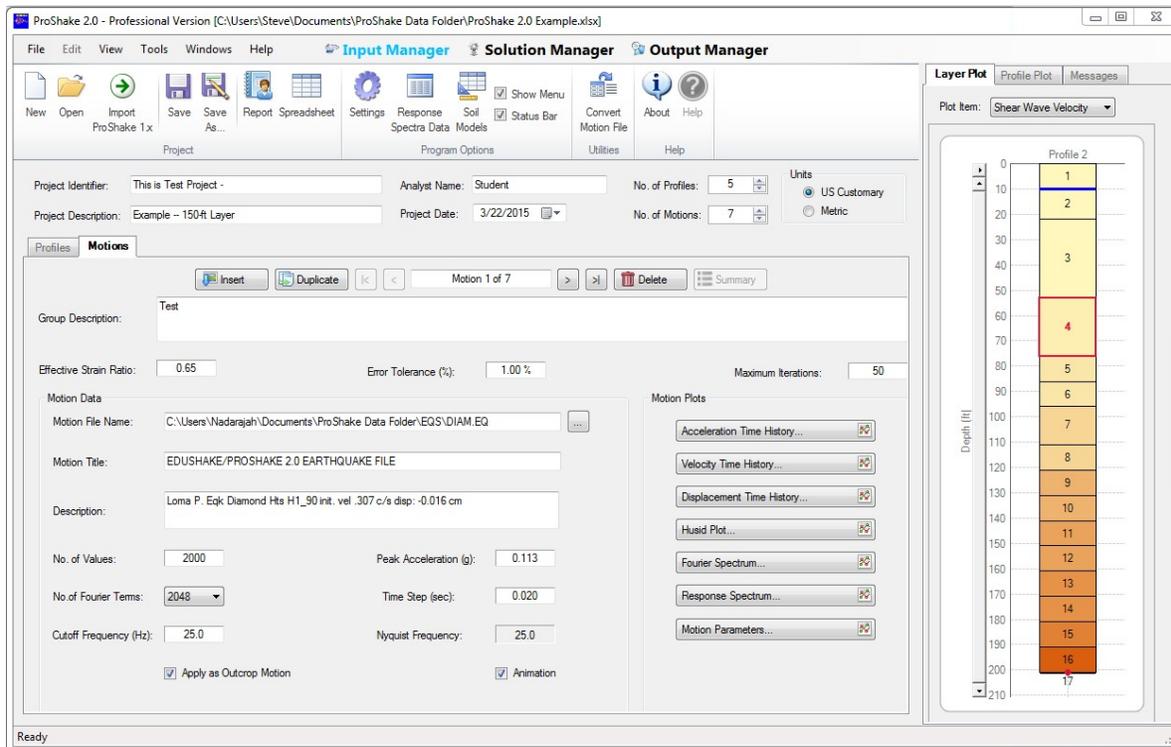
On the right side of the screen, you will see a tall, narrow pane with tabs labeled Layer Plot, Profile Plot, and Messages (see below). The Layer Plot and Profile Plot tabs allow you to plot a variety of soil parameters over the thickness of the profile. The Layer Plot tab shows the selected

Plot Item (shear wave velocity is the default parameter) by shades of color with the thicknesses of the layers being proportional to their actual thickness. This plot adjusts itself - as you add layers and layer data to your profile in the Input Manager, the plot will reflect the changes. The lowest parameter value is given a light tan color and the highest a medium brown color; the RGB color coordinates are interpolated on the basis of parameter value to obtain the intermediate colors. The vertical axis of the layer plot can be scaled (zoomed) using the right arrow button just to the left of the origin of the plot. The Layer Plot can be very useful for catching data entry errors during preparation of the input file. The Profile Plot tab does the same thing as the Layer Plot tab, but the data is plotted on a conventional x-y line plot. Finally, the Messages tab shows the depths of the top, center, and bottom of the active layer as well as the total and effective vertical stresses at the center of the layer.



## INPUT MOTIONS

Input motions are entered on the Motions tab, the layout of which is shown below. The motions tab allows you to define a suite of motions that will be applied to each profile in the project. An unlimited number of motions can be specified.



**Motion Data** – The individual input motions can be selected and their characteristics displayed in a set of controls on the Motions tab. Many of the values are contained within the input motion files and are displayed after the input motion is entered.

**Motion Navigation:** Navigation controls are located at the top of the Motions tab. At the center is a text box indicating the active motion. Immediately to the left and right of the center text box are navigation buttons that use standard notation to take the user to the previous (<) or next (>) motion, or to the first (|<) or last (>|) motion.

**Insert button:** The Insert button will insert a new motion immediately after the displayed motion. The number of motions will be increased by one.

**Duplicate button:** The Duplicate button will insert a duplicate of the displayed motion immediately after the displayed motion. The number of motions will be increased by one. The duplication feature can be handy for parametric analyses when one characteristic of a particular motion (e.g., *PGA*) is to be changed.

**Delete button:** The Delete button will delete the displayed motion. The number of motions will be decreased by one.

**Group Description:** A text box is available to allow description of the suite of motions used in the analyses.

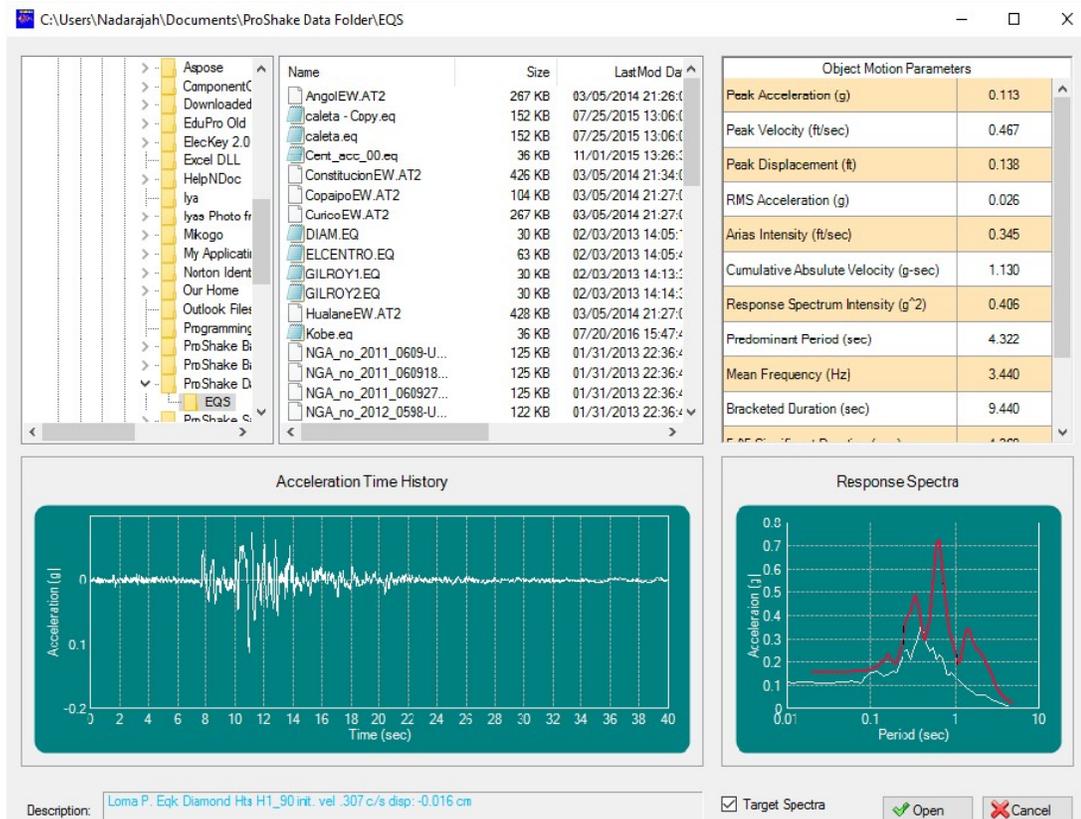
**Effective Strain Ratio:** Ratio of effective strain to peak strain, usually set to 0.65. Iterations toward strain compatibility are based on the effective strain.

**Error Tolerance:** Maximum difference (in percent) between modulus and damping ratio values in successive iterations below which convergence is considered acceptable. A lower error tolerance will lead to more accurate solutions, but more iterations will be required to do so. The default tolerance is 1.0%.

**Maximum Iterations:** Maximum number of iterations to be allowed. If convergence with respect to error tolerance is not achieved, iterations will stop when maximum number of iterations has been reached. The default maximum number of iterations is 50.

**Motion Data:** The Motion Data box allows entry/display of data associated with the individual input motions that have been entered into the program.

**Motion File Name:** Path and name of input motion file name. To add a motion file, either type the path and name of the desired file or (more likely) click on the ellipsis (three-dot-button) immediately to the right of the filename text box. That button will take you to a form that allows you to select and add motions to your input file. ProShake will automatically recognize two input motion formats – the ProShake format used in the previous version of the program, and the .at2 format used by the Pacific Earthquake Engineering Research (PEER) Center ground motion database. A convert motion utility is available to convert motions files from any other format to a ProShake-accepted format that is described later under the Utilities section of this manual. When a valid motion file is selected, ProShake will show you the time history, response spectrum, target spectrum (in red if it had already been defined) and several scalar parameters for your inspection before adding them to the suite. Clicking once will display information about the motion; double-clicking will add the motion to your project.



**Motion Title:** A text box is provided to allow entry of a title identifying the motion. This field will be filled in when the input motion is added to the motion group.

**Description:** Another text box that allows for a more complete description of the input motion. This field will be filled in when the input motion is added to the motion group.

**No. of Values:** Number of acceleration values in input motion. This field will be filled in when the input motion is added to the motion group.

**No. of Fourier Terms:** Number of terms in Fourier series used to represent input motion. By default, this will be the next power of 2 above the number of acceleration values in the input motion. If a longer “quiet zone” is desired, this value can be increased.

**Cutoff Frequency:** Highest frequency to be considered in the analysis. Default is set to Nyquist frequency but can be set to lower value to speed calculations up.

**Peak Acceleration:** Peak absolute acceleration in the input motion. This field will be filled in when the input motion is added to the motion group. The value can be changed, however, to scale the input motion up or down as desired; the same scaling factor is applied to all acceleration values in the motion.

**Time Step:** Time step of input motion. This field will be filled in when the input motion is added to the motion group. The value can be changed, but is not recommended since it changes the frequency content and duration of the motion.

**Nyquist Frequency:** Highest frequency that can be represented in Fourier series. Calculated as  $1/(2\Delta t)$ .

**Apply as Outcrop Motion:** Check box if input motion is an outcrop motion (i.e., if it was recorded at, or is intended to represent the motion at, a free surface). If this box is not checked, the motion will be applied directly at the input motion locations as though the motion was recorded at that depth – this is equivalent to assuming a rigid base at that depth.

**Animation:** Check box if an animation of the horizontal displacement of the profile is desired. During the analysis, animations are created as Adobe Flash format files that can be played in ProShake, or can be used for viewing outside of ProShake, insertion into Microsoft PowerPoint® presentations, or other purposes.

