DEEPSOIL V3.7

1-D Non-linear and Equivalent Linear Wave Propagation Analysis Program
for Geotechnical Seismic Site Response Analysis of Soil Deposits

Version 3.7 Beta

www.illinois.edu/~deepsoil

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USER MANUAL and TUTORIAL

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UNIT 1 Background

1.1 *About DEEPSOIL*

DEEPSOIL is a one-dimensional site response analysis program that can perform both a) 1-D nonlinear and b) 1-D equivalent linear analyses and features an intuitive graphical user interface.

DEEPSOIL was developed under the direction of Prof. Youssef M.A. Hashash in collaboration with several graduate and undergraduate students including Duhee Park, Chi-Chin Tsai, Camilo Phillips, David Groholski and Daniel Turner at the University of Illinois at Urbana-Champaign.

Development of DEEPSOIL was supported in part through Earthquake Engineering Research Centers Program of the National Science Foundation under Award Number EEC-9701785; the Mid-America Earthquake Center. Additional support was received from University of Illinois at Urbana-Champaign. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors gratefully acknowledge this support.

Please see the program license for additional information.

When referencing the DEEPSOIL program in a publication (Journal or conference paper, professional reports) please use the following reference format:

Hashash, Y.M.A, Groholski, D.R., Phillips, C. A., Park, D. (2009) “DEEPSOIL V3.7beta, User Manual and Tutorial.” 88 p.

The program is provided as-is and the user assumes responsibility for all results. The use of the DEEPSOIL program requires knowledge in the theory and procedures for seismic site response analysis. It is suggested that the user reviews relevant literature.

1.2 *Program installation*

Installing DEEPSOIL Using Setup

Hardware Requirements
Pentium 400MHz+ (700+ recommended).

Software Requirements
Windows XP SP2 or later.
Microsoft .NET Framework 2.0 or later.

Installation
Run Deepsoilv3_7.msi.

Main Features

1-D equivalent linear frequency domain analysis method.

1-D non-linear time domain wave propagation analysis method.

Graphical User Interface

1.3 *DEEPSOIL features*

The main features of DEEPSOIL are:

1D equivalent linear analysis:

- Unlimited number of layers / material properties / number of acceleration data points of input ground motion
- 3 types of complex shear modulus

1D nonlinear analysis:

- Confining pressure dependent soil model
- 4 types of viscous damping formulations
- Increased numerical accuracy and efficiency
- Pore water pressure generation (Matasovic and Vucetic, 1993, 1995; Green et al., 2000)/dissipation capability.

Graphical user-interface:

- Visual selection of optimum modes/frequencies of the viscous damping formulation
- Visual selection of nonlinear soil parameters: Once the nonlinear soil parameters are selected, G/Gmax and damping ratio curves can be calculated / displayed and compared to selected reference curves.
- Allows both English and metric units
- Animation of horizontal displacement of the soil column (only for time domain analysis)
- Convergence check (only for equivalent linear analysis): DEEPSOIL displays the maximum strain profile for each iteration in performing equivalent linear analysis. This feature allows easy checking of whether the solution has converged.
- PGA profile
- DEEPSOIL displays acceleration, strain, stress time histories, Fourier response spectrum, Fourier amplification ratio spectrum, and response spectrum at selected layers. It is also possible to export output into text files
- DEEPSOIL can convert NEHRP Site class A motion to Site class B/C motion and vice versa.
- DEEPSOIL can baseline correct any motion in the library
- Output data is automatically exported for the user's future reference

1.4 *DEEPSOIL updates from v2.6*

- The DEEPSOIL user interface has been revamped. It now consists of individual windows instead of multiple windows nested within a multiple-document interface.
- Hotkeys have been enabled for copying, cutting, and pasting components from/to spreadsheet cells
- The Damping Ratio column in Step 2/6 is now properly labeled with a "%"
- When running a linear frequency domain analysis, the input for effective shear strain is now disabled
- The "Tab" order of the Half-space form has been reorganized
- Saving a material data file now warns the user of possible overwriting
- The equations for Complex Shear Modulus on Step 3/6 have been corrected
- The selection of "Analysis Type" has been moved to Step 1/6
- The radio buttons for "Pore Pressure Model" have been removed from Step 2/6
- The radio buttons for "Input Motion Location" have been removed from Step 4/6 and are now inherently selected when the user selects either an elastic or rigid half-space.
- DEEPSOIL now allows the user to specify a "working directory" in Step 1/6. This will be the default directory to save profiles and exported output. You may change this directory at any time by selecting "Change Workspace" from the "File" menu or from the "Change Workspace" button in Step 1/6.
- Output from the analysis is now automatically exported to "ExportOutput.txt" in your working directory. The "Export Output" button has been removed from Step 6/6,
- The options for pore water pressure generation and dissipation are now enabled for analysis
- Selecting an "Effective Stress Analysis including Porewater Pressure Dissipation" now requires the user to specify the boundary condition for the bottom of the profile. The bottom of the profile can be treated as either a fully permeable or impermeable boundary.
- Selection of bedrock type has been removed from Step 1/6 and is now only located in Step 2b/6.
- The table in Step 2/6 now requires entries for the pore water pressure models if an "Effective Stress" analysis is chosen in Step 1/6
- A new "Model Properties" button has been added to Step 2/6. This button performs the same function as the "Save/Calc Curves" command.

- A curve fitting procedure for fitting the G/GMAX and Damping curves has been provided in the Model/Layer Properties form. Instructions for using this procedure are illustrated in Unit 3.4.
- The “Check Max. Frequency” button has been removed from Step 2/6. “Check Max. Frequency” is now an automatic step which takes place after Step 2/6 for time domain analyses.
- Step 5/6 now includes a “Use Recommended Frequencies” button for the user. The initial estimates for recommended frequencies are: 1) the natural frequency of the soil profile, and 2) five times the natural frequency of the soil profile. The button is only available if the damping matrix is defined by frequencies.
- A new "Model Properties" button has been added to Step 2. This button functions the same as selecting the "Save/Calc Curves" menu item from the spreadsheet or profile.
- Batch Mode Analysis is now available to the user. In this analysis, the user defines a soil profile and may subject it to many input motions during one session (i.e. the user will not have to re-define or re-open the profile to perform the same type of analysis with a different input motion).
- The functionality of the cell tables used for data entering/editing have been improved such that the copying and pasting of data functions similar to other spreadsheet-style applications.
- The Delete key will now clear the contents of the selected cell in the cell tables.
- DEEPSOIL can now export output data directly to a Microsoft Excel file. This option is available in Step 6.
- Included a new pore water pressure generation model for sands – the GMP Model (Green et al., 2000)

1.5 *DEEPSOIL a historical perspective*

DEEPSOIL has been under development at UIUC since 1998. The driving motivation of the development of DEEPSOIL was and continues to be making site response analysis readily accessible to students and engineers and to support research activities at UIUC.

In DEEPSOIL we maintain that it is always necessary to perform both equivalent linear and nonlinear site response analyses. Therefore DEEPSOIL since its inception has incorporated both analysis capabilities. As with any development, DEEPSOIL has benefited from many prior developments by other researchers as well as current and former students at UIUC. For the interested reader, a detailed description of many of the theoretical developments and the background literature can be found in the following publications:

Hashash, Youssef M. A., and Duhee Park (2001) "Non-linear one-dimensional seismic ground motion propagation in the Mississippi embayment," Engineering Geology, Vol. 62, No. 1-3, pp 185-206.

Hashash, Y. M. A., and D. Park (2002) "Viscous damping formulation and high frequency motion propagation in nonlinear site response analysis," Soil Dynamics and Earthquake Engineering, Vol. 22, No. 7, pp pp. 611-624.

Hashash, Y. M.A., Chi-Chin Tsai, C. Phillips, and D. Park (2008) "Soil column depth dependent seismic site coefficients and hazard maps for the Upper Mississippi Embayment," Bull. Seism. Soc. Am., Vol. in press.

Park, D. (2003) "Estimation of non-linear seismic site effects for deep deposits of the Mississippi Embayment," Ph.D. Thesis. Department of Civil and Environmental Engineering. Urbana: University of Illinois, p 311 p.

Park, D., and Y. M. A. Hashash (2004) "Soil damping formulation in nonlinear time domain site response analysis," Journal of Earthquake Engineering, Vol. 8, No. 2, pp 249-274.

Park, D., and Y.M.A. Hashash (2005) "Estimation of seismic factors in the Mississippi Embayment: I. Estimation of dynamic properties," Soil Dynamics and Earthquake Engineering, Vol. 25, pp pp. 133-144.

Park, D., and Y.M.A. Hashash (2005) "Estimation of seismic factors in the Mississippi Embayment: II. Probabilistic seismic hazard with nonlinear site effects," Soil Dynamics and Earthquake Engineering, Vol. 25, pp pp. 145-156.

Tsai, Chi-Chin (2007) "Seismic Site Response and Interpretation of Dynamic Soil Behavior from Downhole Array Measurements," Ph.D. Thesis. Department of Civil and Environmental Engineering. Urbana: University of Illinois at Urbana-Champaign.

Tsai, Chi-Chin, and Y. M. A. Hashash (2008) "A novel framework integrating downhole array data and site response analysis to extract dynamic soil behavior.," Soil Dynamics and Earthquake Engineering, Vol. Volume 28, No. Issue 3, pp pp 181-197.

Tsai, Chi-Chin, and Youssef M.A. Hashash (2009) "Learning of dynamic soil behavior from downhole arrays," Journal of geotechincal and geoenvironmental engineering, Vol. in press.

Phillips, Camilo, and Youssef M. A. Hashash (2008) "A new simplified constitutive model to simultaneously match modulus reduction and damping soil curves for nonlinear site response analysis," Geotechnical Earthquake Engineering & Soil Dynamics IV (GEESD IV). Sacramento, California.

Phillips, C. and Hashash, Y. (2009) “Damping formulation for non-linear 1D site response analyses” Soil Dynamics and Earthquake Engineering, Vol. 29, No. 7, pp 1143-1158.

The executable version of DEEPSOIL was originally (circa 1998-1999) developed as a MATLAB program and (circa 1999) later redeveloped as a C based executable to improve computational efficiency. A visual user interface was added soon afterwards. Since then, numerous developments have been added. Listed below are some important milestones:

- DEEPSOIL v1.0: First version of DEEPSOIL with both an equivalent linear analysis capability and a new pressure dependent hyperbolic model in nonlinear analysis:
    - The equivalent linear capability was based on the pioneering work of Idriss and Seed (1968), and Seed and Idriss (1970) as employed in the widely used program SHAKE (Schnabel, et al., 1972) and its more current version SHAKE91 (Idriss and Sun, 1992).
    - The new pressure dependent hyperbolic model introduced by Park and Hashash (2001) is employed in nonlinear analysis. This model extended the hyperbolic model introduced by Matasovic (1992) and employed in the nonlinear site response code D-MOD, which was in turn a modification of the Konder and Zelasko (1963) hyperbolic model. The hyperbolic model had been employed with Masing criteria earlier in the program DESRA by Lee and Finn (1975, 1978). The hyperbolic model was originally proposed by Duncan and Chang (1970), with numerous modifications in other works such as Hardin and Drnevich (1972) and Finn et al. (1977).
- DEEPSOIL v2.0-2.6:
    - Full and extended Rayleigh damping is introduced in DEEPSOIL (Hashash and Park, 2002; Park and Hashash, 2004) with a user interface. This was in part based on Clough and Penzein (1993) and the findings of Hudson et al. (1994) as implemented in the program QUAD4-M.
    - Additional developments and modification are made in DEEPSOIL benefited greatly from the PEER lifeline project "Benchmarking of Nonlinear Geotechnical Ground Response Analysis Procedures (PEER 2G02)". http://cee.ea.ucla.edu/faculty/jstewart/groundmotions/PEER2G02/index.htm.
- DEEPSOIL v3.0-3.7: Additional enhancements are made to the user interface as well
    - Pore water pressure generation capability is added to DEEPSOIL including dissipation.
        - Current pore water pressure models employed include the same model introduced by Matasovic (1992), Matasovic and Vucetic [1993, 1995]) and employed in the program D_MOD.

        - The current dissipation model used in DEEPSOIL is derived from FDM considerations.

    - DEEPSOIL v3.5: A new soil constitutive model is introduced to allow for significantly enhanced matching of both the target modulus reduction and damping curves (Phillips and Hashash, 2008).

    - A new functionality in the user interface is implemented that allows the user to automatically generate hyperbolic model parameters using a variety of methods (Phillips and Hashash, 2008).

    - DEEPSOIL v3.7: A new pore water pressure generation model for sands is added – the GMP Model (Green et al., 2000), in addition to various improvements in the user interface, as well as the capability to export output data to a Microsoft Excel file.

The evolution of DEEPSOIL is a continuous process with a number of planned developments for future release. Some of these planned developments are listed below:

- Further enhancement of the user interface
- Implementation of additional pore water pressure generation models
- Automatic randomization of soil profiles for batch mode analysis
- User-optional implementation of neural network models

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Hardin, B. O. and Drnevich, V. P. (1972) “Shear modulus and damping in soils: Design equations and curves.” Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 98, No. SM7, 667-692.

Hashash, Y. M. A., and D. Park (2002) "Viscous damping formulation and high frequency motion propagation in nonlinear site response analysis," Soil Dynamics and Earthquake Engineering, Vol. 22, No. 7, pp pp. 611-624.

Hudson, M., Idriss, I.M., and Beikae, M. 1994. (1994) "QUAD4M - A computer program to evaluate the seismic response of soil structures using finite element procedures and incorporating a compliant base." Davis, CA: Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis, CA.

Idriss, I. M. and Seed, H. B. (1968) “Seismic response of horizontal soil layers.” Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 94, No. SM4, pp 1003-1031.

Idriss, I. M. and Sun, J. I. (1992) “User’s Manual for SHAKE91, A Computer Program for Conducting Equivalent Linear Seismic Response Analyses of Horizontally Layered Soil Deposits”

Konder, R. L. and Zelasko, J. S. (1963) “A hyperbolic stress-strain formulation of sands.” Proceedings of the 2nd Pan American Conference on Soil Mechanics and Foundation Engineering, Sao Paulo, Brasil, 289-324.

Lee, M. K. W. and Finn, W. D. L (1975) “DESRA-1, Program for the dynamic effective stress response analysis of soil deposits including liquefaction evaluation.” Soil Mechanics Series No. 36, Department of Civil Engineering, University of British Columbia, Vancouver, Canada.

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Matasovic, N. (1992) “Seismic response of composite horizontally-layered soil deposits.” Ph.D. Thesis, University of California, Los Angeles.

Matasovic, Neven, and M. Vucetic (1993) "Cyclic Characterization of Liquefiable Sands," ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 119, No. 11, pp 1805-1822.