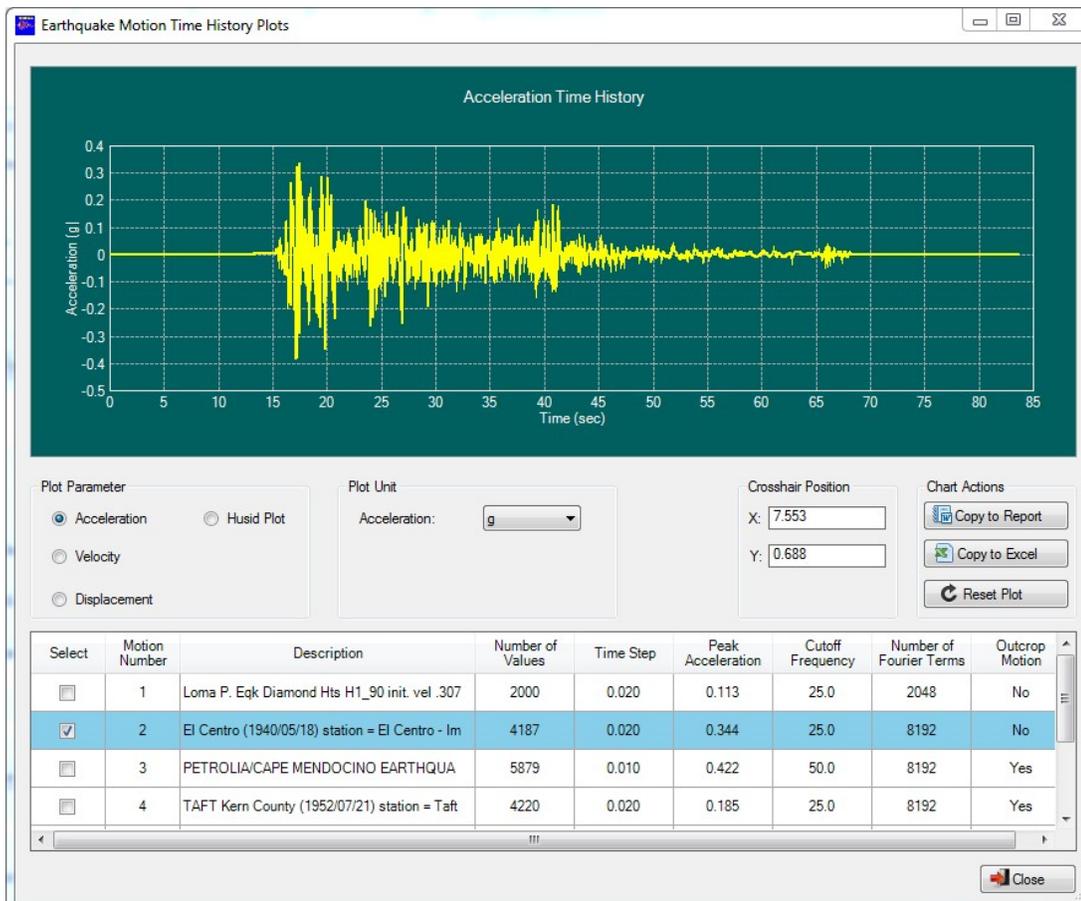
**Motion Plots** – ProShake allows the user to plot various characteristics of the input motions prior to performing the site response analyses. Separate buttons for acceleration, velocity, displacement, and Husid plots are available for quick reference, but a user can change from any one of those time history plots to any other from the motion plot form without returning to the Motions tab.

**Acceleration Time History:** Plots the acceleration time history for the active motion on an Earthquake Motion Time History form with the appearance indicated below. The time history of the selected motion is plotted. Any motion can be selected by clicking the check box in the left-most column labeled Select. On this form, velocity, displacement, and Husid parameter time histories can be plotted. The units of the plotted variable can be changed, and the cursor can be moved around the plot with its coordinates shown in the Crosshair Position box. If the user wants to zoom in on a particular part of the plot, holding the CTRL key down while drawing a box on the plot (by left-clicking and holding while dragging the cursor across the plot before releasing) will resize the plot to conform to the area of the drawn box. Holding CTRL+Shift while dragging the cursor across the plot will scale the plot in both the x- and y-directions. Any alterations made to the plot can be eliminated by pressing the Reset Plot button. Finally, the plot can be copied to the Report (Word file) or Spreadsheet (Excel file) using the buttons in the Chart Action box.

**Velocity Time History:** Plots the velocity time history for the active motion on the Earthquake Motion Time History form.

**Displacement Time History:** Plots the displacement time history for the active motion on the Earthquake Motion Time History form.

**Husid Plot:** Plots the time history of the Husid parameter for the active motion on the Earthquake Motion Time History form. The Husid parameter is the Arias intensity at time,  $t$ , divided by the total Arias intensity of the record.



**Fourier Spectrum:** Plots the Fourier amplitude spectrum of the active motion on an Earthquake Motion Fourier Spectrum Plots form. Once on that form, the phase spectrum or power spectrum can also be plotted. All spectra can be plotted as functions of frequency or period, and with either or both axes set to linear or logarithmic scales. Right-clicking anywhere within the Select column allows plotting the spectra of all motions together with one left-click. When all motions are plotted, the highlighted motion (highlighted in blue in the table below the plot) will be displayed in “Selected Line Color” while the others are all plotted in “Normal Line Color.” The colors are defined using the “Settings” feature described on page 7.

**Response Spectrum:** Plots the response spectrum of the active motion on an Earthquake Motion Response Spectrum Plots form. Once on that form, velocity and displacement spectra can be plotted. All spectra can be plotted as functions of period or frequency, and with either or both axes set to linear or logarithmic scales. The units of the plotted variable can be changed, and the acceleration spectra can be normalized by the 0.01-sec spectral acceleration. As the cursor is moved around in the plot area, its coordinates are displayed in the Crosshair Position box and a red dot appears at the location of the closest data point. When multiple spectra are plotted, the 84<sup>th</sup>, 50<sup>th</sup>, and 16<sup>th</sup> percentile spectra can be plotted by checking the Log Statistics box. These spectra are superimposed upon the selected spectra, and can be seen more easily by checking the Hide Selected box. If a

target spectrum has been entered, it can be added to the plot by checking the Target Spectrum check box.

**Motion Parameters:** Computes commonly used ground motion parameters for all motions in the project. For selected motions, the mean, standard deviation, median, dispersion (standard deviation of natural logarithms of parameter values), 84<sup>th</sup> percentile, and 16<sup>th</sup> percentile values are also computed. Parameters include peak ground acceleration, peak ground velocity, peak ground displacement, RMS acceleration, Arias intensity, cumulative absolute velocity, response spectrum intensity, predominant period, mean frequency, bracketed duration, 5-95 significant duration, and 5-75 significant duration.

## SOLUTION MANAGER

The Solution Manager is where the actual site response analyses are executed. All motions are applied to all soil profiles and the data specified in the Input Manager is written to the project Excel file. The Solution Manager displays all combinations of soil profiles and ground motions to allow the user to gauge the progress and completeness of the analyses as they are being performed.

Before accessing Solution Manager to conduct the analysis, the user is advised to check the data for any missing or incorrect data using the “Validate Data” button in the Input Manager. Regardless, before initiating an analysis, ProShake will conduct data validation and will display a message if there are any missing or incorrect data. The Solution Manager also generates or updates the Report that summarizes the input of your analysis.

The analyses are initiated by clicking the Analyze button in the lower right corner. The Messages tab will display the progress of the analyses and indicate the time required to complete them. When a profile has been completed, the number of iterations required to reach strain-compatible stiffness and damping values are displayed in tabular form along with the maximum modulus and damping errors, i.e., the maximum differences in those quantities (over the thickness of the profile) at the point of the last iteration.

ProShake 2.0

ProShake 2.0 Beta - Educational Version [C:\Users\Nadarajah\Documents\ProShake Data Folder\ProShake 1.0 Example.xlsx]

File Edit View Tools Windows Help **Input Manager** **Solution Manager** **Output Manager**

New Open Import ProShake 1.x Save Save As... Validate Data Report Spreadsheet Settings Response Spectrum Data Soil Models Show Menu Status Bar Convert Motion File About Help

Project Identifier: Imported from ProShake 1.x Data File C:\EduPro\ProShake USB Key\SHAKE.DAT

Profile Number	Profile Description	Motion Number	Motion Description	Number of Iterations	Max G Error (%)	Max Damping Error (%)	Status
1	Example -- 150-ft layer	1	TREASURE ISLAND -	8	0.72 %	0.56 %	Completed
1	Example -- 150-ft layer	2	TAFT Kern County (19	5	0.58 %	0.93 %	Completed
1	Example -- 150-ft layer	3	Northridge Earthquake	6	0.30 %	0.50 %	Completed
1	Example -- 150-ft layer	4	Loma P. Eqk Diamond	5	0.17 %	0.35 %	Completed
1	Example -- 150-ft layer	5	YERBA BUENA ISLAN	4	0.32 %	1.00 %	Completed
2	Example -- 150-ft layer	1	TREASURE ISLAND -	8	0.72 %	0.56 %	Completed
2	Example -- 150-ft layer	2	TAFT Kern County (19	5	0.58 %	0.93 %	Completed
2	Example -- 150-ft layer	3	Northridge Earthquake	6	0.30 %	0.50 %	Completed
2	Example -- 150-ft layer	4	Loma P. Eqk Diamond	5	0.17 %	0.35 %	Completed
2	Example -- 150-ft layer	5	YERBA BUENA ISLAN	4	0.32 %	1.00 %	Completed

Messages

Analysis started @ 10:25:21.266

Preparing analysis data/updating report...

Profile 1 started @ 10:25:22.486  
 Motion 1 completed in 1.017 sec  
 Motion 2 completed in 1.138 sec  
 Motion 3 completed in 1.071 sec  
 Motion 4 completed in 0.970 sec  
 Motion 5 completed in 0.940 sec  
 Profile 1 completed @ 10:25:33.974

Profile 2 started @ 10:25:33.995  
 Motion 1 completed in 0.931 sec  
 Motion 2 completed in 1.101 sec  
 Motion 3 completed in 1.155 sec  
 Motion 4 completed in 0.916 sec  
 Motion 5 completed in 0.885 sec  
 Profile 2 completed @ 10:25:45.097

Analysis completed @ 10:25:45.558

Total elapsed time = 24.292 sec

Analyze

Ready

## OUTPUT MANAGER

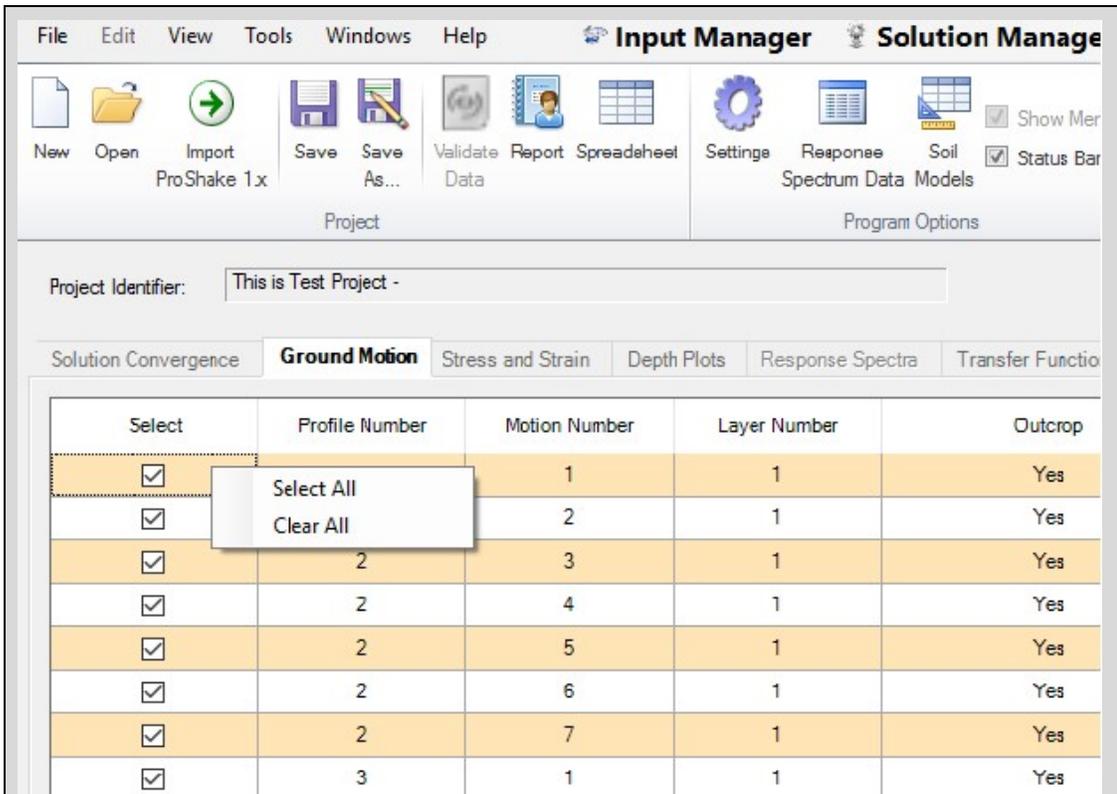
The Output Manager allows you to examine your data in the form of many useful plots, and to save those plots and the data they contain in convenient, spreadsheet formats for processing with other graphics programs or data archiving. The plots are exported to the project Excel data file as Chart objects (including the underlying data). The plots can also be exported to the project Report file as Windows Meta File images using the Copy to Report button. The Output Manager is organized in a series of tabs for different types of graphical display of the output. Seven tabs are available – Solution Convergence, Ground Motion, Stress and Strain, Depth Plots, Response Spectra, Transfer Function, and Animation.

There are several “global” features of ProShake that apply to all of the tabs in the Output Manager – those features are described in the shaded boxes below.

### **ProShake Table Navigation**

Many of the Output Manager tabs have tables that describe the quantities that can be plotted. In some cases, such as acceleration time histories, you would likely just plot one quantity at a time. In other cases, such as response spectra, you may want to see the output for several input motions on the same plot. ProShake presents your plotting options in tabular form, and has features that make choosing the plot(s) extremely quick and convenient.

All of the tables have a column of Select check boxes on the left side. You can go through the table and select individual quantities to plot if you wish. However, if you would like to select all of the quantities, just right-click anywhere in the Select column of check boxes and choose Select All. You can also clear all selections using the same procedure (right-click, then Clear All).



The screenshot shows the ProShake 2.0 software interface. The menu bar includes File, Edit, View, Tools, Windows, and Help. The main toolbar contains icons for New, Open, Import (ProShake 1.x), Save, Save As..., Validate Data, Report, Spreadsheet, Settings, Response Spectrum Data, and Soil Models. The Project Identifier field contains "This is Test Project -". The "Ground Motion" tab is active, showing a table with columns: Select, Profile Number, Motion Number, Layer Number, and Outcrop. A context menu is open over the first row, showing "Select All" and "Clear All" options.

Select	Profile Number	Motion Number	Layer Number	Outcrop
<input checked="" type="checkbox"/>	1	1	1	Yes
<input checked="" type="checkbox"/>	2	2	1	Yes
<input checked="" type="checkbox"/>	2	3	1	Yes
<input checked="" type="checkbox"/>	2	4	1	Yes
<input checked="" type="checkbox"/>	2	5	1	Yes
<input checked="" type="checkbox"/>	2	6	1	Yes
<input checked="" type="checkbox"/>	2	7	1	Yes
<input checked="" type="checkbox"/>	3	1	1	Yes

Moving to another column, ProShake 2.0 also has filtering capabilities. If you want to see only the plots for a particular profile (say, Profile 2), right-click on any of the Profile 2 cells and select Filter Profile Number 2 – that will automatically select all of the Profile 2 cases and remove all other profiles from the display (note that they can easily be returned to the tab by right-clicking and then removing all filters). The same thing can be done for motion numbers, so you can very quickly view the responses of all profiles to Motion 3, for example. You can also filter by layer number, so you can view the responses of all profiles to all ground motions at the ground surface (top of Layer 1) if you like. You can also combine filters, for example, to view the response of the ground surface of Profile 2 to all input motions. If you play around with the filter/select features, you will quickly see how easy and helpful it is when dealing with multiple profiles and multiple motions.

The screenshot shows the ProShake 2.0 software interface. The menu bar includes File, Edit, View, Tools, Windows, and Help. Below the menu bar are two main sections: 'Input Manager' and 'Solution Manager'. The 'Input Manager' section contains icons for New, Open, Import ProShake 1.x, Save, Save As..., Validate Data, Report, and Spreadsheet. The 'Solution Manager' section contains icons for Settings, Response Spectrum Data, and Soil Models, along with checkboxes for Show Menu and Status Bar. Below these sections is a 'Project Identifier' field containing 'This is Test Project -'. The main workspace is divided into tabs: Solution Convergence, **Ground Motion**, Stress and Strain, Depth Plots, Response Spectra, and Transfer Function. The 'Ground Motion' tab is active, displaying a table with the following data:

Select	Profile Number	Motion Number	Layer Number	Outcrop
<input checked="" type="checkbox"/>	2	1	1	Yes
<input checked="" type="checkbox"/>	2	2	1	Yes
<input checked="" type="checkbox"/>	2	3	1	Yes
<input checked="" type="checkbox"/>	2	4	1	Yes
<input checked="" type="checkbox"/>	2	5	1	Yes
<input checked="" type="checkbox"/>	2	6	1	Yes
<input checked="" type="checkbox"/>	2	7	1	Yes
<input checked="" type="checkbox"/>	3	1	1	Yes
<input checked="" type="checkbox"/>	3	1	1	Yes
<input checked="" type="checkbox"/>	3	1	1	Yes
<input checked="" type="checkbox"/>	3	4	1	Yes
<input checked="" type="checkbox"/>	3	5	1	Yes
<input checked="" type="checkbox"/>	3	6	1	Yes

A context menu is open over the table, showing the following options:

- Filter Profile Number 3
- Clear Current Filter
- Clear All Filters

### **Zoom, Scale, and Chart Properties**

ProShake also has some handy features that allow convenient examination of graphical data. When a plot is displayed, you can zoom in on a particular part of the plot by holding the CTRL key down and using the mouse (holding the left button down) to draw a rectangle around the section of the plot you are interested in. When you release the left button, the area of the rectangle will fill the entire plot window. You can undo this action by clicking on the Reset Plot button. You can rescale the plot by holding down CTRL+Shift and moving the mouse in any direction – this action can also be undone by clicking Reset Plot. Finally, double-clicking on the plot itself will take you to a Chart Properties form that will allow you to change various characteristics of the plot itself.

### **Chart Actions**

Each ProShake plot form has buttons labeled Copy to Report and Copy to Excel. These buttons do what they sound like they do.

ProShake prepares a report of each analysis in the form of a Word format file. The basic report includes a compact summary of all of the input data (project data, soil profile, ground motions, etc.) – the intent of the report is to help the user document his/her analysis in a consistent and concise manner. The Copy to Report button allows the user to paste the current plot into the report file, as Windows Meta File image. The figures are added to the end of the report file in the order that they are copied there.

ProShake uses an Excel format file for saving and retrieving project input data and analysis results. This Excel file also has worksheets for storing exported plots and data. The Copy to Excel button will export the plot being viewed as a Chart object to the “Exported Charts” worksheet and the underlying to a worksheet labeled “Exported Data” in the Excel file. The intent of this feature is to allow the user to easily export data into a different graphics program for more flexibility in plotting.

## SOLUTION CONVERGENCE TAB

The Solution Convergence tab presents much of the same information shown in the Solution Manager, but also displays the average modulus and damping errors in addition to the maximum values, and a Travel Time Ratio. The Travel Time Ratio is the ratio of the travel time for an s-wave propagating from the top of the half-space to the ground surface based on the strain-compatible modulus values (used to compute a consistent shear wave velocity) to the travel time based on  $G_{max}$  values. The ratio provides an indication of the degree of nonlinearity induced in the profile since it is affected by both the amount of modulus degradation and the thicknesses of the zones in which the modulus has decreased.

## GROUND MOTION TAB

The Ground Motion tab allows plotting of various ground motion characteristics, including time histories, Fourier spectra, response spectra, and ground motion parameters.

Under the Plot Type header, radio buttons can be used to select the specific type of plot that is desired. Plots of the quantities listed in the table below are all available. These plots are presented in the same format used to display these characteristics of the input motions in the Input Manager, so detailed descriptions of those plots are not repeated here.

<b>Time Histories</b>	<b>Fourier Spectra</b>	<b>Response Spectra</b>
Acceleration	Amplitude	Acceleration
Velocity	Phase	Velocity
Displacement	Power	Displacement
Husid Parameter		

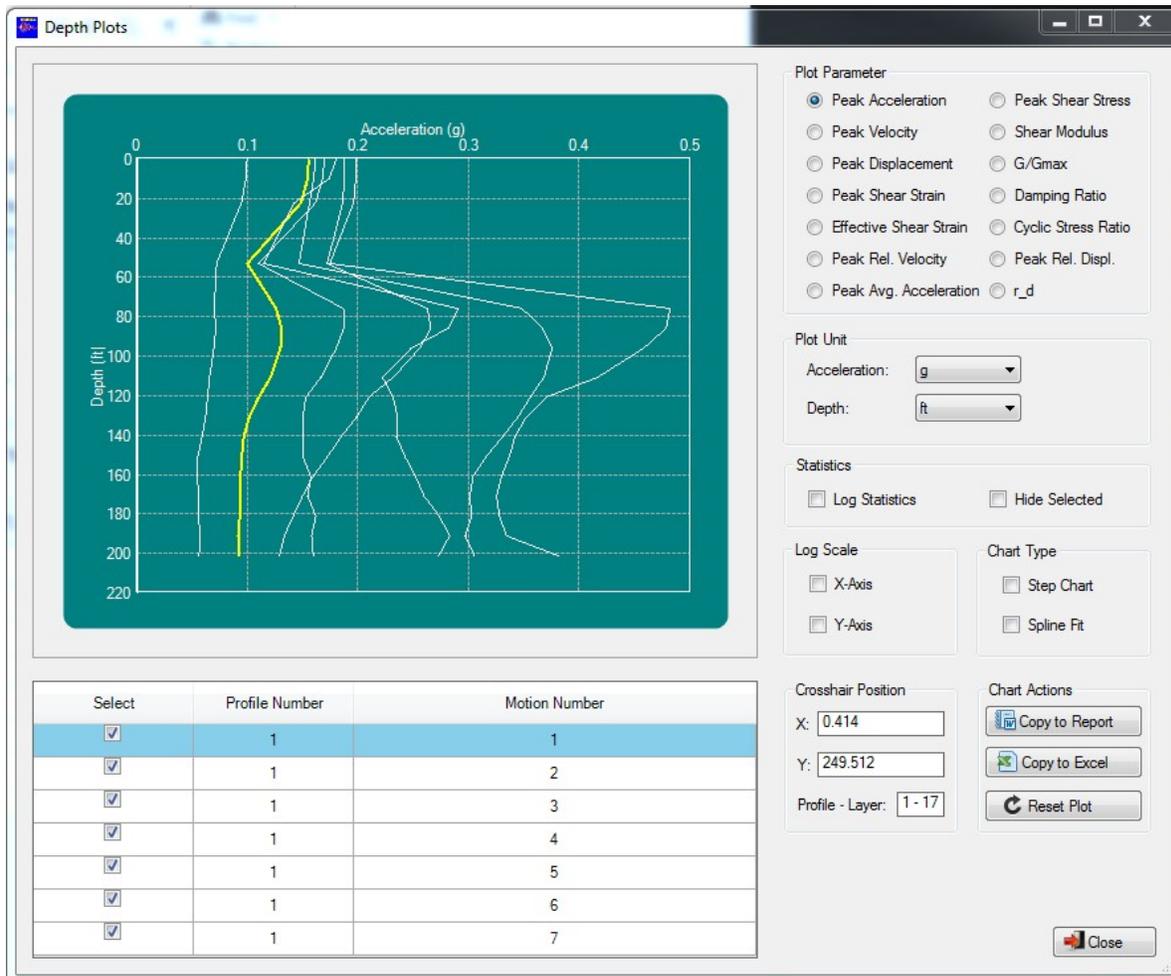
#### STRESS AND STRAIN TAB

Shear stress and shear strain values can be plotted as time histories, or Fourier spectra of both shear stress and shear strain can be plotted.