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Phillips, Camilo, and Youssef M. A. Hashash (2008) "A new simplified constitutive model to simultaneously match modulus reduction and damping soil curves for nonlinear site response analysis," Geotechnical Earthquake Engineering & Soil Dynamics IV (GEESD IV). Sacramento, California.

Phillips, C. and Hashash, Y. (2009) "Damping formulation for non-linear 1D site response analyses" Soil Dynamics and Earthquake Engineering, accepted for publication.

Schnabel, P. B., Lysmer, J. and Seed, H. B. (1972) "SHAKE: A computer program for earthquake response analysis of horizontally layered sites." Report No. EERC 72-12, Earthquake Engineering Research Center, University of California, Berkeley, California.

Seed, H. B. and Idriss, I. M. (1970) "Soil moduli and damping factors for dynamic response analyses." Report No. EERC 70-10, Earthquake Engineering Research Center, University of California, Berkeley, California, 40p.

1.6 *Known issues*

There are some known issues with DEEPSOIL that have yet to be resolved, including:

- A "Save Changes" prompt appears when clicking "Analyze" even when everything has already been saved.
- While working with any graphs, a runtime error is generated and the program terminates if the "B" key is pressed
- Scaling of the layer profile is not implemented at this time
- The ability to copy plots from the program as an image file is not implemented at this time (NOTE: The DynaPlot User Interface Navigation information presents an alternative to capturing an image of the plot)

UNIT 2 User Manual

2.1 *DEEPSOIL Structure*

The DEEPSOIL graphical user interface is composed of 5 (for equivalent linear) / 6 (for nonlinear) stages/windows and intuitively guides the user from the beginning to the end of the site response analysis. The logic is mapped out in the flowchart below:

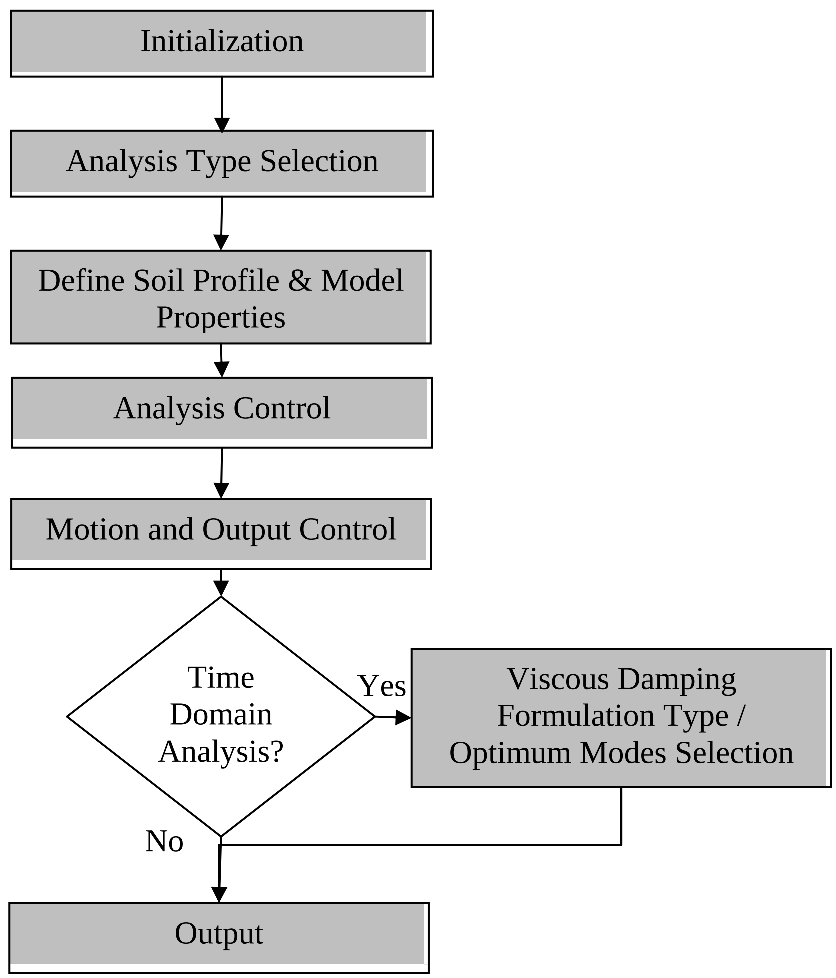


Figure 1. DEEPSOIL structure flowchart.

2.2 *Initialization*

Upon starting the DEEPSOIL program, the user is presented with the initialization screen shown in Figure 2.

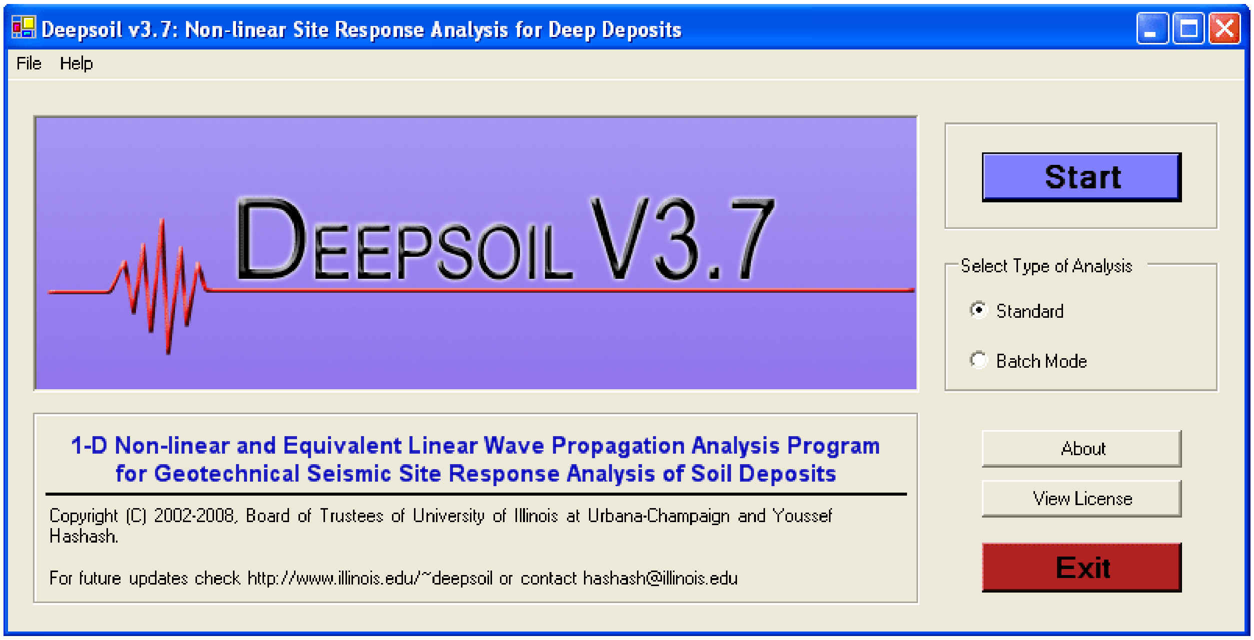


Figure 2. DEEPSOIL Start/Initialization screen.

At this stage, the user must select whether a Standard or Batch Mode analysis will be performed. In the Standard analysis, the user defines a profile and corresponding properties and propagates a single input motion through the profile. In the Batch Mode analysis, the user defines a profile and corresponding properties as in the Standard analysis, but a queue of input motions is constructed to propagate through the soil profile. In the Batch Mode, an individual analysis will be performed with output data automatically exported to the user workspace for each input motion.

The “About” button provides summary data regarding the DEEPSOIL program.

“View License” will allow the user to review the DEEPSOIL license agreement.

The “Exit” button closes the DEEPSOIL program.

Once the user has selected either the Standard or Batch Mode analysis, the “Start” key will initialize the corresponding program. If this is the user’s first time starting DEEPSOIL, the license agreement will appear and will need to be accepted before the program will function.

2.3 *Analysis Type Selection: Step 1 of 6*

The first step in the analysis requires the selection of analysis type. Figure 3 illustrates the form for Step 1. At this stage, the user may either: a) open a previously saved profile by clicking the “Open Existing Profile” button, or b) create a new analysis. The user may also specify a workspace or “working directory” to use during this session.

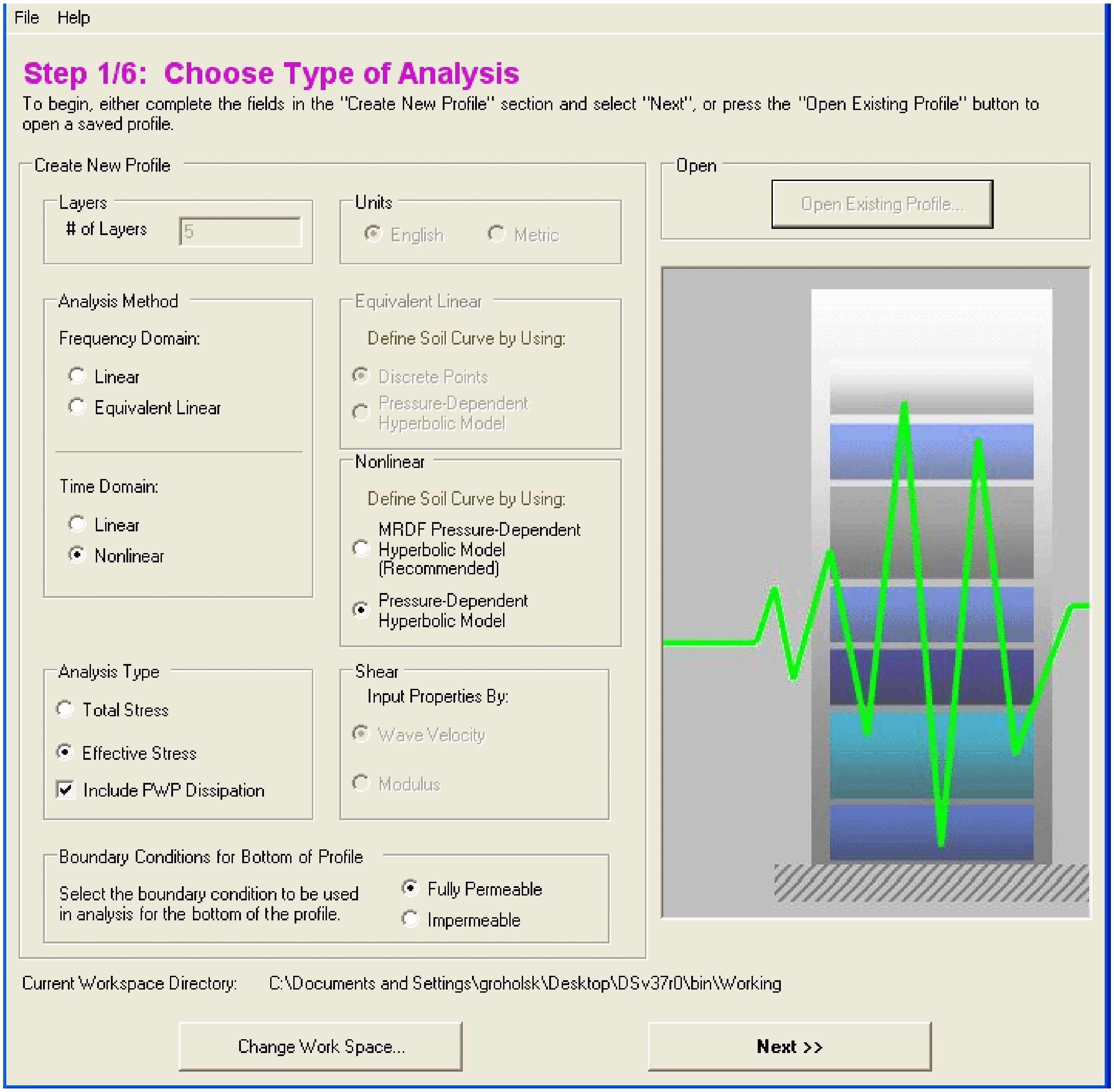


Figure 3. Step 1/6: Choose type of analysis.

Before creating a new profile or opening an existing profile, it is recommended to verify the "Current Workspace Directory" at the bottom of the page. The DEEPSOIL "Working" directory is chosen by default. If a different directory is preferred, press the "Change Work Space" button to bring up a folder browser and select the new directory. The specified directory should automatically update in Step 1/6.

To use a previously saved profile, click the "Open Existing Profile" button located at the top-right corner of the form. A browser window will appear which allows the user to navigate folders to find an existing profile. Note that the default directory will be either: a) the user-defined working directory, or b) the DEEPSOIL program directory (if the user-defined working directory does not exist).

To create a new analysis, the user must specify the type of analysis before proceeding to the next stage of analysis. The user must specify:

1. The number of layers to be used in the profile.

2. The analysis method:
    - Frequency Domain
        - Linear
        - Equivalent Linear
    - Time Domain
        - Linear
        - Nonlinear

3. The type of input for shear properties:
    - Shear Modulus
    - Shear Wave Velocity

4. The units to be used in analysis:
    - English
    - Metric

5. The analysis type:
    - Total Stress Analysis
    - Effective Stress Analysis (Pore Water Pressure generation only)
        - Include PWP Dissipation (PWP generation and dissipation)

6. The method to define the soil curve:
    - For Equivalent Linear
        - Discrete Points
        - Pressure-Dependent Hyperbolic Model
    - For Nonlinear
        - MRDF Pressure-Dependent Hyperbolic Model
        - Pressure-Dependent Hyperbolic Model

7. The boundary conditions (for Effective Stress Analysis Incl. PWP Dissipation)
    - Fully Permeable
    - Impermeable

The Effective Stress Analysis option is only available for a Nonlinear (Time Domain) analysis. Note that (1), (3), and (4) can be changed in the next stage.

2.4 *Defining Soil Profile & Model Properties: Step 2a of 6*

This stage is divided into two partitions. The first partition to be considered requires the user to define the soil profile and specify the soil properties of each layer (Figure 4). The type of input required depends on the analysis parameters selected in Step 1.