## DEPTH PLOT TAB

The Depth Plot tab allows plotting of the variation of a wide variety of parameters as functions of depth over the thickness of the soil profile. These include the following parameters:

- Peak acceleration:** maximum absolute value of acceleration at the top of each layer
- Peak velocity:** maximum absolute value of velocity at the top of each layer
- Peak displacement:** maximum absolute value of displacement at the top of each layer
- Peak average acceleration:** peak value of average acceleration of all material above indicated depth, equivalent to maximum horizontal equivalent acceleration (MHEA)
- Peak relative velocity:** maximum absolute value of the difference in velocity between that at the top of each layer and top of the halfspace
- Peak relative displacement:** maximum absolute value of the difference in displacement between that at the top of each layer and top of the halfspace
- Peak shear stress:** maximum absolute value of shear stress at the center of each layer
- Peak shear strain:** maximum absolute value of shear strain at the center of each layer
- Cyclic stress ratio:** 65% of ratio of peak shear stress to initial vertical effective stress
- Effective shear strain:** 65% of peak shear strain
- $G/G_{\max}$ :** strain-compatible modulus reduction ratio
- Damping ratio:** strain-compatible damping ratio
- Shear modulus:** strain-compatible secant shear modulus
- $r_d$ :** depth reduction factor (ratio of peak shear stress to shear stress if overlying material was rigid), as used in liquefaction analyses.



The Depth Plot form has several features that allow you to examine your data more thoroughly and completely. These include:

**Plot Units** – you can control the units used on both axes

**Statistics** – you can plot 50<sup>th</sup> (median) and 84<sup>th</sup> and 16<sup>th</sup> percentile values of the plotted parameter. If you want to see only those three curves, use the check box to hide the selected motions.

**Log scale** – either or both axes can be converted to logarithmic scales using the check boxes. Some variables (e.g., strain, shear modulus, etc.) vary so much that the plots can become distorted by the highest value in a plot with arithmetic axes.

**Chart type** – the default plotting style in ProShake uses linear interpolation between data points. Recognizing that some variables (e.g., shear modulus, damping ratio) are inherently assumed to be constant within each layer, a Step Chart option is provided to better view the actual variation of those parameters with depth. Since many other variables vary smoothly with depth, a Spline Fit option is also provided. This option fits a cubic spline to the discrete data points – note that a spline can fit some unrealistic “wiggles” into a curve when there are large variations in parameter values over relatively short distance ranges. When looking at

data with the spline fit option, it is advisable to toggle the spline fit check box off and on while watching the position of the curves to confirm that the spline is producing reasonable values.

**Crosshair position** – the coordinates of the crosshair are provided when the cursor is moved across the plotting area. The Profile-Layer item displays the profile and layer number for the curve that the cursor is closest to – sometimes it is difficult to know which case a particular curve corresponds to, and this feature makes it easy to determine that.

#### RESPONSE SPECTRA TAB

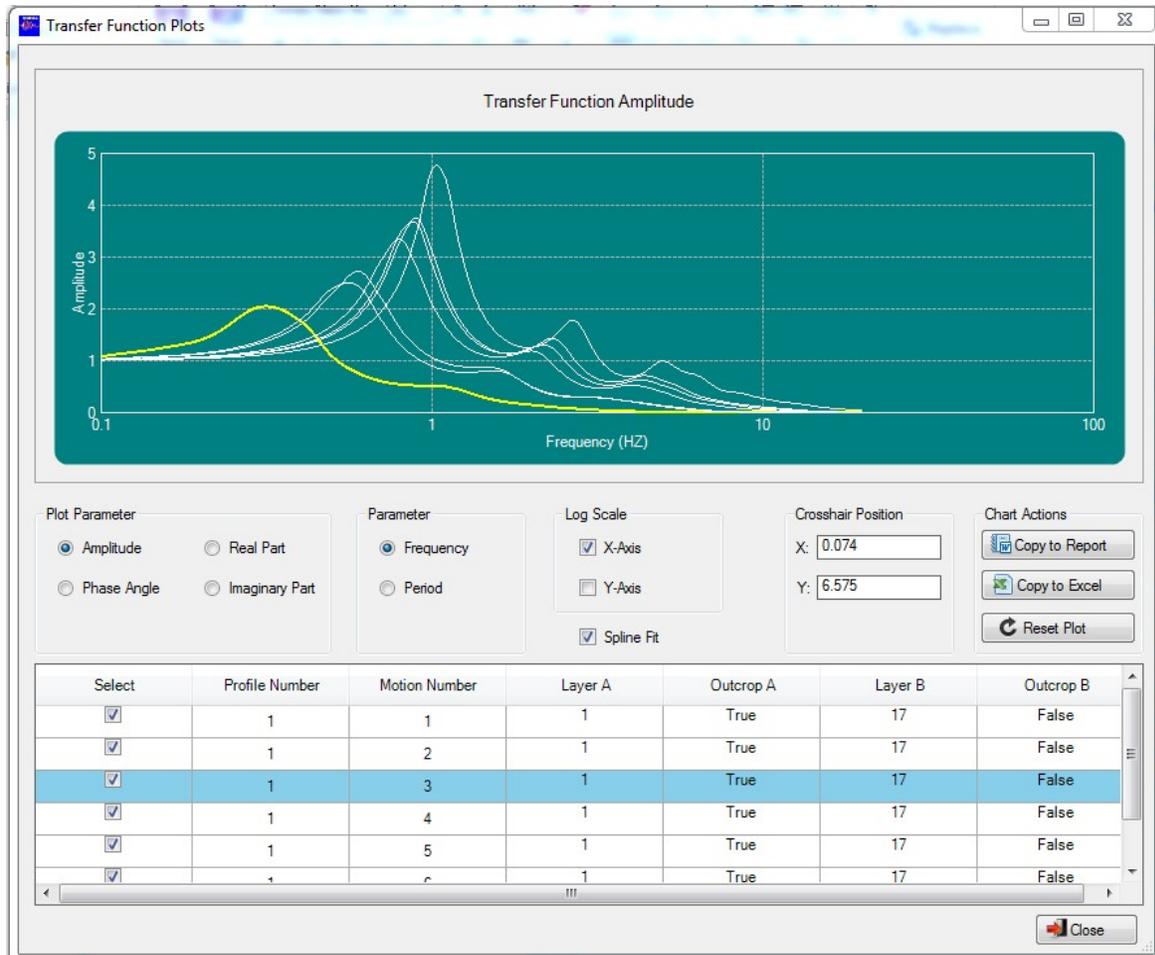
Selected response spectra can be plotted using the Response Spectra tab. The plotting form is the same as that used in the Input Manager. Please see that section of the User's Manual for details about the response spectrum plots.

#### TRANSFER FUNCTION TAB

The transfer function tab allows you to plot transfer functions relating accelerations at any layer to any other layer. Since the transfer function relating surface motion to halfspace motion is typically of greatest interest, the ground surface is indicated as Layer A and the halfspace as Layer B when the Transfer Function tab is selected. You can change the layer numbers for Layer A or Layer B, however, to any layers you choose. You can also designate any layer as an outcrop layer and obtain the transfer function based on the motion that would have occurred if that layer was an outcrop (even if it wasn't an outcropping layer in your profile). Of course, Layer 1 (the uppermost layer whose top is at the ground surface) is always an outcropping layer so checking the outcrop check box for that layer will have no effect.

Although 99% of people will only be interested in the amplitude of the transfer function (since it is commonly interpreted as an "amplification factor"), options for plotting the phase angle and the real and imaginary parts (if there is any damping, the transfer function is complex) are also provided.

Options for plotting the transfer function vs. frequency or period are provided, as are options for using log scales on either axis.



## ANIMATION TAB

The Animation tab allows you to view animations of the displacement of your soil profile for a particular motion. Because the animation requires storing the displacement histories at all layers of the profile (which consumes storage and slows down execution of the analysis), you must specify that you want an animation before running the program.

The animations are written as Adobe Flash formatted files so that they can be viewed outside of ProShake or included in presentations (e.g., embedded in PowerPoint presentations). The animation includes a plot of the ground surface acceleration history with an indicator that shows the time corresponding to the displaced shape of the profile. The animation will repeat itself as long as the window is open.

The animations currently appear clearer when viewed outside of ProShake. We are trying to determine a procedure to improve their rendering within the program and will update the program when that issue has been addressed.

## PROSHAKE FILE STRUCTURE

ProShake uses three types of files. These are the program data file, project data file, and project report file. Each of these are described below.

**Program Data File** – ProShake uses an Excel format file to store basic program level data needed for all analyses, such as soil models, response spectrum periods, user-defined target spectra, etc. The program data file has one worksheet named “Program Data” that is a specially formatted worksheet with named ranges that hold tables of data. It is possible to edit this file directly. However, we strongly recommend that you make a copy of this file before attempting any modifications of it; that way, if your modifications are unsuccessful, you will have the original file to go back to.

**Project Data File** – For saving and retrieving project data, analysis results, and any user exported plots and underlying data, ProShake uses an Excel format file, hereafter referred to as the project data file. The project data file has several worksheets – the “Input Data” worksheet is a specially formatted worksheet with named ranges that hold tables of input data. Analysis results are saved to worksheets named “Output – Profile X”, with one worksheet for each profile in the project where “X” is the profile number. User-exported charts are copied to the “Exported Charts” worksheet and their underlying data are copied to “Exported Data” worksheet. When ProShake is installed, a formatted blank project data file named “ProShake 2.0 Excel Base.xlsx” is copied to user ProShake Data Folder and used as a template when new projects are created.

**Project Report File** – ProShake uses a Word format file for documenting the analysis and creating a report for the project. The project report file will include project input data and any user-exported plots as Windows Metafile images. When ProShake is installed, a formatted blank project data file named “ProShake 2.0 Report Base.docx” is copied to the user’s ProShake Data Folder and used as a template when reports for new projects are created. The user can edit the “ProShake 2.0 Report Base.docx” file to add their company logo/name so future reports contain this information.

ProShake 2.0 Report



ProShake 2.0 Input Data

Project Data			
Project Date:		Unit:	
Project Identifier:			
Project Description:			
Number of Profiles:		Number of Motions:	
Motion Group Description:			
Max. Number of Iterations:		Strain Ratio:	
Error Tolerance:		Analysis Completed:	
Analyst Name:		Analysis Date:	
Data File Name:			

While ProShake uses Excel format files for project and program data and Word format file for report, ProShake does not require the user to have Microsoft Excel or Word installed on their computer to use ProShake. However, if the user has Microsoft Excel or Word, they can open ProShake files in the respective program for further analysis or customization. For example, the user can open “ProShake 2.0 Report Base.docx” in Microsoft Word to add their company information to the header section so that all future project reports will contain such information. However, since these files have specially formatted areas, the user must take care in inadvertently modifying such areas. We strongly recommend that you make a copy of this file before attempting any modifications of it; that way, if your modifications are unsuccessful, you will have the original file to go back to.

## CONVERT MOTION

Digitized earthquake ground motions are available from many different sources, and the formats in which they are provided by those sources are often different. ProShake 2.0, like any other ground response analysis program, expects to see the ground motion values in a particular format. The ProShake 2.0 motion file format is similar to PEER-formatted (.AT2) motions and PEER-formatted (.AT2) motions can be used as is. To allow the user to specify any other format ground motion as a ProShake 2.0 input motion, ProShake 2.0 includes a utility for converting and saving ground motions in the format required by ProShake 2.0.