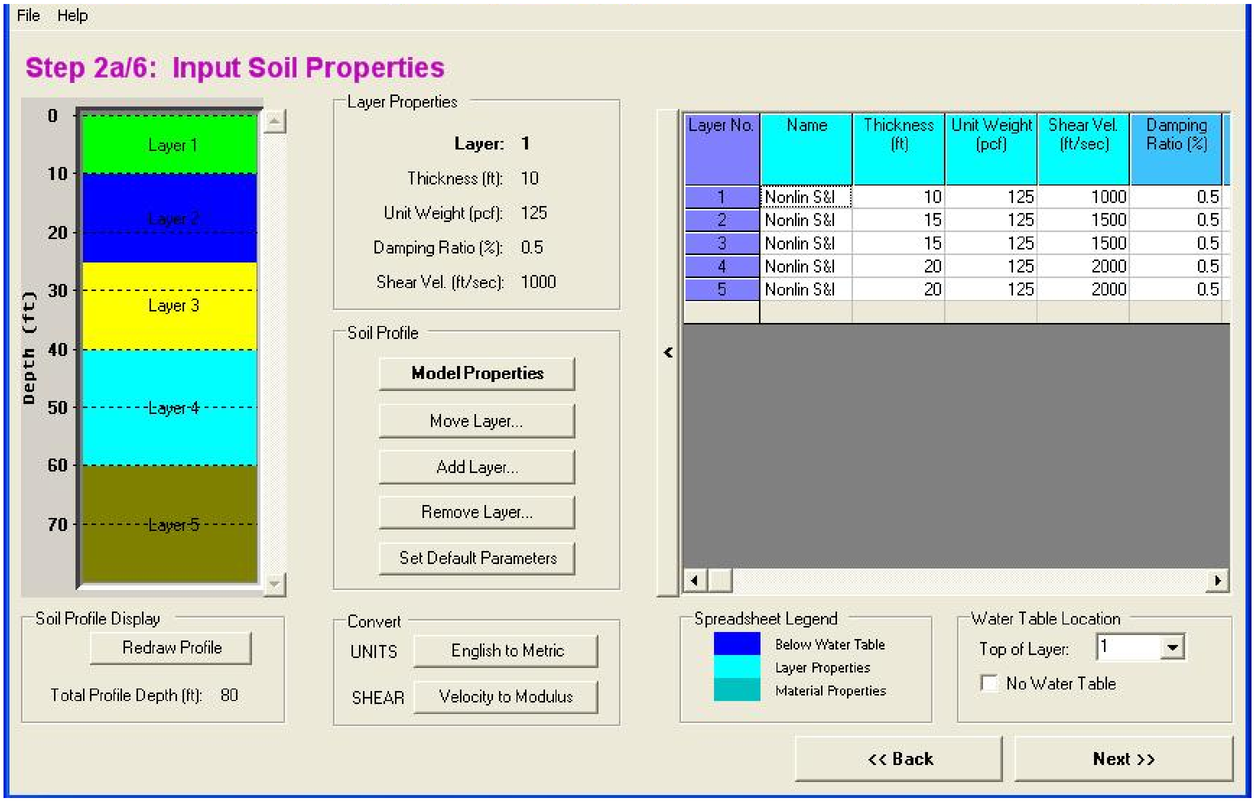


Figure 4. Step 2a/6: Input Soil Properties.

The entire form is broken up into three sections. The section located at the left is a visual display of the soil profile. The section at the right is the table where the values for required input parameters must be entered, but the location of the water table must also be specified. The section in the middle contains layer property information, conversion functions, and soil profile modifier commands.

If a total stress analysis is selected, the user must specify the typical soil properties of each layer based on the type of analysis that was selected (Linear, Nonlinear, etc).

If an effective stress analysis is selected, the user must specify additional parameters including the model to be used (Sand/Clay) and their respective parameters. The models are identified as Sand (S) or Clay (C), and by the initials of the model developer (e.g. M for Matasovic, D for Dobry, GMP for Green, Mitchell, Polito):

- PWP Model (1 = S-M/D; 2 = C-M; 3 = S-GMP)
- f/s/D_r (Define f for Sand model, s for Clay model, D_r (%) for GMP model)
- p/r/FC (Define p for Sand model, r for Clay model, FC (%) for GMP model)
- F/A/- (Define F for Sand model, A for Clay model, leave blank for GMP model)
- s/b/- (Define s for Sand model, b for Clay model, leave blank for GMP model)
- g/C/- (Define g for Sand model, C for Clay model, leave blank for GMP model)
- v/D/v (Define v for Sand model, Define D for Clay model, v for GMP model)
- -/g/- (Leave blank for Sand model, Define g for Clay model, leave blank for GMP)

These parameters, and the means of determining these parameters, are discussed in Unit 2.5.

If an effective stress analysis is selected with the option to Include PWP Dissipation, the user must also specify:

- C_v (Define C_v for both Sand and Clay model)

The **Sand** model parameters are:

f = 1 for 1-D directional generation of water pressure; 2 for 2-D
p = Curve fitting parameter
F = Curve fitting parameter
s = Curve fitting parameter
g = Practical volumetric threshold shear strain
v = Curve fitting parameter*

*For v, Matasovic (1993) recommends a value ranging from 3.5 – 5.0, with an average value of 3.8.

The **Clay** model parameters are:

s = Curve fitting parameter
r = Curve fitting parameter
A = Curve fitting parameter
B = Curve fitting parameter
C = Curve fitting parameter
D = Curve fitting parameter
g = Practical volumetric threshold shear strain

The **GMP-UIUC** model parameters, which can be used for sands, are:

D_r (%) = Relative density
FC (%) = Fines Content
v = Curve fitting parameter* (same as used in the Matasovic (1993) Sand model)

For “Effective Stress Analysis” with the “Include PWP Dissipation” option:

Cv = Coefficient of consolidation

Units

Values can be entered in either English or SI units.

Thickness	feet (ft)/meters (m)
Unit Weight	pound force per cubic feet (pcf)/ kilo Newton per cubic meter (kN/m^3)
Initial Shear Modulus, G	pounds per square feet (psf)/ kilo Pascal (kPa)
Small strain damping ratio	percentage (%)
Reference strain	(%)
Reference stress	mega Pascal (MPa)
Beta	[unitless]
s	[unitless]
b	[unitless]
Cv	feet-squared per second (ft^2/s) / meters-squared per second (m^2/s)

2.4.1 Creating/Modifying Soil Profiles

a. *Model Properties / Defining Model Properties:* Details will be provided in the next section.

b. *Move Layer:* Moves the selected layer to a new position in the soil column. The layer will retain all of its previously specified parameter values. This command is located in the soil properties pop-up menu and also as a button in the mid-section of Step 2a/6. To access this pop-up menu, first left-click a cell of a layer to select that layer. Then, right-click to make the soil properties pop-up menu appear. Select **Move Layer** either from the pop-up menu or by clicking the appropriately labeled button. This will bring up the “Move Layer” form (Figure 5) where you may move the layer to any position in the soil profile.

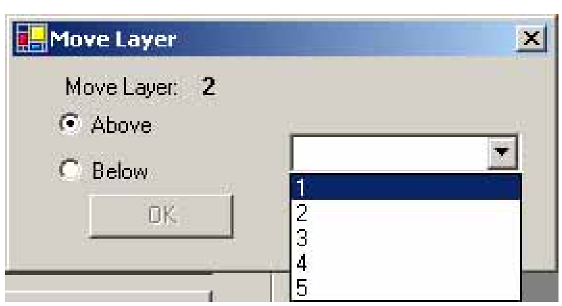


Figure 5. Move Layer.

c. *Add Layer:* Adds a layer to the soil column. The new layer has no properties and is labeled in sequence with pre-existing layers. This command is located in the soil properties pop-up menu and also as a button in the mid-section of Step 2a/6. Select **Add Layer** to bring up the “Add Layer” form (Figure 6) where you may add an additional layer above or below any other layer.

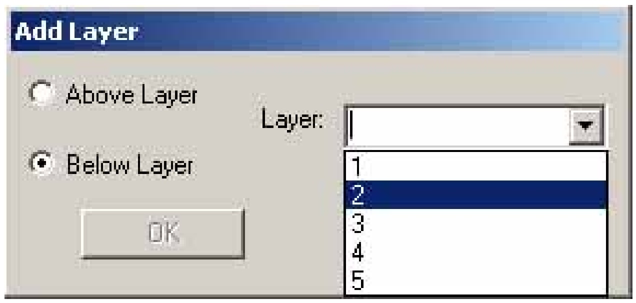


Figure 6. Add Layer.

d. *Remove Layer:* Removes selected layer(s) from the soil column. This command is also located in the soil properties pop-up menu and the mid-section of Step 2a/6. Select **Remove Layer** from the pop-up menu or press the **Remove Layer** button to bring up the “Remove Layer” form (Figure 7) where you may remove any number of layers.

Figure 7. Remove Layer.

e. *Convert Units:* Convert all units from English to Metric or vice versa.

f. *Convert Shear:* Convert shear modulus to shear wave velocity or vice versa. All layers require a unit weight to perform this conversion.

g. *Layer Properties Window:* The window is located in the upper middle of the window. This is only an informational display. Alterations must be made using the Soil Column display or the spreadsheet, which will be discussed at later time. The properties displayed are for the individual layer of soil that has been selected in the spreadsheet or Soil Column display, including:

- Thickness
- Unit Weight

- Small Strain Damping Ratio (%)
- Initial Shear Modulus/Shear Wave Velocity

h. *Water Table:* Choose the depth of the water table by clicking the pull-down menu. The layers appear in ascending order, so click the layer that the water table will be above. The Graphical soil column display responds to this by changing the background color of every layer beneath the water table to light blue. The location of the water table is only of influence when introducing the pressure dependent soil parameters or performing an effective stress analysis. The location of the water table does not influence the frequency domain solution.

i. *Save profile:* Save a modified or created profile by clicking **Save Profile** from the **File** menu.

2.5 *Soil properties/models*

A variety of models are available for DEEPSOIL analyses. These models include: a) Equivalent Linear, b) Hyperbolic (MR, MRD, DC), c) a New Hyperbolic model (MRDF), and d) Porewater Pressure Generation and Dissipation.

2.5.1 Equivalent Linear

The equivalent linear model employs an iterative procedure in the selection of the shear modulus and damping ratio soil properties. These properties can be defined by discrete points or by defining the soil parameters to be used in the hyperbolic model.

The option of defining the soil curves using discrete points is only applicable for the Equivalent Linear analysis. For this option, the G/Gmax (-) and Damping ratio (%) are defined as functions of strain (%).

2.5.2 Hyperbolic / Pressure-Dependent Hyperbolic

DEEPSOIL incorporates the pressure-dependent hyperbolic model. The modified hyperbolic model, developed by (Matasovic, 1993), is based on the *hyperbolic model* by (Konder and Zelasko, 1963), but adds two additional parameters **Beta** and **s** that adjust the shape of the backbone curve β:

$$\tau = \frac{G_{mo}\gamma}{1 + Beta\left(\dfrac{G_{mo}\gamma}{\tau_{mo}}\right)^{s}} = \frac{G_{mo}\gamma}{1 + Beta\left(\dfrac{\gamma}{\gamma_r}\right)^{s}}$$

where G_{mo} = initial shear modulus, τ_{mo} = shear strength, γ = shear strain. *Beta*, *s*, and γ_r are model parameters. There is no coupling between the confining pressure and shear stress.

DEEPSOIL extends the model to allow coupling by making γ_r confining pressure dependent as follows (Hashash and Park, 2001):

$$\gamma_r = REF.strain\left(\frac{\sigma_v'}{REF.stress}\right)^b$$

where σ_v' is the effective vertical stress. Ref. stress is the vertical effective stress at which γ_r = Ref. stress. This model is termed as the "pressure-dependent hyperbolic model."

The pressure-dependent modified hyperbolic model is almost linear at small strains and results in zero hysteretic damping at small strains. Small strain damping has to be added separately to simulate actual soil behavior which exhibits damping even at very small strains (Hashash and Park, 2001). The small strain damping is defined as

$$\xi = Small\,strain\,damping\left(\frac{1}{\sigma_v'}\right)^d$$

d can be set to zero in case a pressure independent small strain damping is desired.
In summary, the parameters to be defined in addition to the layer properties are:

- *Reference Strain*
- *Stress-strain curve parameter, Beta*
- *Stress-strain curve parameter, s*
- *Pressure dependent (reference strain) parameter, b*
- *Reference Stress*
- *Pressure dependent (damping curve) parameter, d*

When the user wishes to fit a soil curve (i.e. determine the model parameters which most closely match the defined curves), the following options are available:

MR: Procedure to find the parameters that provide the best fit for the modulus reduction curve

MRD: Procedure to find the parameters that provide the best fit for both the modulus reduction and damping curve

DC: Procedure to find the parameters that provide the best fit for the damping curve.

2.5.3 MRDF Pressure-Dependent Hyperbolic

The MRDF Pressure-Dependent Hyperbolic model available in DEEPSOIL allows the user to introduce a reduction factor into the hyperbolic model. This reduction factor has the form:

$$R = P1 - P2(1 - (G/Go))^{P3}$$

where P1, P2, and P3 are fitting parameters.

By setting P1 = 1, P2 = 0, and P3 = 10 (or any number), the reduction factor is equal to 1, and the model is reduced to the hyperbolic model described in Unit 2.5.3.

When the user wishes to fit a soil curve using the MRDF Pressure-Dependent Hyperbolic model, only one selection is available:

MRDF:Procedure to find the parameters that provide the best fit for the modulus reduction curve, damping curve, and reduction factor parameters.

2.5.4 Porewater Pressure Generation & Dissipation

The Matasovic (1993) pore water pressure generation parameters must be determined by a curve-fitting procedure of cyclic undrained lab-test data. Once you have obtained such data, use the following equations (proposed by Matasovic and Vucetic [1993, 1995]) to determine the best-fit parameters to be used in analysis.

For Sands (Matasovic and Vucetic, 1993):

$$u_N = \frac{p \cdot f \cdot N_c \cdot F \cdot (\gamma_{ct} - \gamma_{tup})^s}{1 + f \cdot N_c \cdot F \cdot (\gamma_{ct} - \gamma_{tup})^s}$$

- u_N is the pore pressure for N cycles
- N_c is the number of cycles
- γ_{tup} is the practical volumetric threshold shear strain, i.e., the γ_c , cyclic strain, below which no significant pore water pressure is generated. γ_{tup} is between 0.01% and 0.02% for most of sands and is represented by the parameter “g” in Deepsoil
- γ_{ct} is the most recent reversal strain.
- *f* is 1 or 2 depending on 1-D or 2-D directional generation of water pressure respectively
- *p*, *s*, and *F* are curve fitting parameters

For Clays (Matasovic and Vucetic, 1995):

$$u_N = AN^{-3\cdot s(\gamma_c - \gamma_{tup})^r} + BN^{-2\cdot s(\gamma_c - \gamma_{tup})^r} + CN^{-s(\gamma_c - \gamma_{tup})^r} + D$$

- u_N is the pore pressure for N cycles
- N_c is the number of cycles
- γ_{tup} is the practical volumetric threshold shear strain, i.e., the γ_{c}, cyclic strain, below which no significant pore water pressure is generated. γ_{tup} for clays is typically greater than sands (by ~0.1%) and is represented by the parameter "g" in Deepsoil
- γ_{ct} is the most recent reversal strain
- *S* and *r* are curve fitting parameters correlated to clay properties such as OCR and PI
- *A, B, C* and *D* are curve fitting coefficients

The pore water pressure dissipation model is based on Terzaghi 1-D consolidation theory:

$$\frac{\partial u}{\partial t} = C_v \left(\frac{\partial^2 u}{\partial z^2}\right)$$

where C_v is the consolidation coefficient.

Dissipation of the excess pore water pressure is assumed to occur in the vertical direction only. Porewater pressure generation and dissipation occur simultaneously during ground shaking.

2.6 *Check Maximum Frequency (for Time Domain Analysis only)*

Upon completing the definition of the soil and model properties, the user is shown a plot of the maximum frequency versus depth for each layer (Figure 8). A plot and table of maximum frequencies (Hz) versus depths of all layers are displayed. The maximum frequency is the highest frequency that the layer can propagate and is calculated as: $f_{max} = Vs/4H$, where Vs is the shear wave velocity of the layer, and H is the thickness of the layer. To increase the maximum frequency, the thickness of the layer should be decreased. This check is performed solely for time domain analyses. It is recommended that the layers have the same maximum frequency throughout the soil profile, though this is not required. For all layers, the maximum frequency should fall between a range of a minimum of 25 Hz and a maximum of 50 Hz.

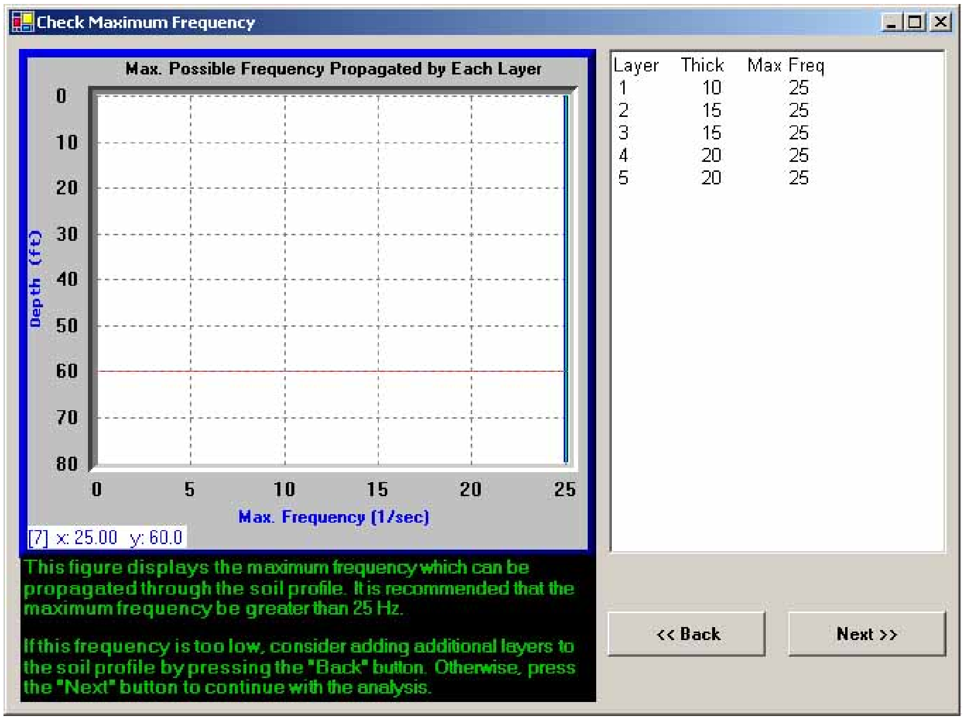


Figure 8. Check Maximum Frequency.

2.7 *Define Rock Properties: Step 2b of 6*

After defining the soil and model properties, the user must now define the rock / half-space properties of the bottom of the profile (Figure 9).

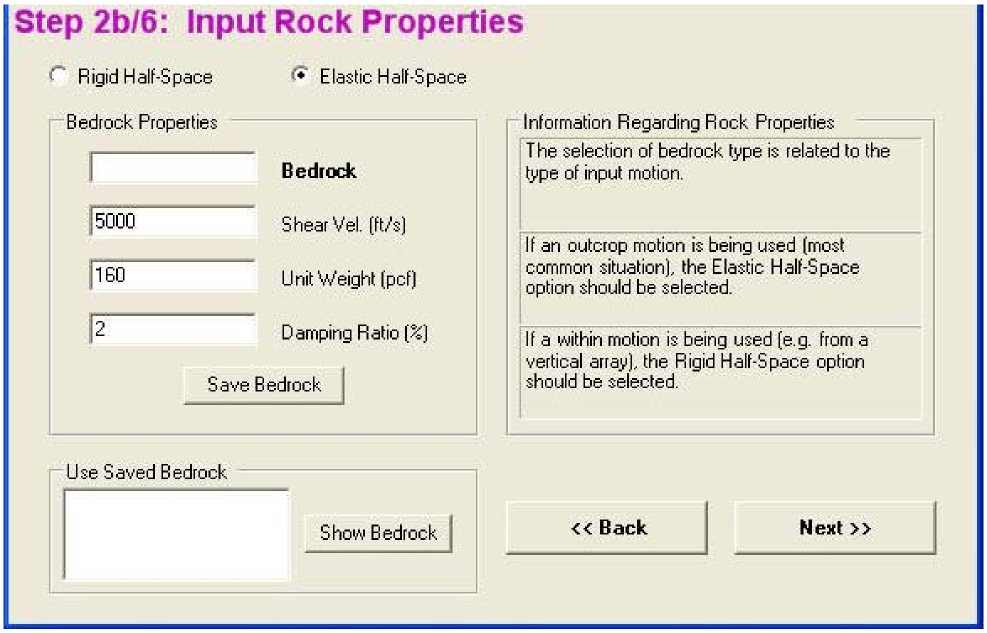


Figure 9. Step 2b/6: Input Rock Properties.

The user has the option of selecting either a **Rigid Half-Space** or an **Elastic Half-Space**. An informational display makes the user aware that a rigid half-space should be chosen if a within motion will be used, and an elastic half-space should be selected if an outcrop motion is being used. If a rigid half-space is being used, no input parameters are required. If an elastic half-space is being used, the user must supply the shear velocity (or modulus), unit weight, and damping ratio of the half-space.

Bedrock properties can be saved by giving the bedrock an appropriate name and pressing **Save Bedrock**. The new bedrock will appear in the list of saved bedrocks below. To use a saved bedrock, select the appropriate file from the list box and press the **Show Bedrock** button.

2.8 *Analysis Control: Step 3 of 6*

In this stage of analysis, the user may specify specific options to be used for either the frequency domain or time domain analysis (Figure 10).

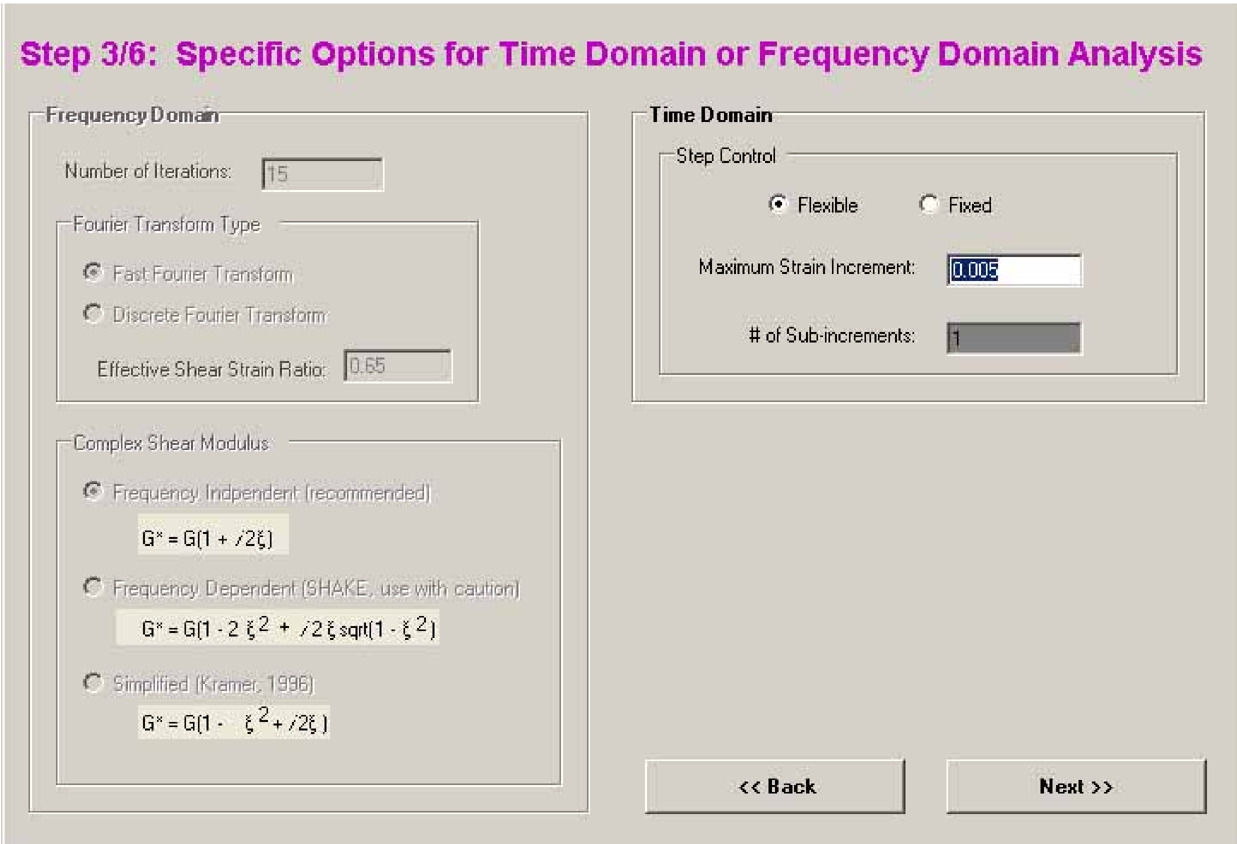


Figure 10. Step 3/6: Specific Options for Time Domain or Frequency Domain Analysis.

2.8.1 Time domain analysis

For a time domain analysis, the options are:

- Step Control
    - o Flexible
    - o Fixed
- Maximum Strain Increment
- Number of Sub-Increments

The accuracy of the time domain solution depends on the time step selected. There are two options in choosing the time step (Hashash and Park, 2001).

Fixed Step

Each time-step is divided into N equal *sub-increments* throughout the time series.

To choose this option:

- Click the option button labeled **Fixed**
- DEEPSOIL responds by disabling the text box labeled ***Maximum Strain Increment*:** and enabling **Number of sub-increments:**
- Type the desired integer value of sub-increments into the text box

Flexible Step

A time increment is subdivided only if computed strains in the soil exceed a specified *maximum strain increment*.

The procedure is the same as that for the Fixed Step above, except the **Flexible** option is chosen. Type the desired ***Maximum Strain Increment*** into the text box. The default and recommended value is 0.005 (%).

2.8.2 Frequency domain analysis

For a frequency domain analysis, the options are:

- Number of Iterations
- Fourier Transform Type
  - Fast Fourier Transform
  - Discrete Fourier Transform
    - Effective Shear Strain
- Complex Shear Modulus
  - Frequency Independent
  - Frequency Dependent
  - Simplified (Kramer, 1996)

Number of Iterations

Determines the number of iterations in performing an equivalent linear analysis. Check whether the solution has converged and the selected iteration number is sufficient by clicking **Check Convergence** during Step 6/6 after running the analysis.

Fourier Transform Type

- Discrete Fourier Transform
  The time it takes to complete this transform is proportional to N^2.

- Fast Fourier Transform
  A *computational algorithm* where N is a power of 2. The time it takes to complete the transform is proportional to $N\log_2 N$; this method is much more efficient than the Discrete Fourier Transform.

Effective Shear Strain Ratio

When performing an equivalent linear analysis, the effective strain needs to be defined. An effective shear strain, calculated as a percentage of the maximum strain, is used to obtain new estimates of shear modulus and damping ratio. The default and recommended value is 0.65 (65%).

Complex shear modulus

DEEPSOIL allows a choice among three types of complex shear modulus formulae in performing frequency domain analysis:

- Frequency Independent Complex Shear Modulus (Kramer, 1996)
  The frequency independent shear modulus results in frequency independent damping, and is thus recommended to be used in the analysis.
  $$G^* = G(1 + i2\xi)$$

- Frequency Dependent Complex Shear modulus (Udaka, 1975)
  The frequency dependent shear modulus results in frequency dependent damping, and should thus be used with caution. This is the same modulus used in SHAKE91.
  $$G^* = G\left(1 - 2\xi^2 + i2\sqrt{1 - \xi^2}\right)$$

- Simplified Complex Shear modulus (Kramer, 1996)
  This is a simplified form of frequency independent shear modulus defined as:
  $$G^* = G(1 - \xi^2 + i2\xi)$$

2.9 *Motion & Output Control*

Depending on the user's selected option during the Initialization stage, the options available in this stage of analysis will vary depending on if a Standard (Figure 11) or Batch Mode (Figure 12) analysis is being performed. In both cases, the input motion(s) and layer(s) for output display will be selected. The user should also choose the damping ratio for the calculated response spectra. The default damping ratio is set to 5%. If the Standard option was chosen during the Initialization stage, deconvolution can also be performed. Generally deconvolution is not needed.