To use the Convert Motion File utility, follow these steps (please refer to image below):

1. Select Convert Ground Motion File from the Utilities menu.
2. A Convert Motion form will then appear on the screen. Use the ellipses (...) button for "Original Motion File" to open the file you wish to convert to ProShake 2.0 format. The content of the original motion file will be displayed in the large text edit box in the form. Alternatively, you can also paste the original motion content from the clipboard directly in to the edit box.
3. Either accept the default output file name for the ProShake 2.0-formatted file you are creating or Use the ellipses (...) button for "Converted Motion File" to specify a name. You can use any filename you wish, but ProShake 2.0 will look first for files with the .eq extension.
4. Enter a description for the motion, such as earthquake name or location, to help identification in the future.
5. Enter the number of header lines. This is the total number of lines at the top of the file before the actual ground motion data. The header lines often contain alphanumeric descriptions and/or numerical information about the motion (number of data points, time step, maximum value, etc.). When the cursor is in the edit box, the line/column number of the cursor location will be displayed below the edit box and can be used to determine the number of header lines.
6. Enter the number of values - the number of data points in the ground motion file. This information is often shown in the header lines.
7. If the original motion file has extra columns of data, such as time column or additional acceleration components, check the "Extra Data Columns" check box and enter the column number of the acceleration data of interest in "Acceleration Column" drop down.
8. Enter the time interval. Each of the acceleration values in the ground motion file will be separated by a certain time interval, usually 0.005, 0.01, or 0.02 sec. The time step is often shown in one of the header lines.
9. Select the units of acceleration in the file you are converting. Choose from fraction of gravity (g), cm/sec<sup>2</sup>, m/sec<sup>2</sup>, in/sec<sup>2</sup>, or ft/sec<sup>2</sup>. Most ground motion files will express accelerations in g's, but some use other units. Note that 1 gal = 1 cm/sec<sup>2</sup>.
10. After providing all of the required information, click on Convert. ProShake 2.0 will read your file and write a new file with the same acceleration data (expressed in g's) arranged in ProShake 2.0 format. Your original file will be unchanged.

**Convert Motion** [X]

Original Motion File: C:\Users\...Google Drive\ProShake Files\PS 2.0 Tech Asst\1985.Sep.AZIH8509.191 ...

Converted Motion File: C:\Users\...Documents\ProShake Data Folder\EQS\1985.Sep.AZIH8509.eq ...

Description: From INSTITUTO DE INGENIERIA, UNAM

No. of Header Lines: 109 No. of Values: 7274

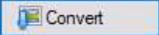
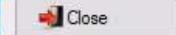
Extra Data Columns:  Acceleration Column: 2

Time Step (sec): 0.010 Acceleration Unit: cm/sec<sup>2</sup>

DATOS DE ACELERACION:

CANAL-1	CANAL-2	CANAL-3
V	N90W	N00W
-0.960	2.870	0.960
0.000	2.870	0.960
1.910	1.910	0.960
2.870	0.000	0.960
2.870	-1.910	0.960
1.910	-3.830	0.000
0.960	-3.830	0.000
0.960	-1.910	0.960
2.870	-0.960	0.960
3.830	-1.910	0.960

Line 110/7383, Column 8

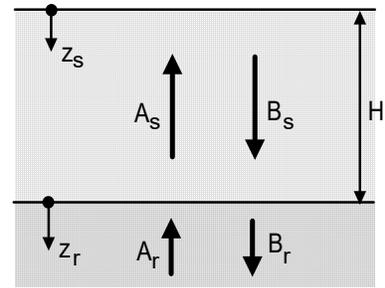
## THEORY

ProShake 2.0 uses a frequency domain approach to solve the ground response problem. In simple terms, the input motion is represented as the sum of a series of sine waves of different amplitudes, frequencies, and phase angles. A relatively simple solution for the response of the soil profile to sine waves of different frequencies (in the form of a transfer function) is used to obtain the response of the soil deposit to each of the input sine waves. The overall response is obtained by summing the individual responses to each of the input sine waves. This section describes the basic mathematics of the process for a problem involving a single soil layer, illustrates how that problem can be solved using a widely available mathematical programming language, and extends the approach to layered systems.

## SINGLE SOIL LAYER

The following paragraphs describe the basis of the analysis used in ProShake 2.0 and follow the general approach of Kramer (1996). That reference provides substantial background material and a more detailed description of ground response analyses than is presented in this User's Manual.

To illustrate the basic approach used in ProShake 2.0, consider a uniform soil layer lying on an elastic layer of rock that extends to infinite depth, as illustrated to the right. If the subscripts  $s$  and  $r$  refer to soil and rock, respectively, the horizontal displacements due to vertically propagating harmonic s-waves in each material can be written as



$$u_s(z_s, t) = A_s e^{i(\omega t + k_s^* z_s)} + B_s e^{i(\omega t - k_s^* z_s)} \quad (1)$$

$$u_r(z_r, t) = A_r e^{i(\omega t + k_r^* z_r)} + B_r e^{i(\omega t - k_r^* z_r)} \quad (2)$$

where  $\omega$  is the circular frequency of the harmonic wave and  $k^*$  is the complex wave number. No shear stress can exist at the ground surface ( $z_s=0$ ), so

$$\tau(0, t) = G_s^* \gamma(0, t) = G_s^* \frac{\partial u_s(0, t)}{\partial z_s} = 0 \quad (3)$$

where  $G_s^* = G(1 + 2i\zeta)$  is the complex shear modulus of the soil. Substituting Equation (1) into Equation (3) and differentiating gives

$$G_s^* i k_s (A_s e^{i k_s(0)} - B_s e^{-i k_s(0)}) e^{i\omega t} = G_s^* i k_s (A_s - B_s) e^{i\omega t} = 0 \quad (4)$$

which is satisfied when  $A_s = B_s$ . Compatibility of displacements and continuity of stresses at the soil/rock boundary require

$$u_s(z_s = H) = u_r(z_r = 0) \quad (5)$$

$$\tau_s(z_s = H) = \tau_r(z_r = 0) \quad (6)$$

Substituting Equations (1) and (2) into Equation (5)

$$A_s \left( e^{ik_s^* H} + e^{-ik_s^* H} \right) = A_r + B_r \quad (7)$$

From Equation (6) and the definition of shear stress ( $\tau = G_s^* \partial u / \partial z$ )

$$A_s i G_s^* k_s^* \left( e^{ik_s^* H} - e^{-ik_s^* H} \right) = i G_r^* k_r^* (A_r - B_r)$$

or

$$\frac{G_s^* k_s^*}{G_r^* k_r^*} A_s \left( e^{ik_s^* H} - e^{-ik_s^* H} \right) = A_r - B_r \quad (8)$$

The ratio

$$\frac{G_s^* k_s^*}{G_r^* k_r^*} = \alpha_z^*$$

where  $\alpha_z^*$  is known as the complex impedance ratio. Solving Equations (7) and (8) simultaneously gives

$$A_r = \frac{1}{2} A_s \left[ (1 + \alpha_z^*) e^{ik_s^* H} + (1 - \alpha_z^*) e^{-ik_s^* H} \right] \quad (9a)$$

$$B_r = \frac{1}{2} A_s \left[ (1 - \alpha_z^*) e^{ik_s^* H} + (1 + \alpha_z^*) e^{-ik_s^* H} \right] \quad (9b)$$

If a vertically propagating shear wave of amplitude,  $A$ , traveled upward through the rock and the soil was not present, the free surface effect at the rock outcrop would produce a bedrock outcropping motion of amplitude  $2A$ . If the soil was present, the free surface motion amplitude would be

$$2 A_s = \frac{4A}{(1 + \alpha_z^*) e^{ik_s^* H} + (1 - \alpha_z^*) e^{-ik_s^* H}}$$

The transfer function,  $F(\omega)$ , defined as the ratio of the soil surface amplitude to the rock outcrop amplitude, is given by

$$F(\omega) = \frac{2}{(1 + \alpha_z^*) e^{ik_s^* H} + (1 - \alpha_z^*) e^{-ik_s^* H}}$$

Obviously, the transfer function is a complex function. It can be rewritten using Euler's Law as

$$F(\omega) = \frac{1}{\cos k_s^* H + i \alpha_z^* \sin k_s^* H} \quad (10)$$

---

#### SOLUTION OF SINGLE LAYER PROBLEM

Because the transfer function is defined as the ratio of the soil surface amplitude to the rock outcrop amplitude, the soil surface amplitude can be obtained as the product of the rock outcrop amplitude and the transfer function. Therefore, the response of the soil layer to a periodic input motion can be obtained by the following steps:

1. Express the input (rock outcrop) motion in the frequency domain as a Fourier series (as the sum of a series of sine waves of different amplitudes, frequencies, and phase angles). For an earthquake motion, this Fourier series will have both real and imaginary parts.
2. Define the transfer function (Equation 10). The transfer function will have both real and imaginary parts.
3. Compute the Fourier series of the output (ground surface) motion as the product of the Fourier series of the input (bedrock) motion and the transfer function. This Fourier series will also have both real and imaginary parts.
4. Express the output motion in the time domain by means of an inverse Fourier transform.

These steps are coded into a program using the mathematical processing program MATLAB in the box located below. The syntax of a MATLAB program is similar to common languages such as FORTRAN and BASIC, but MATLAB contains high-level functions that allow many complicated calculations and graphics commands to be processed in a single line of text. The MATLAB program is well-commented, and should be relatively easy to follow.

```
% EX73.M - A MATLAB script for computing the seismic response of a uniform
%          damped soil layer on elastic bedrock. Input data corresponds to
%          Example 7.3 in Kramer, S.L. (1996), Geotechnical Earthquake
%          Engineering, Prentice Hall, 653 pp.
%
height=540;           % soil layer thickness
vss=1500;            % soil shear wave velocity
vsr=5000;           % rock shear wave velocity
rho_s=125;          % soil unit weight
```

```

rho_r=160;           % rock unit weight
xs=0.05;            % soil damping ratio
xr=0.02;           % rock damping ratio
load gle.dat        % load input motion
n=length(gle);
for j=2:n+1
    a(j)=gle(j-1)/981; % shift and convert input motion to g's
end
a(1)=0.0;
dt=0.02;           % time step
df=1./(n*dt);     % frequency increment
t=0.0:dt:n*dt;    % set up time vector
f=0.0:df:n*df;    % set up frequency vector
afft=fft(a)/n;
absfft=abs(afft);
for j=1:n/2+1      % set up single-sided FAS
    b(j)=2.*absfft(j);
    ff(j)=f(j);
end
alpha_z=(rho_s*vss*(1+i*xs))/(rho_r*vsr*(1+i*xr)); % complex impedance ratio
h(1)=1.0;
for j=2:n/2+1
    ksH(j)=2*pi*f(j)*height/(vss+xs*i*vss); % wave number x thickness
    h(j)=1./(cos(ksH(j))+i*alpha_z*sin(ksH(j))); % left half of transfer function
    h(n+3-j)=conj(h(j)); % right half of transfer function
end
for j=1:n/2+1
    habs(j)=abs(h(j)); % modulus of transfer function (for plotting)
end
subplot(5,1,1)
plot(t,a)          % plot input motion (time domain)
subplot(5,1,2)
plot(ff,b)         % plot FAS of input motion (frequency domain)
subplot(5,1,3)
plot(ff,habs)     % plot modulus of transfer function (freq. domain)

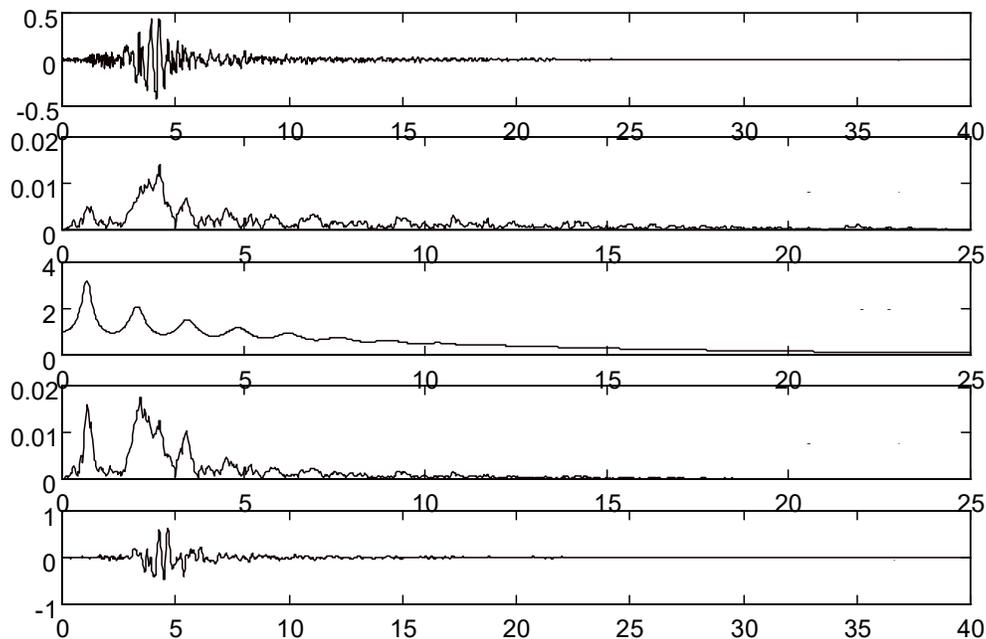
```

```

for j=1:n+1
    acc(j)=afst(j)*h(j);    % compute output motion in frequency domain
end
for j=1:n/2+1
    acc1(j)=2.*abs(acc(j)); % compute FAS of output motion
end
subplot(5,1,4)
plot(ff,acc1)              % plot FAS of output motion (frequency domain)
atime=n*real(ifft(acc));
subplot(5,1,5)
plot(t,atime)              % plot output motion (time domain)

```

The variables defined in the first part of the MATLAB program correspond to Example 7.3 in Kramer (1996). This example considers the response of a 540 ft thick soil layer of soil ( $v_{ss}=1500$  ft/sec,  $\rho=125$  pcf, and  $\zeta=5\%$ ) overlying bedrock ( $v_{sr}=5000$  ft/sec,  $\rho=160$  pcf, and  $\zeta=2\%$ ). The MATLAB program generates the plots shown below.