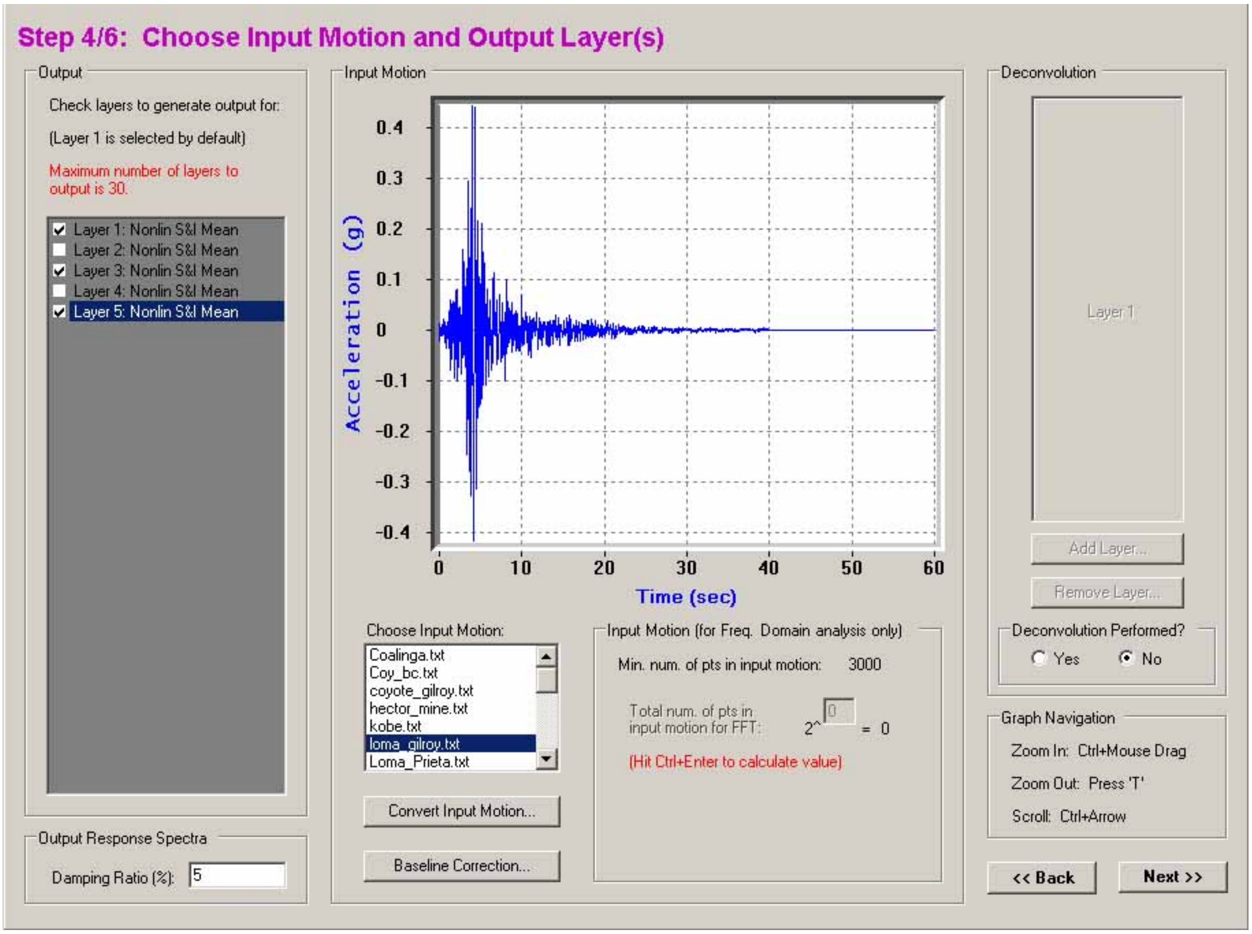


Figure 11. Step 4/6: Choose Input Motion and Output Layer(s) [Standard Analysis]

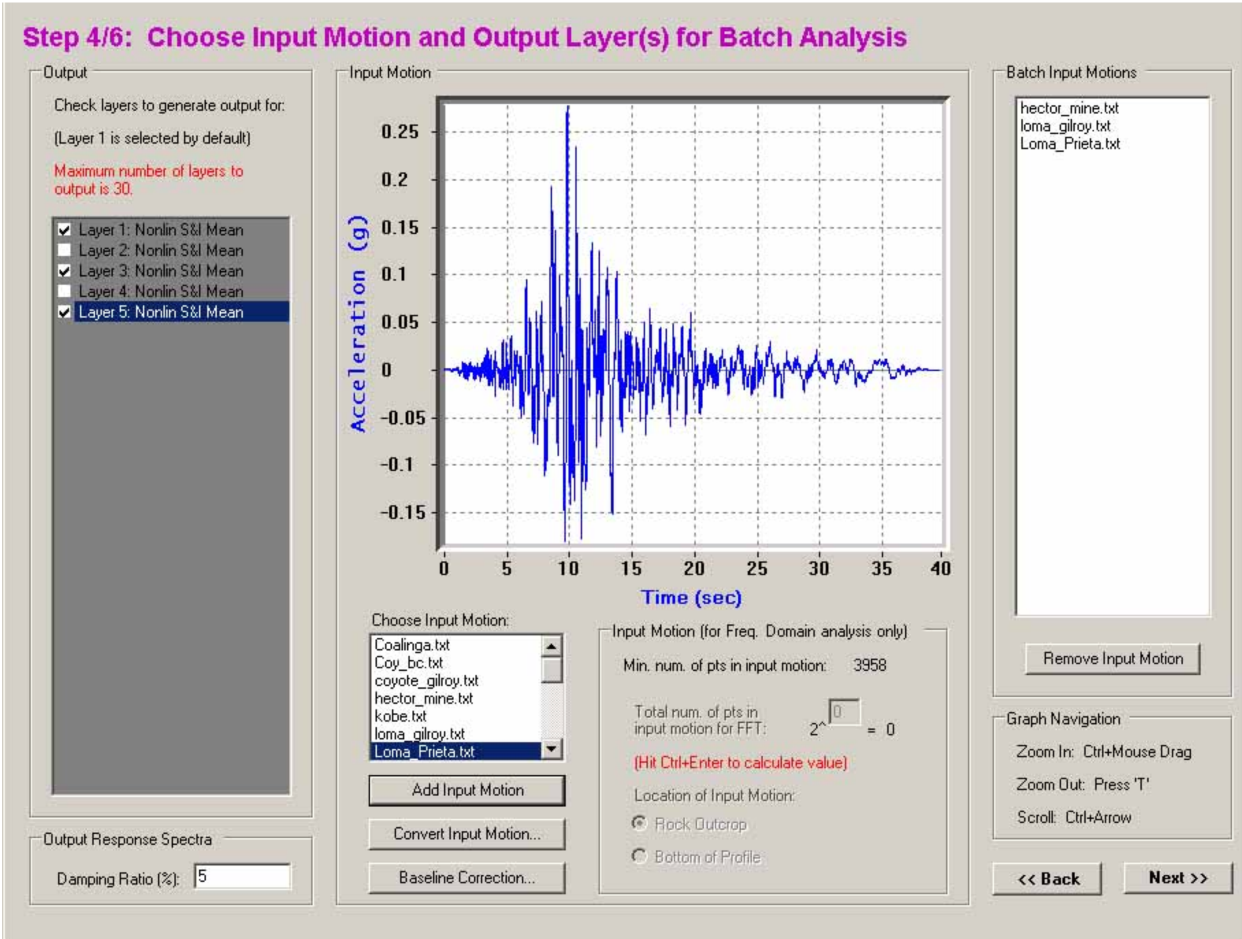


Figure 12. Choose Input Motion and Output Layer(s) for Batch Analysis.

The motion control stage allows the user to specify the input motion to be used in analysis and selection of the layers to be analyzed. The input motion can be selected from the provided library (to which the user may add additional motions). The layers to be analyzed may be selected by checking the appropriate checkbox at the left of the form.

The number of calculation points is only relevant in the frequency domain and should be specified when using the Fast Fourier Transform. Note that DEEPSOIL will provide an estimate of the number of points to be used for any input motion.

Further options include: a) Convert Input Motion, b) Baseline Correction, and c) Deconvolution (for Standard analysis mode). The Damping Ratio of the output response spectra should also be specified.

If the analysis type is a Frequency Domain Analysis, the user may click the “Analyze” button to perform the analysis.

If the analysis type is a Time Domain Analysis, the user must click the “Next” button to proceed to Step 5 of the analysis.

2.9.1 Choosing an input motion

On the motion control page, select the layer(s) to be analyzed by left-clicking the layer's corresponding checkbox button located in the left column. DEEPSOIL responds by highlighting the selection light blue. The user may select any number of layers for analysis. Note that the time required for analysis increases with the selection of more layers.

Select an input motion by single clicking one of the ".txt" files in the **Choose Input Motion** list located at the lower center of the form. DEEPSOIL will display the **Minimum Number of data points in input motion** and **Total number of points in the input motion for FFT:** directly to the right of the motion library. A graphical representation of the selected input motion is displayed in the center of the window.
Note: Input motions with an extremely large number of data points are the most accurate, but take a considerable amount of time to process. If a quick estimation is needed, select an input motion of fewer *data points.*

In a Batch Mode analysis, the user can select many input motions by first following the process above, and then pressing the **Add Input Motion** button. A list of batch mode input motions will be updated with all of the previously selected input motions.

2.9.2 Convert Input Motion

By clicking **Convert Input Motion** you will be able to convert the motion from NEHRP Site Class A to Site Class B/C boundary conditions and vice versa (Figure 13). This option is particularly useful in using the generated ground motions from the USGS website. The USGS website generates motions at Site class B/C boundary, which have to be converted to Site class A to be imposed at the bottom of the bedrock. The converted input motion is then saved under a user-defined filename.

USGS hazard maps are developed for a Site Class B/C boundary (according to 1997 NEHRP Provisions) that represent a weak rock condition. The USGS website allows generation of representative ground motions anywhere in the U.S. The generated motions represent motions at a Site Class B/C boundary. The motions can be used as input motions imposed at the bottom of the soil column. However, the motions cannot be used in the original form. The motion has to be converted to Site Class A condition, which represents a hard rock condition. DEEPSOIL allows converting of a Site Class A motion to Site Class B/C motion and vice versa.

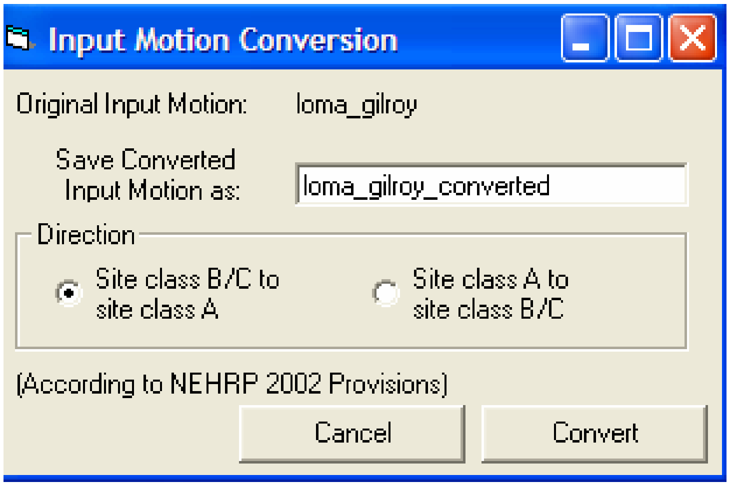


Figure 13. Input Motion Conversion.

2.9.3 Baseline Correction

DEEPSOIL can perform baseline correction for an input motion (Figure 14). By selecting an input motion and pressing the "Baseline Correction" button, a new window appears which shows the acceleration, velocity, and displacement time-histories corresponding to the motion. Motions which exhibit non-zero displacement time-histories for the latter part of the motion should be corrected. The corrected time-histories are presented to the user. The baseline corrected motion can then be stored as a file defined by the user.

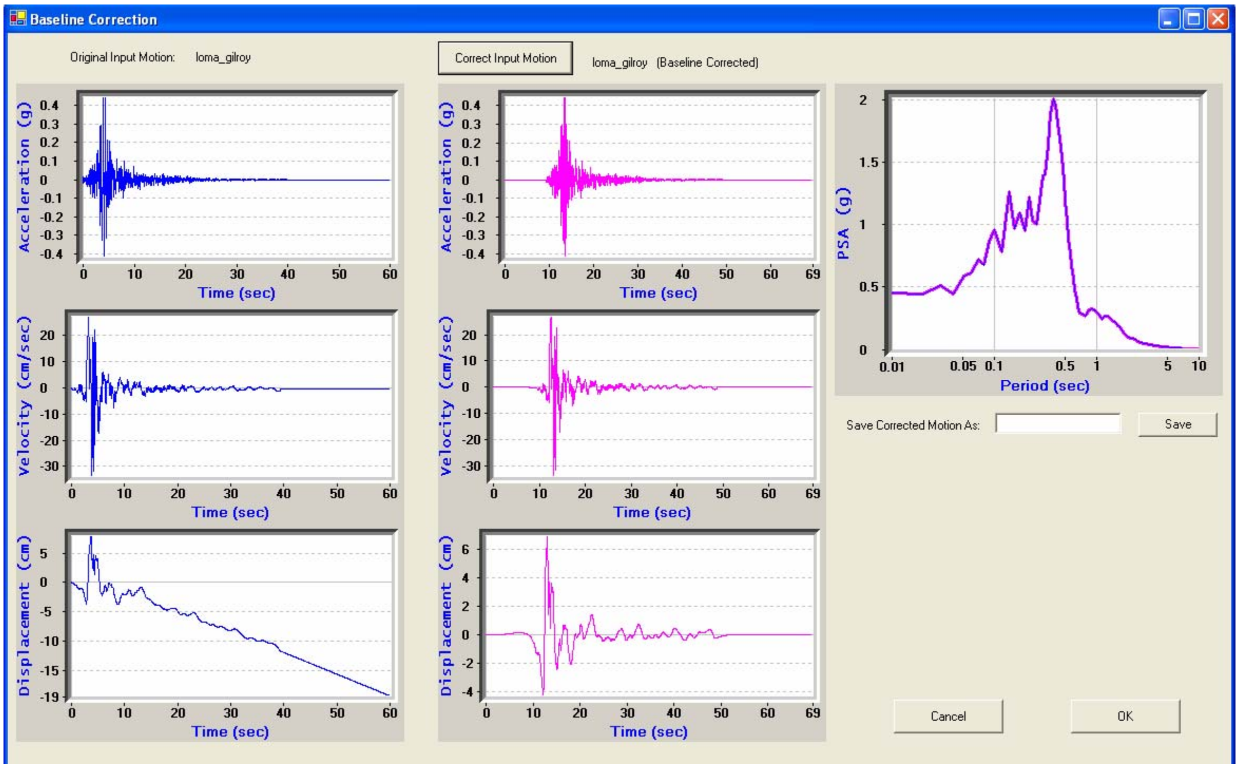


Figure 14. Baseline Correction.

2.9.4 Adding Additional Input Motions

Adding Additional Motions to the Library

To add an input motion to the **Choose Input Motion** menu, enter the necessary data, in the format described below, and save as a .TXT file in the Input Motion folder, in the following directory:
C:\\Program Files\UIUC\Deepsoil v3.5 BETA\Working\Input Motion\

Units and Format

Units should be in g.

The format should be as follows:

1st row: Number of data points & time step
2nd and subsequent rows: time & acceleration

2.9.5 Deconvolution

Deconvolution is available for a Standard analysis and allows for converting an outcrop motion to a motion to be imposed at the bottom of the soil profile.
Deconvolution also requires selecting the profile. The following properties need to be defined:

- Thickness
- Shear Wave Velocity
- Damping Ratio (%)
- Unit Weight

To perform the deconvolution for a single layer of uniform properties,

1. Click the **Layer 1** button
2. Specify the basic profile properties in the appropriate text box (remember to make unit conversions, if necessary) in the dialog box that appears.

To perform the deconvolution for a multiple layered column

1. Click **Add Layer**. A dialog box will appear with the basic soil profile properties mentioned above.
2. Enter in the desired properties into the appropriate text box (remember to convert units, if necessary)

By default DEEPSOIL displays one layer (Layer 1) whose thickness is equal to the total depth. When adding a layer, the sum of the individual thickness must equal the total depth.