The first of these plots shows a time history of acceleration of the 40-sec input motion in the time domain. Immediately below this is the Fourier amplitude spectrum of the input motion - the Fourier amplitude spectrum shows the variation of amplitude with frequency for each of the frequencies in the Fourier series. The abscissas of the second, third, and fourth plots are

frequency in Hz. The third plot shows the modulus (the square root of the sum of the squares of the real and imaginary parts) of the transfer function. The transfer function is clearly seen to have a series of local peaks that illustrate the nature of amplification that will take place at the natural frequencies of the soil layer; note that the greatest amplification will take place at the lowest natural frequency (where the transfer function reaches its global maximum). The fourth plot shows the Fourier amplitude spectrum of the output (ground surface) motion which is numerically equal to the product of the input motion (second plot) and the transfer function (third plot). The origin of this spectrum is clearly seen by comparing the second, third, and fourth plots - the peaks in the fourth plot (the output motion) are related to the peaks in the second plot (the input motion) and the third plot (the transfer function). Finally, the last plot shows the output (ground surface) motion in the time domain as obtained by taking the inverse Fourier transform of the output motion in the frequency domain.

## MULTIPLE SOIL LAYERS

The basic approach described in the preceding sections is also used to analyze layered soil deposits in ProShake 2.0 - the only difference is that the transfer function is different for a layered soil deposit. The transfer function for a layered soil deposit must account for the transmission and reflection of waves at boundaries between adjacent layers, much as those factors were accounted for at the soil/rock boundary in the previous section.

Consider the soil deposit shown to the right. Within a given layer, say layer  $j$ , the horizontal displacements will be given by

$$u_j(z_j, t) = \left( A_j e^{ik_j^* z_j} + B_j e^{-ik_j^* z_j} \right) e^{i\omega t} \quad (11)$$

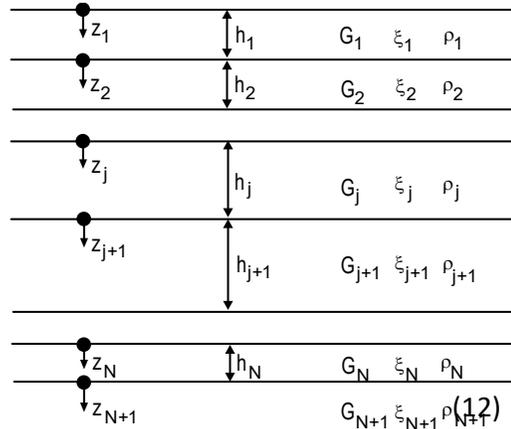
At the boundary between layer  $j$  and layer  $j+1$ , compatibility of displacements requires that

$$A_{j+1} + B_{j+1} = A_j e^{ik_j^* h_j} + B_j e^{-ik_j^* h_j}$$

Continuity of shear stresses requires that

$$A_{j+1} - B_{j+1} = \frac{G_j^* k_j^*}{G_{j+1}^* k_{j+1}^*} \left( A_j e^{ik_s^* h_j} - B_j e^{-ik_s^* h_j} \right) \quad (13)$$

Note that Equations (12) and (13) are analogous to Equations (7) and (8), respectively. Defining  $\alpha_j^*$  as the complex impedance ratio at the boundary between layers  $j$  and  $j+1$ , the wave amplitudes for layer  $j+1$  can be obtained from the amplitudes of layer  $j$  by solving Equations (12) and (13)



$$A_{j+1} = \frac{1}{2} A_j (1 + \alpha_j^*) e^{ik_j^* h_j} + \frac{1}{2} B_j (1 - \alpha_j^*) e^{-ik_j^* h_j} \quad (14a)$$

$$B_{j+1} = \frac{1}{2} A_j (1 - \alpha_j^*) e^{ik_j^* h_j} + \frac{1}{2} B_j (1 + \alpha_j^*) e^{-ik_j^* h_j} \quad (14b)$$

At the ground surface ( $z_1 = 0$ ), the requirement that the shear stress must be zero means that  $A_1 = B_1$ . Applying Equations (14) recursively for  $j = 1, 2, 3, \dots, N$ , the coefficients  $A_{j+1}$  and  $B_{j+1}$  can be related to  $A_j$  and  $B_j$  by

$$A_{j+1} = a_{j+1}(\omega) A_1 \quad (15a)$$

$$B_{j+1} = b_{j+1}(\omega) B_1 \quad (15b)$$

where the functions  $a_{j+1}(\omega)$  and  $b_{j+1}(\omega)$  represent the effects of the wave interactions that take place at all of the layer interfaces above layer  $j+1$ . Then, a transfer function relating the motions at the tops of any two layers, say layers  $i$  and  $j$ , can be expressed as

$$F_{ij}(\omega) = \frac{a_i(\omega) + b_i(\omega)}{a_j(\omega) + b_j(\omega)} \quad (16)$$

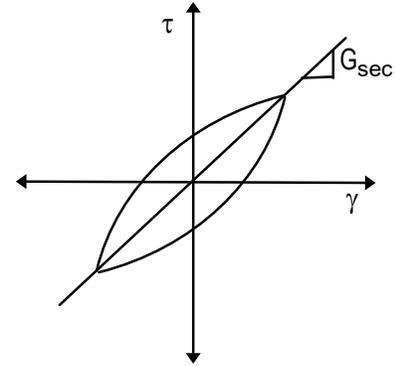
This transfer function can become quite complicated, but it is used in exactly the same way as the much simpler transfer function developed for the single layer case. In fact, the MATLAB program that illustrated the single layer case could be used to compute the response for a multi-layered problem by changing only one line - the line where the transfer function is defined (with the comment % left half of transfer function).

---

#### EQUIVALENT LINEAR ANALYSIS

The nonlinear and inelastic behavior of soil is well established in geotechnical engineering. The nonlinearity of soil stress-strain behavior means that the shear modulus of the soil is constantly changing. The inelasticity means that the soil unloads along a different path than its loading path, thereby dissipating energy at the points of contact between particles. Rigorous analysis of the mechanical response of soils to any type of loading, dynamic or otherwise, would require that the stress-strain behavior of each element of soil be tracked directly in the time domain. The method of analysis used in SHAKE (and ProShake 2.0) cannot allow for nonlinear stress-strain behavior because its representation of the input motion by a Fourier series and use of transfer functions for solution of the wave equation rely on the principle of superposition - which is only valid for linear systems.

To approximate the actual nonlinear, inelastic response of soil, an equivalent linear approach can be utilized. In the equivalent linear approach, linear analyses are performed with soil properties that are iteratively adjusted to be consistent with an effective level of shear strain induced in the soil. In the equivalent linear approach, the shear modulus is taken as the secant shear modulus which, as shown to the right, approximates an “average” shear modulus over an entire cycle of loading. As the level of shear strain increases, the secant shear modulus decreases. The relationship between secant shear modulus and shear strain amplitude can be characterized by means of a modulus reduction curve. The nature of this curve, which has an ordinate of modulus ratio ( $= G/G_{max}$ ) and an abscissa of  $\log$  (shear strain), has been well established for many soils. ProShake 2.0 has a library of modulus reduction relationships that can be selected in the Input Manager. The solution algorithm used in SHAKE (and ProShake 2.0) assumes viscous soil damping which it represents using a complex shear modulus. Viscous damping implies behavior that would be characterized by elliptical stress-strain loops. Because actual stress-strain loops are seldom elliptical, an equivalent damping ratio is used - the equivalent damping ratio is equal to the damping ratio that would be computed based on the area within the hysteresis loop, the secant shear modulus, and the maximum shear strain. The relationship between this equivalent damping ratio and shear strain is characterized by means of a damping curve. The nature of this curve, which has an ordinate of damping ratio and an abscissa of  $\log$  (shear strain), has been well established for many soils. ProShake 2.0 has a library of damping curves that can be selected in the Input Manager.



In an equivalent linear analysis, the first iteration is performed using shear modulus and damping ratios that correspond to some initially estimated level of shear strain. In ProShake 2.0, the first iteration is based on an assumed shear strain of 0.001%. Following the first iteration, the effective shear strain, defined as

$$\gamma_{eff} = R_{\gamma} \gamma_{max}$$

where  $R_{\gamma}$  is a strain reduction factor often taken as

$$R_{\gamma} = \frac{M-1}{10}$$

is computed. The shear modulus and damping ratio corresponding to  $\gamma_{eff}$  is then used for the next iteration. This process is repeated until the computed effective strain does not change much from one iteration to the next. At this point, the equivalent linear process is said to have converged.

While the equivalent linear approach allows the most important effects of nonlinear, inelastic soil behavior to be approximated, it must be emphasized that it remains a linear method of

analysis. The strain-compatible shear modulus and damping ratio remain constant throughout the duration of an earthquake - when the strains induced in the soil are small and when they are large. Permanent strains cannot be computed and porewater pressures cannot be computed. However, the equivalent linear approach has been shown to provide reasonable estimates of soil response under many conditions of practical importance.

## Verification

As stated earlier in the User's Manual, ProShake 2.0 was written from scratch using the same computational procedure used in the original version of SHAKE (Schnabel et al., 1972). Though the basic procedures are the same, some aspects of their numerical implementation were different. As a result, verification of the accuracy of ProShake 2.0 and comparison of its results with the results from previous versions of SHAKE are required.

### Verification Using Analytical Solutions

ProShake 2.0 has been verified against exact analytical solutions for the simple loading cases for which such solutions are available and found to produce accelerations that match the exact solutions perfectly to at least the first six decimal points (with acceleration measured in g's).

### Comparison with SHAKE

Additional verification of the numerical implementation of ProShake 2.0 can be obtained by comparing its results with those of previous versions of SHAKE when both are applied to the same problem. Because SHAKE91 is the most commonly used version of SHAKE in geotechnical earthquake engineering practice, a number of such comparisons between ProShake 2.0 and SHAKE91 have been performed; the results of a typical comparison are described in this section.