2.10 *Viscous Damping Formulation / Optimum Modes Selection: Step 5 of 6*

This stage will only appear for time domain analysis. In this stage, the type of viscous damping formulation and optimum modes/frequencies for each stage is selected (Figure 15). This window is unique to DEEPSOIL. This window will help control the introduction of numerical damping through frequency dependent nature of the viscous damping formulation. Note that for Batch Mode analysis, the selected modes/frequencies are constant for all selected input motions.

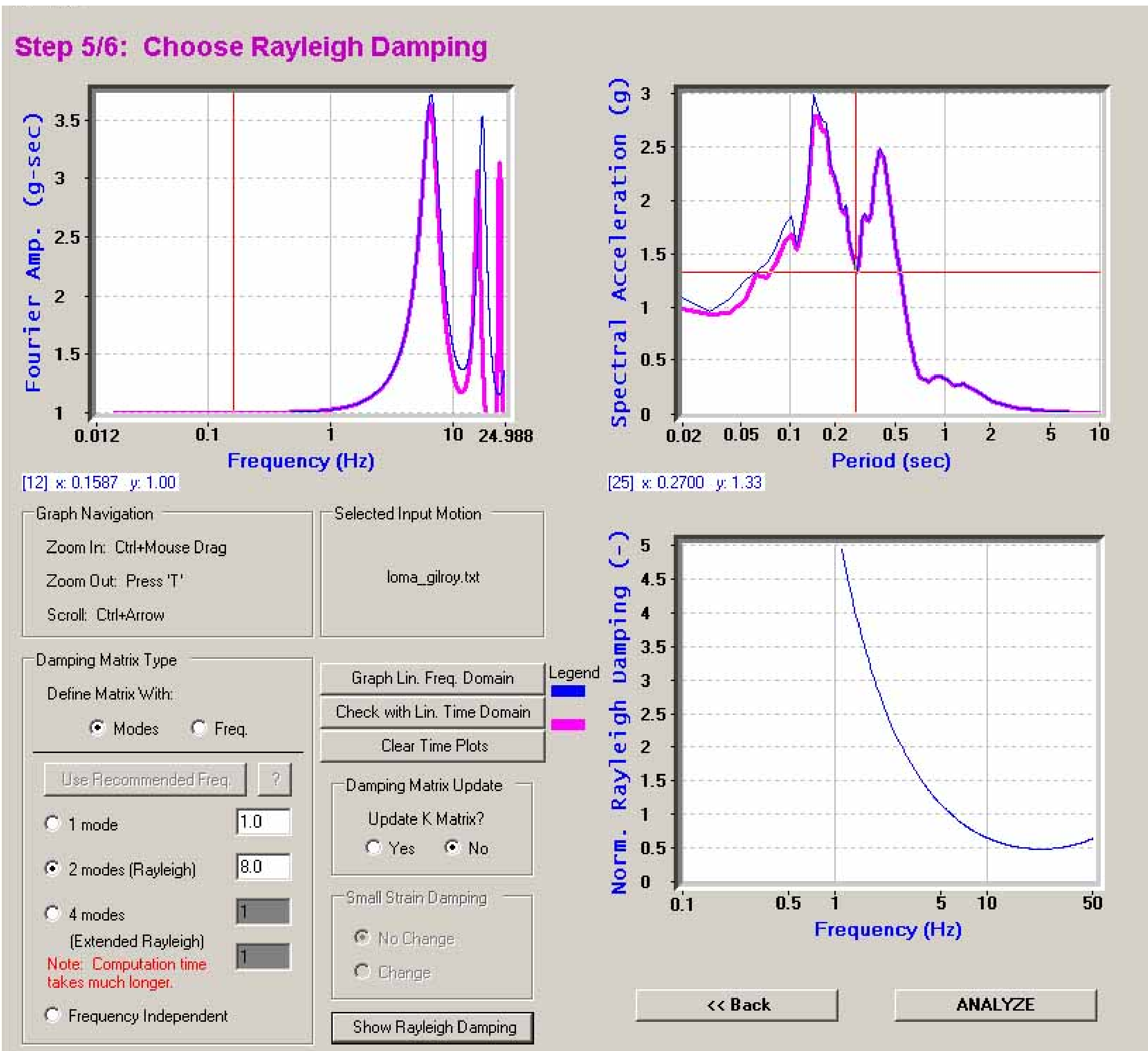


Figure 15. Step 5/6: Choose Rayleigh Damping.

The following options must be specified:

- Damping Matrix Type
  - Define Matrix with (Modes/Freq.)
    - 1 mode/freq.
    - 2 modes/freq. (Rayleigh)
    - 4 modes/freq. (Extended Rayleigh)
    - Frequency Independent (Frequency Only)
- Damping Matrix Update
  - Update K Matrix?
    - Yes
    - No
- Small Strain Damping
  - No Change
  - Change

The remaining options are at the discretion of the user:

- Graph Lin. Frequency Domain – Graphs the linear frequency domain for specified options above
  - Check with Lin. Time Domain – Graphs corresponding linear time domain
- Clear Time Plots – Clears the time domain graphs
- Show Rayleigh Damping – Graphs the Rayleigh damping

For more details on this stage, please refer to Example 6 in the tutorial.

When ready to proceed, click “Analyze”

Viscous damping formulation is used to model small strain damping. The viscous damping formulation results in frequency dependent damping and can introduce significant artificial damping. It is therefore important to select appropriate viscous damping formulation and corresponding coefficients to reduce the numerical damping (Hashash and Park, 2002; Park and Hashash, 2004). There are three types of Rayleigh damping formulations in DEEPSOIL, as listed below. It is recommended that Full Rayleigh damping formulation be selected for most analyses.

2.10.1 Rayleigh Damping formulation types

- Simplified Rayleigh Damping formulation (1 mode/frequency)
  Uses one mode/frequency to define viscous damping.

- Full Rayleigh Damping formulation (2 modes/frequencies)
  Uses two modes/frequencies to define viscous damping.

- Extended Rayleigh Damping formulation (4 modes)
  Uses four modes/frequencies to define viscous damping. Note that the Extended Rayleigh damping formulation is very computationally expensive.

- Frequency Independent Damping formulation
  This procedure solves for the eigenvalues and eigenvectors of the damping matrix and requires no specification of modes or frequencies. This formulation is computationally expensive, however it removes many of the limitations of Rayleigh Damping.

2.10.2 Mode/frequencies selection

There are two options available for selecting modes. The first option is choosing the natural modes (e.g. 1st and 2nd modes). The second option is choosing the frequencies for Rayleigh damping directly. The resulting Rayleigh damping curve can be displayed by pressing **Show Rayleigh Damping** and the curve will be displayed at the right bottom window. Note again that the viscous damping is frequency dependent. The goal in time domain analysis is to make the viscous damping as constant as possible at significant frequencies.

2.10.3 Verification of the selected modes/frequencies

The time domain solution uses the frequency dependent Rayleigh damping formulation, whereas actual viscous damping of soils is known to be fairly frequency independent. The frequency domain solution uses frequency independent viscous damping. The appropriateness of the chosen modes/frequencies should be therefore verified with the linear frequency domain solution.

Press **Graph. Freq Domain**. The results of the linear frequency domain solution (Frequency ratio vs. Freq. and Response spectrum plots) will be displayed as blue curves. The goal is to choose the appropriate modes/frequencies that compare well with the linear frequency domain solution.

Enter the desired modes/frequencies as input. Then press the **Check with Time Domain** button. The results (in the same window as frequency domain solution) will be displayed as red curves. Choose the modes/frequencies that agree well with the linear frequency domain solution. This is an iterative procedure and optimum modes/frequencies should be chosen by trial and error.

2.10.4 Update K matrix in Viscous Damping Formulation

This option is only applicable for a) nonlinear solution and b) when modes (not frequencies) are selected. During the excitation, the frequencies corresponding to natural modes change due to the stiffness change at each time step. The natural modes selected are recalculated at each time step to incorporate the change in stiffness.

This feature is enabled by clicking the **Yes** button, in the **Damping Matrix Update** selection window. Note that using this feature may significantly increase the time required to perform analysis.

2.10.5 Small strain damping update

This enables changing the small strain damping. Always choose **No change** in this version.

2.11 *Output: Step 6 of 6*

Upon completion of analysis, the following output for each selected layer will be directly exported to a text file "ExportOutput.txt" in your working directory (see Figure 16):

Figure 16. Exported Output.

For "Total Stress Analysis"

- Accleration (g) vs Time (sec)
- Strain (%) vs Time (sec)
- Stress (shear/effective vertical) vs Time (sec)
- Response Spectra: PSA (g) vs Period (sec)
- Fourier Amplitude (g-sec) vs Frequency (Hz)
- Fourier Amplitude Ratio (surface/input) vs Frequency (Hz)
- PGA Profile: Max PGA vs Depth
- Strain Profile: Max Strain vs Depth

For "Effective Stress Analysis"

- All from "Total Stress Analysis"
- Pore Water Pressure (pwp/effective vertical) vs Time (sec)

- ➢ PWP Profile: Max PWP vs Depth

If a Batch Mode analysis was selected, the user will be notified to move the exported data to a safe directory and will then close out the session. For a Standard analysis, the user may immediately view the following output visually (Figure 17) by selecting the appropriate tab for the selected layer:

- ➢ Accleration (g) vs Time (sec)
- ➢ Strain (%) vs Time (sec)
- ➢ Stress (shear/effective vertical) vs Time (sec)
- ➢ Stress (shear/effective vertical) vs Strain (%)
- ➢ Fourier Amplitude (g-sec) vs Frequency (Hz)
- ➢ Fourier Amplitude Ratio (surface/input) vs Frequency (Hz)
- ➢ Response Spectra: PSA (g) vs Period (sec)

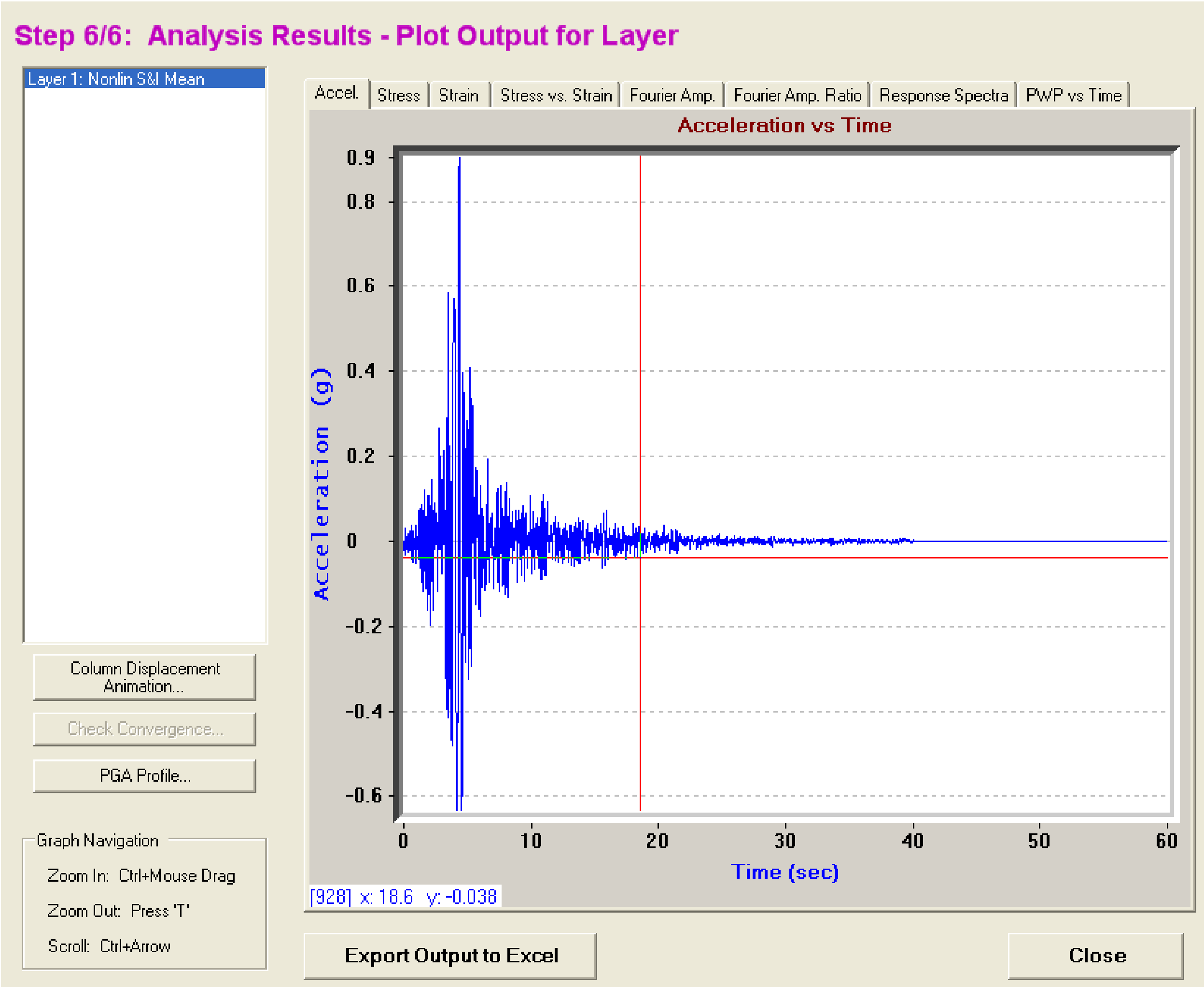


Figure 17. Step6/6: Analysis Results - Plot Output for Layer.

The PGA profile (Figure 18) may also be displayed by clicking the "PGA Profile" button.