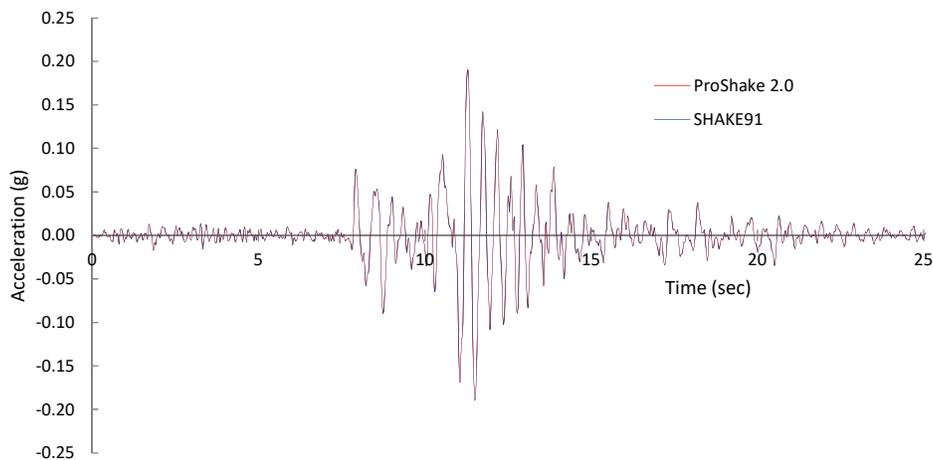
The numerical implementation of ProShake 2.0 differs from that of SHAKE91 in the following ways:

1. ProShake 2.0 uses 32-bit (and 64-bit in the 64-bit version) arithmetic rather than the 16-bit arithmetic used in SHAKE91. This is primarily a result of advances in computing technology and development platforms.
2. ProShake 2.0 uses a different Fast Fourier Transform (FFT) routine. The routine used in ProShake 2.0, taken from the International Mathematical Software Library (IMSL<sup>®</sup>) Numerical Libraries, represents a more recent and efficient implementation of the FFT.
3. ProShake 2.0 uses a more efficient and robust procedure to iterate toward strain-compatible soil properties. For most analyses, the last iteration required to drop the modulus and damping error below the specified error tolerance in ProShake 2.0 will produce smaller final errors than the last iteration for the same error tolerance in SHAKE91.
4. ProShake 2.0 handles cutoff frequencies slightly differently than SHAKE91. SHAKE91 applies its cutoff frequency *after* scaling the input motion to the specified peak acceleration; as a result, the actual peak acceleration used in the analysis can be different than the desired peak acceleration. ProShake 2.0 applies the cutoff frequency *before* any required scaling - in this way, the accelerations that are actually used as input in the analysis are equal to the desired accelerations. The

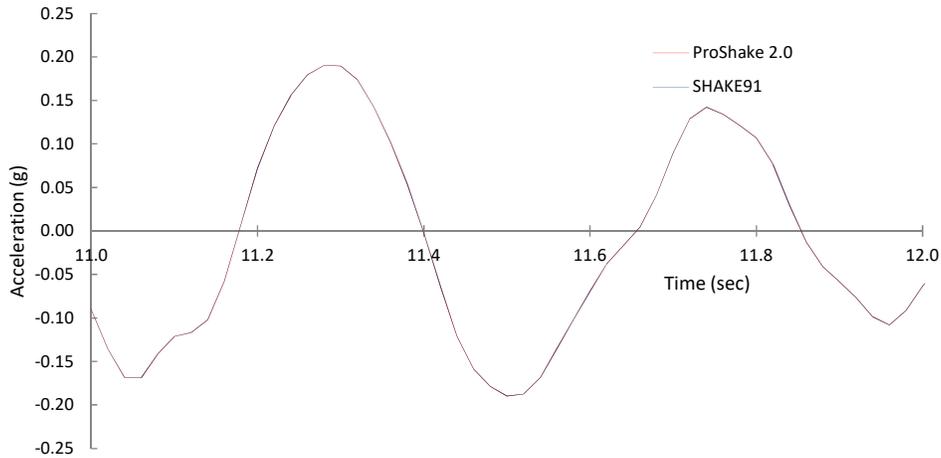
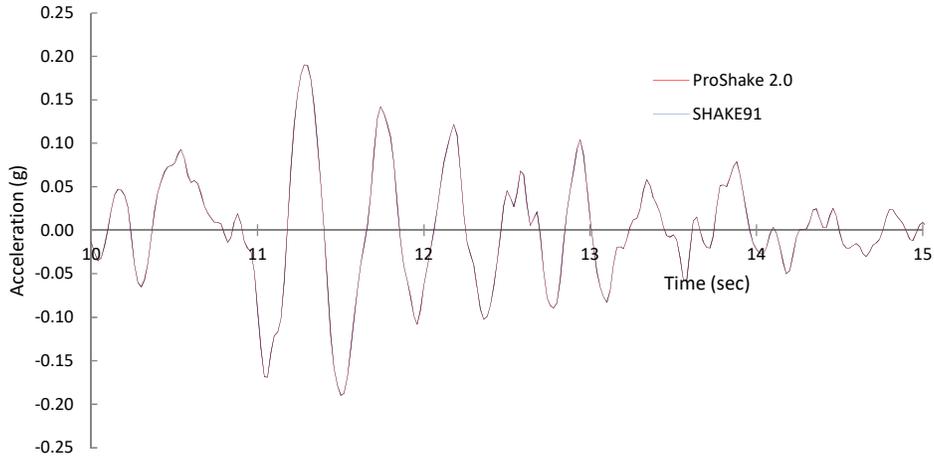
difference between these approaches is small for reasonably high cutoff frequencies, but the approach taken in ProShake 2.0 is considered to be more appropriate. To achieve the same behavior in ProShake 2.0 as SHAKE91, the user can set the cutoff frequency to Nyquist frequency, calculated as  $1/(2\Delta t)$ , the default value set by ProShake 2.0.

5. ProShake 2.0 uses a more precise value of  $32.174 \text{ ft/s}^2$  for standard acceleration of gravity while SHAKE91 uses  $32.2 \text{ ft/s}^2$ .
6. Though SHAKE91 accepts strain-dependent modulus reduction and damping curves for the halfspace, internally it does not use the modulus reduction and damping curves provided during iterating towards strain-compatible values, instead it uses the maximum modulus and damping values specified for halfspace in Soil Profile data section. ProShake 2.0 uses modulus reduction and damping curves provided for halfspace when iterating towards strain-compatible values, using strain values at the top of the halfspace. To achieve the same behavior in ProShake 2.0 as SHAKE91, the user can specify linear material type for halfspace.

The relative performance of ProShake 2.0 and SHAKE91 can be illustrated using the example problem from the original SHAKE User's Manual (Schnabel et al., 1972). This problem, for which the input file is contained in the file shake.dat, involves the response of a 150-ft-thick soil deposit. Analyzing the deposit using both ProShake 2.0 and SHAKE91 produces the time histories of ground surface acceleration shown below:

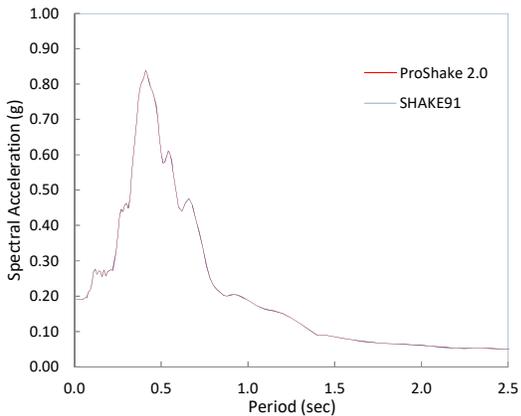


The differences between the ground surface accelerations produced by ProShake 2.0 and SHAKE91 are very small. To make these differences more apparent, portions of the time histories are expanded in the two plots shown below:

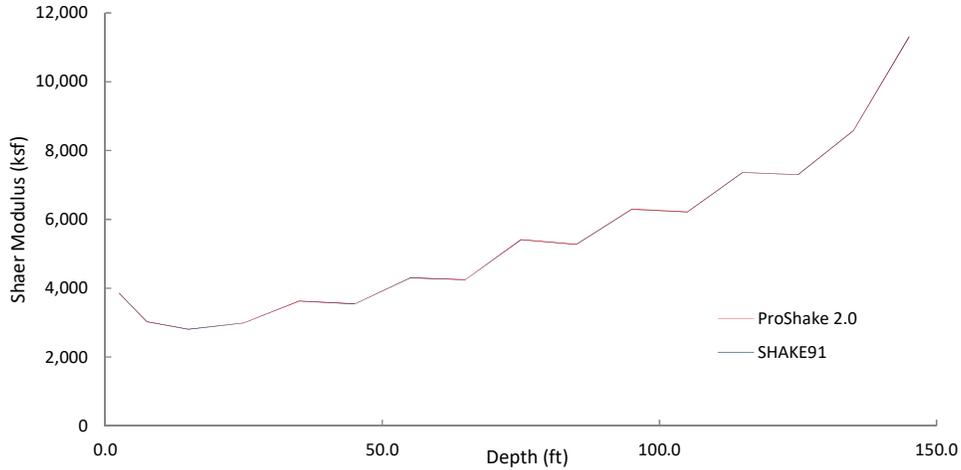


Even when the time scale is expanded tremendously, the strongest part of the computed response shows very close agreement between the two programs.

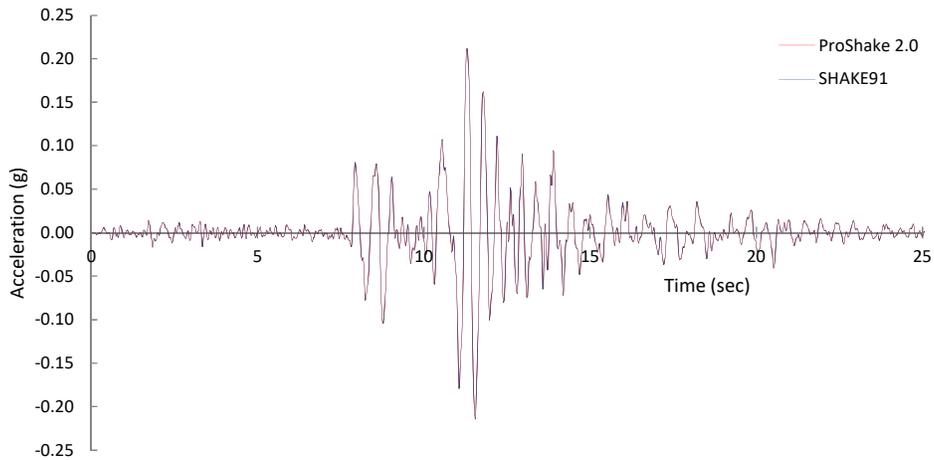
The programs can also be compared from the standpoint of response spectra - the computed ground surface response spectra for structural damping ratios of 5% is illustrated to the right. Again, the response spectra are very similar.



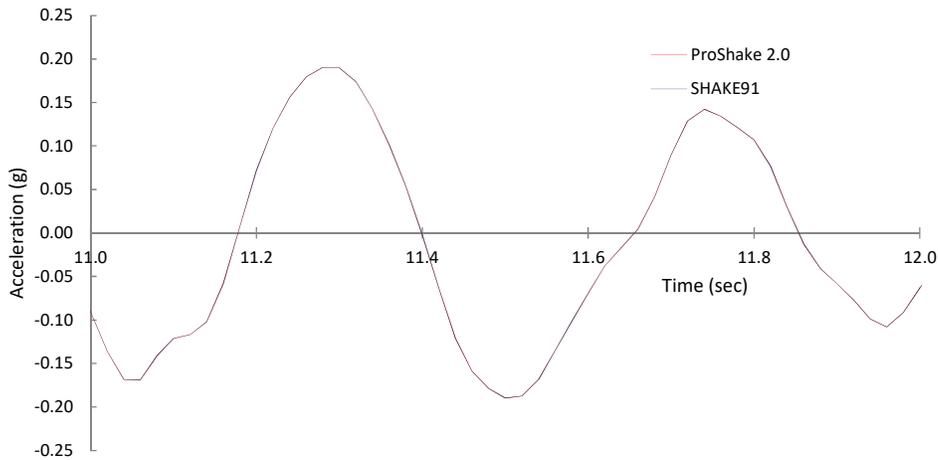
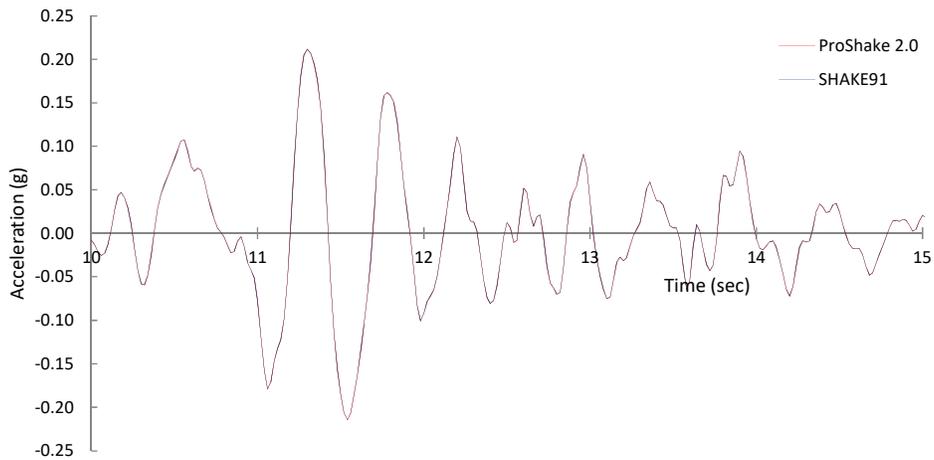
Another comparison can be made with respect to the equivalent linear properties that both programs converge to. The equivalent linear shear moduli from the final iteration of ProShake 2.0 and SHAKE91 are shown below. Again, the very close agreement between the moduli from the two programs verifies their consistency.