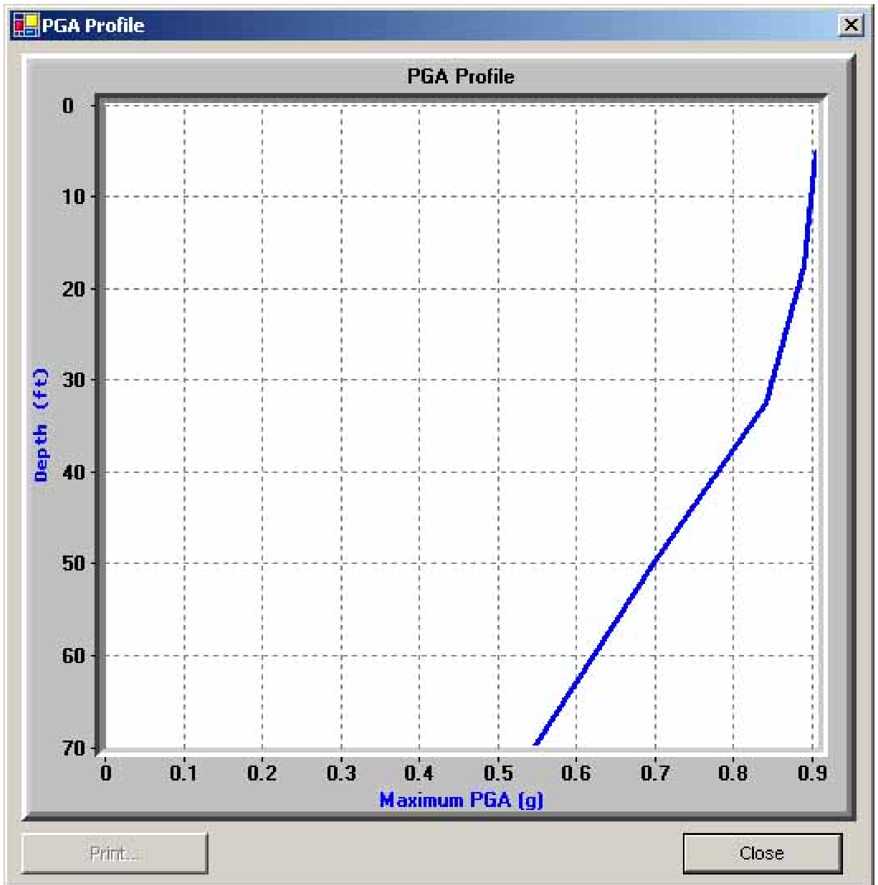


Figure 18. PGA Profile.

The column displacement time history (Figure 19) can be animated for a time domain analysis by selecting the “Column Displacement Animation” button.

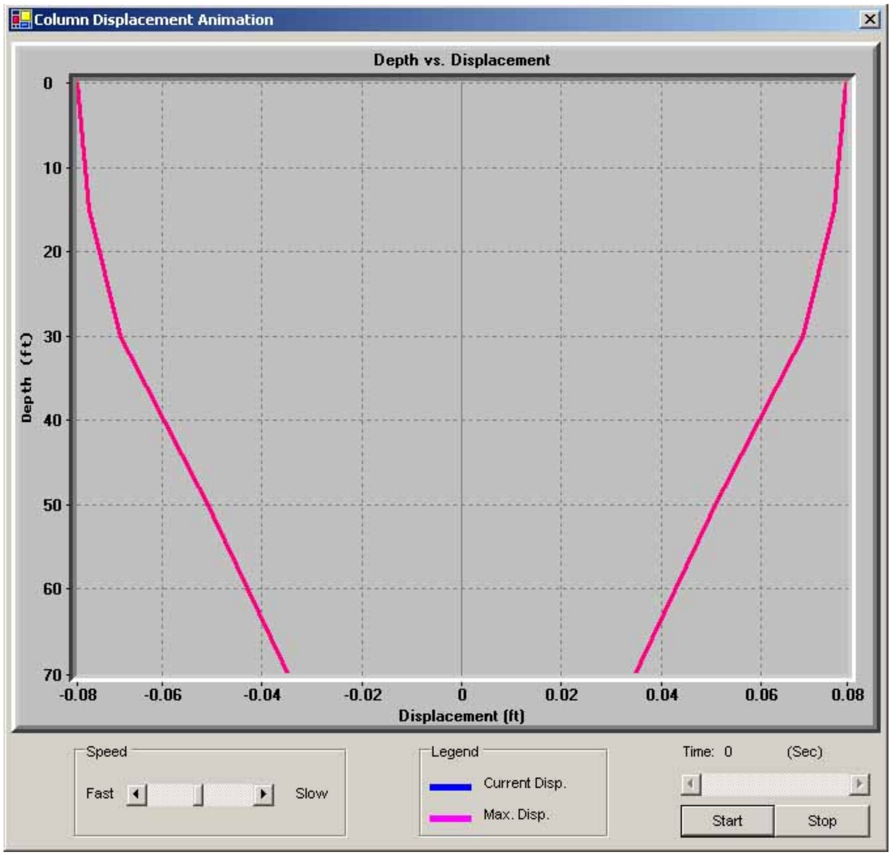


Figure 19. Column Displacement Animation.

Finally, the "Convergence Check" button may be clicked to see if the equivalent linear analysis has converged or if the selected iteration number was sufficient (Figure 20).

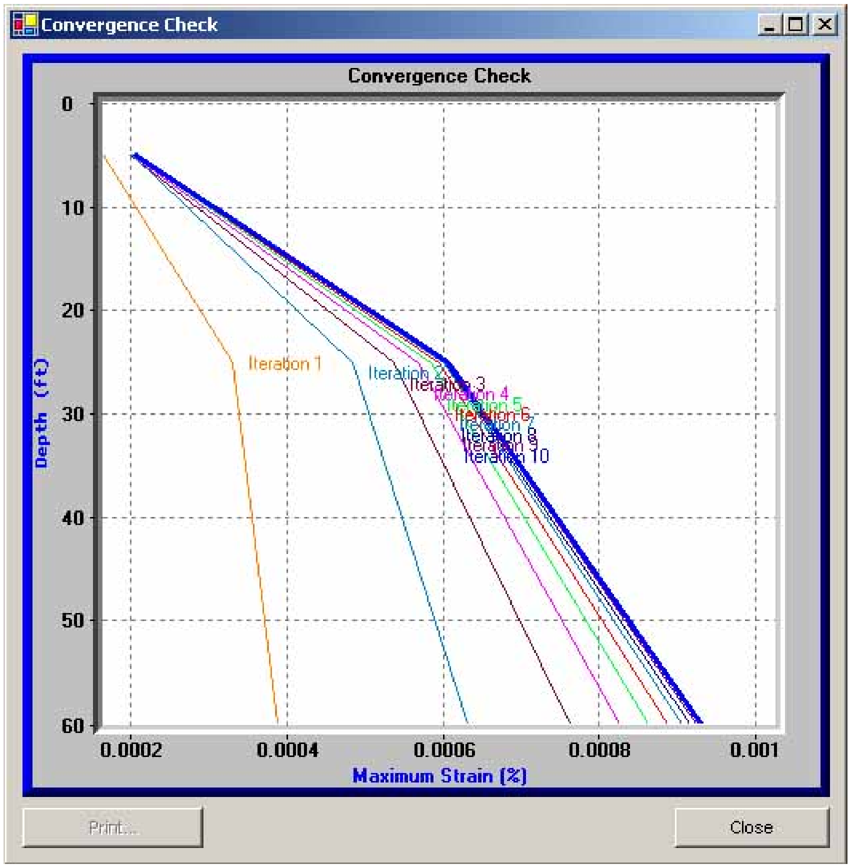


Figure 20. Convergence Check.

The following are the output options:

- Acceleration
- Strain
- Stress
- Strain vs. Stress
- Fourier Spectrum
- Fourier Spectrum ratio
- Response spectrum

2.11.1 Export output data file

Output data for each layer analyzed is automatically exported to “ExportOutput.txt” in the user’s working directory.

2.11.2 PGA Profile

To view the PGA profile click the command button labeled **PGA Profile** in the lower left-hand side of the window.

A plot of PGA (peak ground acceleration) versus depth is displayed (Figure 18).

2.11.3 Displacement profile and animation

To view the displacement profile and animation click the command button labeled **Column Displacement Animation** in the lower left-hand side of the window.

DEEPSOIL displays **Speed** scrollbar control, legend, and time scrollbar control all under an empty animation box (Figure 19). This option is only enabled in a time domain analysis.

2.11.4 Convergence results, equivalent linear analysis only

To view the convergence click the command button labeled **Check Convergence** in the lower left-hand side of the window.

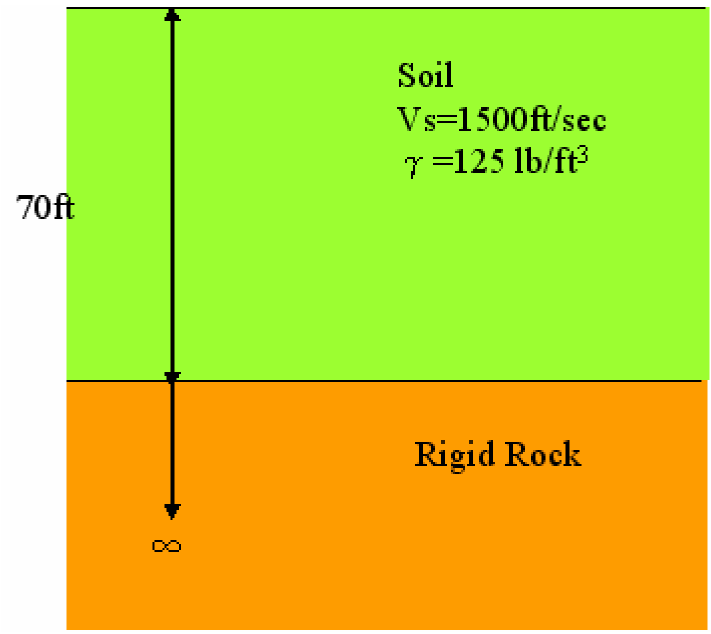
This option enables checking whether the solution has converged in an equivalent linear analysis. Plots of maximum strain profiles for each iteration are displayed (Figure 20).

UNIT 3 Tutorial

The tutorial is intended to help users get familiar with DEEPSOIL. Seven examples are prepared to guide the users through the various features of DEEPSOIL. It is recommended that the examples are followed in the order that appears in the tutorial. The example files are stored in the “Saved Profiles” folder under the DEEPSOIL directory.

3.1 *Example 1 Linear Frequency Domain Analysis / Undamped Elastic Layer, Rigid Rock*

The first example considers a simple linear frequency domain analysis. The profile for Example 1 (“Ex1_Lin_Freq_Undamped_Rigid.dp”) is shown below.



The profile consists of a 70-ft thick column overlying rigid bedrock. The soil layer is assumed to be undamped (zero damping) and linear elastic.

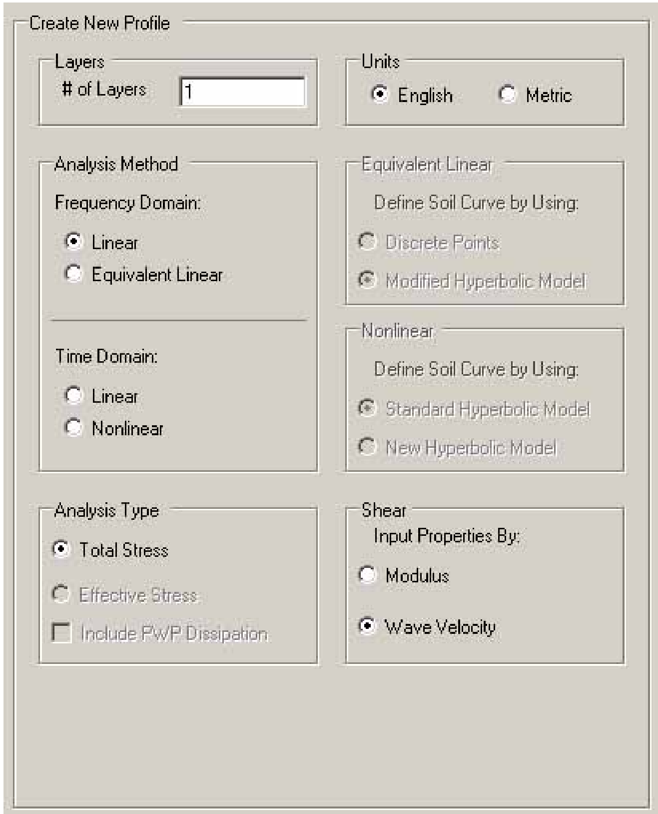
STEP 1/6

For Step 1/6, first choose the method of analysis by selecting Frequency Domain - “Linear Analysis.”

For this example, the number of layers will be 1. Check that the value in the “# of Layers” input box is 1.

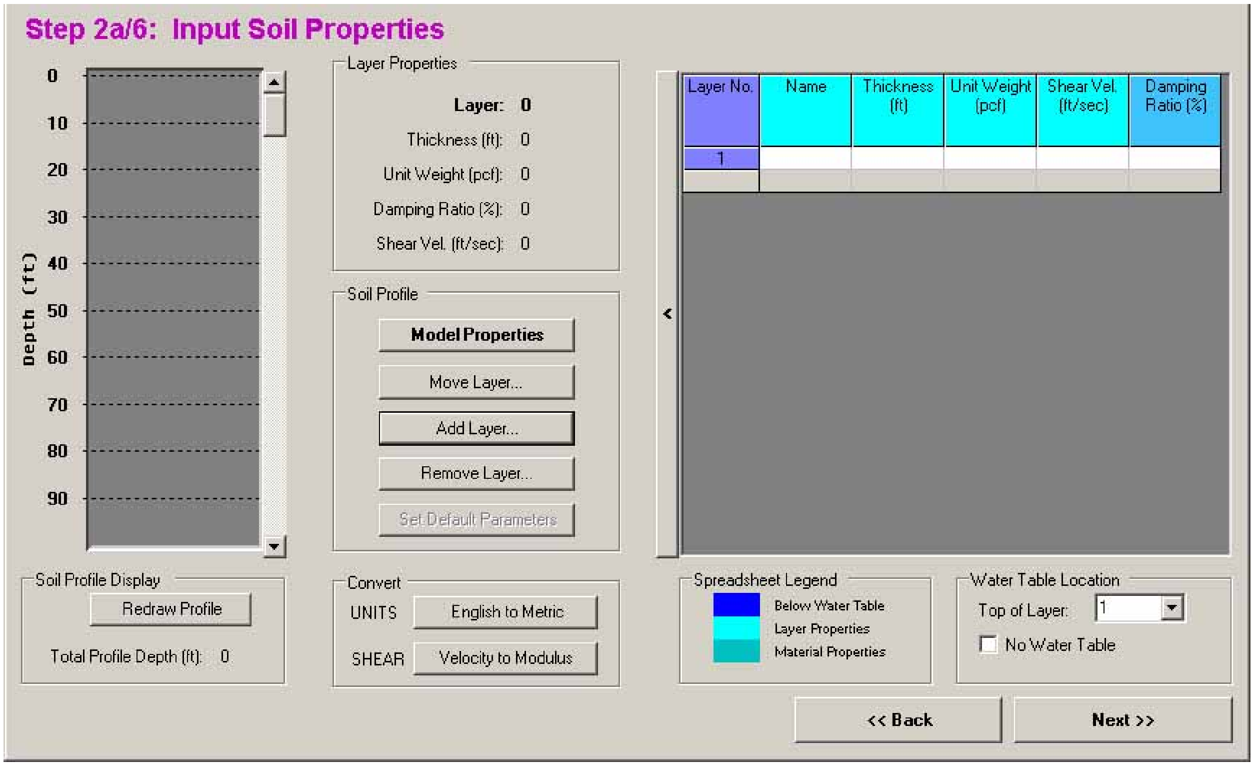
Now we must choose whether to define the stiffness of the layer in shear wave velocity or shear modulus. Select “Wave Velocity.”