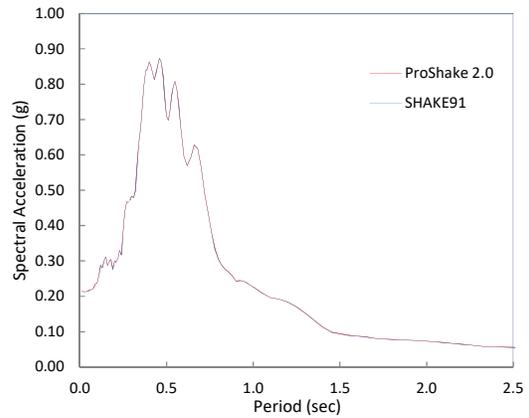
The same set of comparisons can be made for other ground response problems. The following plots compare the responses predicted by ProShake 2.0 and SHAKE91 when both are applied to the problem described in the Tutorial section of this User’s Manual. The tutorial problem involved a 50 ft thick layer of soft silty clay overlaying a 50 ft thick layer of stiff clay. The earthquake motion file uses in DIAM.EQ (Loma P. Eqk Diamond Hts H1\_90) and “Modulus for Clay - Seed & Sun 1989 Upper Range” modulus reduction and “Damping for Clay (Idriss 1990)” damping curves were used for all soil layers. “Rock (Idriss)” modulus reduction and damping curves were used for bedrock (halfspace). The thick, soft nature of the silty clay layer also produces ground surface motions with relatively low accelerations and long periods. The following plot illustrates this response:



Again, the differences between the ground surface accelerations produced by ProShake 2.0 and SHAKE91 are very small, even when the time scale is expanded as shown below:



Response spectra are also very similar as illustrated for structural damping ratio of 5% to the right. The distinguishing feature of the tutorial problem, from the ground response standpoint, is the presence of the strong impedance contrast at the boundary between the soft silty clay and the stiff clay. This impedance contrast causes large strains near the bottom of the soft silty clay layer that leads to low shear moduli in the equivalent linear model.



## STRONG MOTION PARAMETERS

ProShake 2.0 will also compute a series of scalar ground motion parameters, or intensity measures (IMs) that can be useful indicators of ground motion characteristics.

### PEAK ACCELERATION

The maximum absolute value of acceleration. The peak acceleration provides a useful measure of the strength of the higher frequency components of a ground motion.

### PEAK VELOCITY

The maximum absolute value of velocity. The peak velocity provides a useful measure of the strength of the intermediate frequency components of a ground motion.

### PEAK DISPLACEMENT

The maximum absolute value of displacement. The peak displacement provides a useful measure of the strength of the lower frequency components of a ground motion.

### RMS ACCELERATION

The RMS acceleration is a single parameter that includes the effects of the amplitude and frequency content of a strong motion record

$$a_{RMS} = \sqrt{\frac{1}{T_d} \int_0^{T_d} [a(t)]^2 dt}$$

where  $T_d$  is the duration of the motion. Because the integral is not strongly influenced by large, high frequency accelerations (which occur only over a very short period of time) and because it is influenced by the duration of the motion, the rms acceleration can be very useful for engineering purposes. ProShake 2.0 uses the Trifunac duration for computation of the RMS acceleration.

### ARIAS INTENSITY

The Arias Intensity (Arias, 1970), also influenced by amplitude, frequency content, and duration, is defined as

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

The Arias Intensity has units of velocity and is usually expressed in meters per second. Since it is obtained by integration over the entire duration, rather than over the duration of strong motion, its value is independent of the method used to define the duration of strong motion.

## RESPONSE SPECTRUM INTENSITY

The response spectrum intensity (Housner, 1959) is defined as

$$SI(\xi) = \int_{0.1}^{2.5} PSV(\xi, T) dT$$

i.e., the area under the pseudo-velocity response spectrum between periods of 0.1 second and 2.5 seconds. In ProShake 2.0, the response spectrum intensity is computed for a structural damping ratio of 5%. It captures important aspects of the amplitude and frequency content (in the range of primary importance for structures) in a single parameter.

## PREDOMINANT PERIOD

The predominant period is the period corresponding to the maximum value of the Fourier spectrum. Because Fourier spectra are typically quite jagged, the period corresponding to the highest peak in a raw spectrum may not correspond well to the strongest part of the motion. For that reason, some users may want to obtain predominant periods from smoothed spectra. The cross-hair feature can be used to estimate predominant period from ProShake 2.0 Fourier spectrum plots.

## BRACKETED DURATION

The bracketed duration is the time interval between the first and last exceedances of a threshold acceleration (Bolt, 1969). The threshold acceleration is set at 0.05g in ProShake 2.0.

## SIGNIFICANT DURATION

The significant duration (Trifunac and Brady, 1975) is defined as the time interval between the points at which 5% and 95% of the energy in a ground motion have been delivered. Numerically, it corresponds to the time between the 5% and 95% points on a Husid plot.

## BUILT-IN SOIL MODELS

### DARENDELI (2001)

Darendeli (2001) supplemented multiple sets of published data with additional resonant column and torsional shear tests on soil samples from multiple sites in California, South Carolina, and Taiwan to develop a database that covers a wide range of soil types, depths, densities, plasticity characteristics, and stress histories. A modified hyperbolic model was found to fit the experimental results well. In the Darendeli (2001) model, the degree of linearity increases with increasing  $PI$ ,  $OCR$ , and mean effective stress,  $\sigma'_{m0}$ .

### EPRI

The Electric Power Research Institute (EPRI) (1993) model was developed following the 1989 Loma Prieta earthquake using strong-motion data from three earthquakes: the 1979 Coyote Lake earthquake, the 1984 Morgan Hill earthquake, and the 1989 Loma Prieta earthquake. The modulus reduction and damping curves were developed for generic applications to cohesionless soils in the general range of gravelly sands to low plasticity silts or sandy clays. EPRI model is presented as function depth ranges and ProShake 2.0 user mid-layer depth to select appropriate curves when EPRI soil model is selected.

### ISHIBASHI & ZHANG (1993)

Modulus reduction and damping characteristics, particularly for low-plasticity soils, are also influenced by effective confining pressure. Ishibashi and Zhang (1993) proposed expressions for shear modulus and damping ratio that accounted for plasticity index and effective confining pressure. ProShake 2.0 will compute the effective confining pressure, but you must provide the plasticity index. In calculating the effective confining pressure an at rest earth pressure coefficient ( $K_0$ ) of 0.5 is assumed. It should be noted that the actual Ishibashi and Zhang equations predict  $G/G_{max}$  values slightly greater than 1 over a range of low strains. ProShake 2.0 sets  $G/G_{max} = 1.0$  for these values. ProShake 2.0 does not modify the damping curves, however, for the effects of this limiting value. See also Ishibashi (1992).

### GRAVEL (SEED ET AL.)

Seed et al. (1984) developed modulus reduction and damping curves for gravel. These curves are based on the average behavior of 12-inch diameter cyclic triaxial tests on four different gravels.

### LINEAR

ProShake 2.0 allows you to specify a linear elastic or linear viscoelastic material. When you select this material, ProShake 2.0 will use the maximum shear modulus and prompt you to enter a damping ratio. You should note that the transfer function for an undamped linear elastic layer

will have singularities at the natural frequencies of the layers; these can lead to numerical problems that prevent program execution.

#### MENQ (2003)

Menq (2003) tested a number of coarse sandy ( $D_{50}$  greater than about 0.3 mm) and gravelly soils and found that the modulus reduction behavior could also be characterized by a modified hyperbolic model. Nonlinearity in the Menq model is unrelated to mean grain size ( $D_{50}$ ), but decreases with increasing effective stress and increases with increasing coefficient of uniformity,  $C_u$ . The Menq model has superseded the Darendeli model for coarse-grained soils

#### ROCK (IDRISS)

Modulus reduction and damping curves for rock were included in sample data files for the original SHAKE program (Schnabel et al., 1970).

#### SAND (SEED & IDRISS)

Seed and Idriss (1970) developed the first widely used modulus reduction and damping curves for sand. Their curves showed a range of modulus reduction behavior. ProShake 2.0 allows you to their upper bound modulus reduction curve along with their lower bound damping curve. This soil model represents the “Sand (Seed-Idriss) – Upper Bound” modulus reduction and “Sand (Seed-Idriss) – Lower Bound” damping curves.

#### VUCETIC-DOBRY

Vucetic and Dobry (1991), building on the work of Kokoshu (1980) in an investigation motivated by the performance of Mexico City clay in the 1985 Michoacan earthquake, showed clearly how modulus and damping behavior are influenced by soil plasticity. Vucetic and Dobry developed families of modulus reduction and damping curves as functions of plasticity index. ProShake 2.0 allows you to specify any plasticity index - the program will determine the corresponding curves by interpolation. The curves originally proposed by Vucetic and Dobry are shown on the plots in green; from left to right, they represent  $PI = 0$ ,  $PI = 15$ ,  $PI = 30$ ,  $PI = 50$ ,  $PI = 100$ , and  $PI = 200$ . The curve for the selected  $PI$  is obtained by linear interpolation and shown in yellow. See also Dobry and Vucetic (1987).

## DEFINITIONS

**Tab Label** - the label found on the protruding portion of a tab form. The tab label shows which of the tab forms is active. Only one tab form can be active at a time.

**Analysis Summary** - a summary of the soil profile, input motion, and output selections for the analysis. The analysis summary is written to the Report - from there, it can be printed and placed in a project or assignment file.

**Input Motion Format** - ProShake 2.0 input motion files are formatted in a certain way. The two input motion files included in the distribution of ProShake 2.0, yerba.eq and treas.eq, are in the proper format. Input motion files in any other format can be converted to ProShake 2.0 Input Motion Format by using the Convert Ground Motion File utility.

**Trailing Zeroes** - acceleration values of 0.0 that are appended to the end of an input motion file to bring the total number of acceleration values to an integer power of 2.

**Quiet Zone** - a portion of an input motion with zero (or very small) accelerations. Because the frequency domain solution of ProShake 2.0 implies periodicity (i.e., that the input motion repeats itself indefinitely), a quiet zone may be required for the computed response to an individual application of the input motion to be distinct.

**Frequency Content** - the distribution of acceleration amplitudes in the frequency domain. The frequency content can be obtained from the shape of the Fourier spectrum of the motion.

**Drag-and-Drop** - By holding the left mouse button down, any line (corresponding to a particular material layer) can be copied and placed at the location of the cursor at the time the left mouse button is released.

**Modulus Error** - the difference between shear modulus values in successive iterations divided by the shear modulus value used in the most recent iteration (expressed as a percentage).

**Damping Error** - the difference between damping ratio values in successive iterations divided by the damping ratio value used in the most recent iteration (expressed as a percentage).

**Impedance Ratio** - the ratio of specific impedances of two adjacent soil layers, where the specific impedance is defined as the product of the density and shear wave velocity of a material.

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