Finally, the stress type analysis will be "Total Stress Analysis." Check that "Total Stress Analysis" is selected and press the "Next" button.



STEP 2/6

In Step 2/6, the user must define the soil column and soil properties. The figure below shows the window that displays the soil properties.



The soil properties can be selected by expanding the soil column worksheet. Do this by clicking on the vertical bar with the expand arrow. Specify the material properties of the layer as follows:

Layer No.	Name	Thickness (ft)	Unit Weight (pcf)	Shear Vel. (ft/sec)	Damping Ratio (%)
1		70	125	1500	0

Press the "Next" button. If the profile was created as a new analysis, you will be prompted to save the profile before continuing.

STEP 2b/6

In Step 2b/6, the properties of the bedrock are specified. In this case, the analysis considers rigid bedrock.

Specify the bedrock to be rigid by selecting the "Rigid Half-Space" option. Press the "Next" button to continue.

STEP 3/6

In Step 3/6, the options for the Frequency Domain analysis must be specified.

First select the Fourier Transform Type you wish to use for analysis. There are two options which are the Fast Fourier Transform (FFT) and Discrete Fourier Transform (DFT). It is generally recommended that FFT be used for analysis. (Note: FFT and DFT will give the same results, but FFT is faster)

Select FFT.

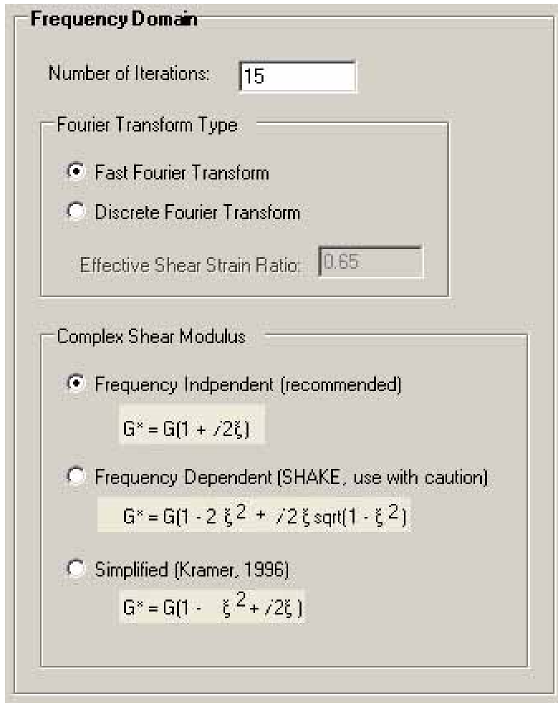
You'll notice that the "Effective Shear Strain" is disabled. This is because the effective shear strain is irrelevant for a linear analysis. Similarly, the "Number of Iterations" for a linear analysis is also irrelevant, so the default value of "15" does not need to be changed.

The final selection in this step is selecting the complex shear modulus. There are three options:

1. Frequency Independent
2. Frequency Dependent
3. Simplified (Kramer, 1996)

It is recommended that the "Frequency Independent" complex shear modulus be used for all analyses. The "Simplified" modulus is based on the "Frequency Independent" modulus, but modified to result in a simpler form (Kramer, 1996). The "Frequency Dependent" modulus is equivalent to the modulus used in SHAKE91.

Select the "Frequency Independent" modulus and press the "Next" button.



STEP 4/6

Step 4/6 involves the selection of a) input motion and b) layers for output.

A motion library is provided which will automatically plot the selected motion for the user's inspection.

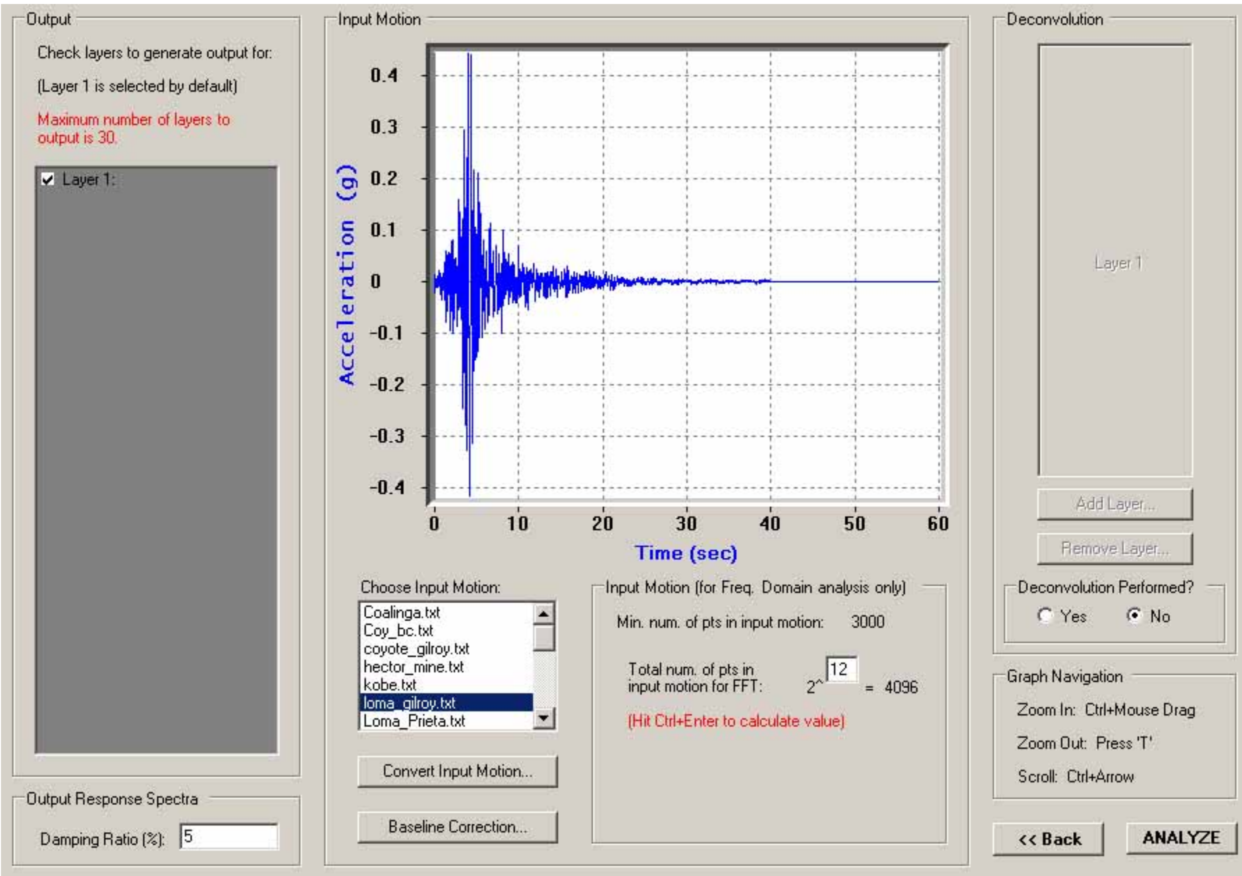
Select the input motion "loma_gilroy.txt" from the motion library.

In the frequency domain analysis, the number of points for the FFT must be defined. The number of points is a power of 2. Deepsoil will calculate the minimum number of points needed for the input motion and automatically sets the number of points to be used in the FFT to this minimum value. Note that the number of points for FFT should not be smaller than the minimum value recommended by Deepsoil.

After selecting the input motion and associated parameters, select the layer(s) for output (shown in the left column). Layer 1 is selected by default.

Finally, enter the damping ratio for the output response spectrum (shown in the lower left corner). The recommended value is 5%.

Press the "Analyze" button to begin the analysis. Before the analysis begins, you will be prompted to save the profile. You will always be prompted to save the profile before proceeding with the analysis regardless if any changes have been made. If you wish to save the profile, click "Yes." To continue with the analysis, click "No" when prompted.



In case the user wishes to define new motions, the format of the ground motion file should be as follows:

```
3000 0.02
0.02    0
0.04    -0.020939
0.06    -0.010396
0.08    0.012722
0.1     0.000847
0.12    -0.011606
0.14    0.002393
0.16    0.000787
0.18    -0.002625
0.2     -0.002768
```

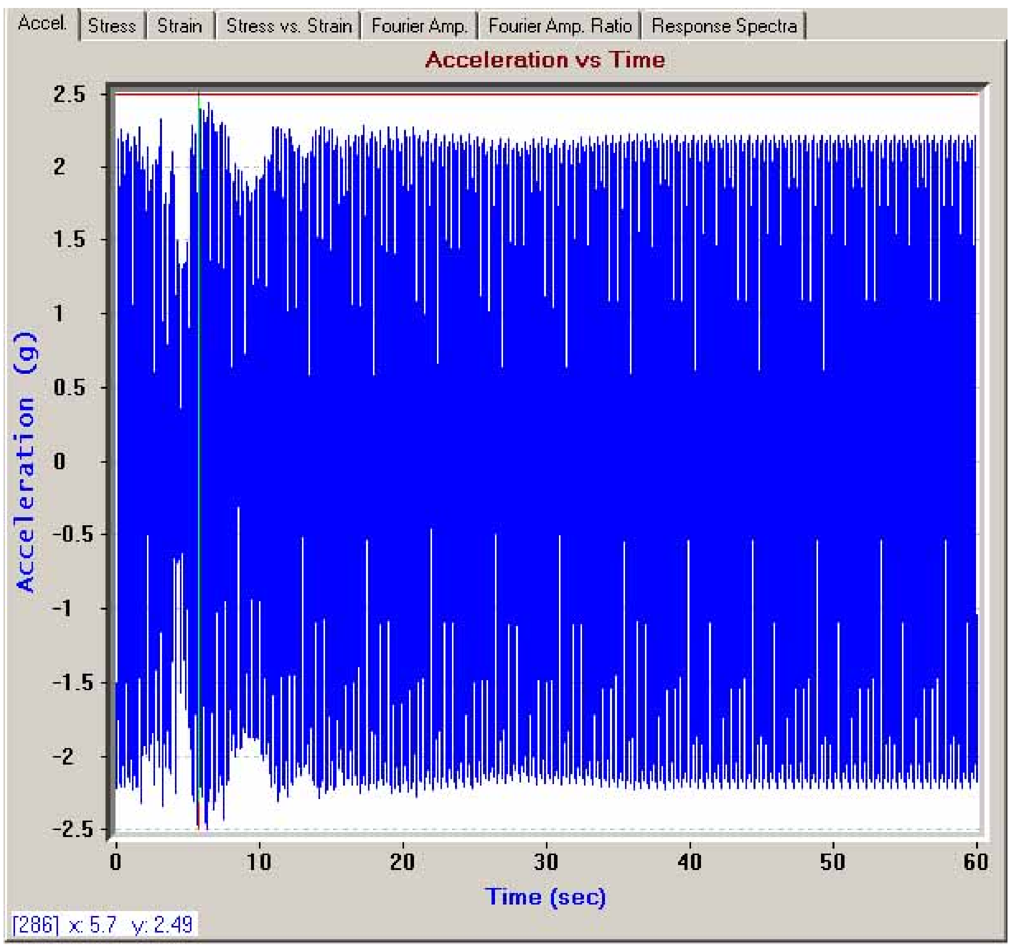
The first number is the total number of data points, the second number is the time interval. The actual time history should be written in two columns, the first column is the time step and the second column is the acceleration. The acceleration should be in units of g.

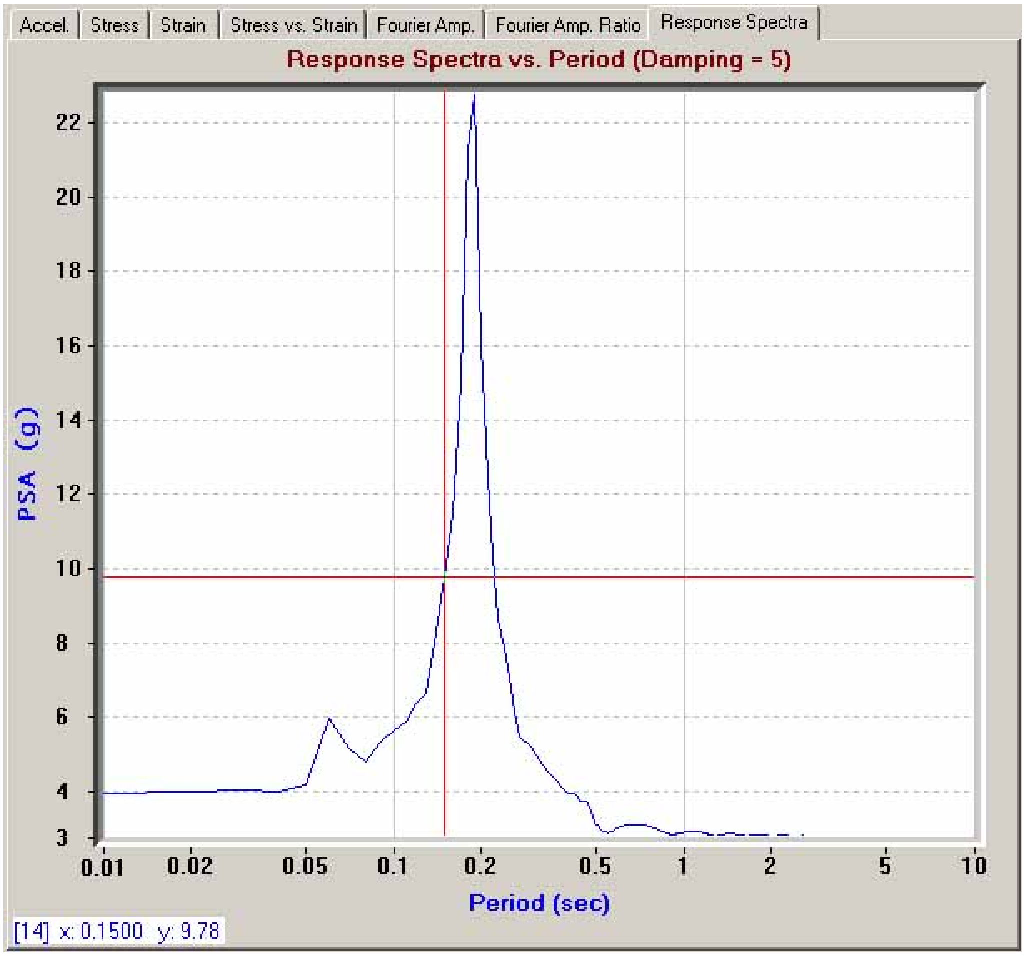
<u>STEP 6/6</u>

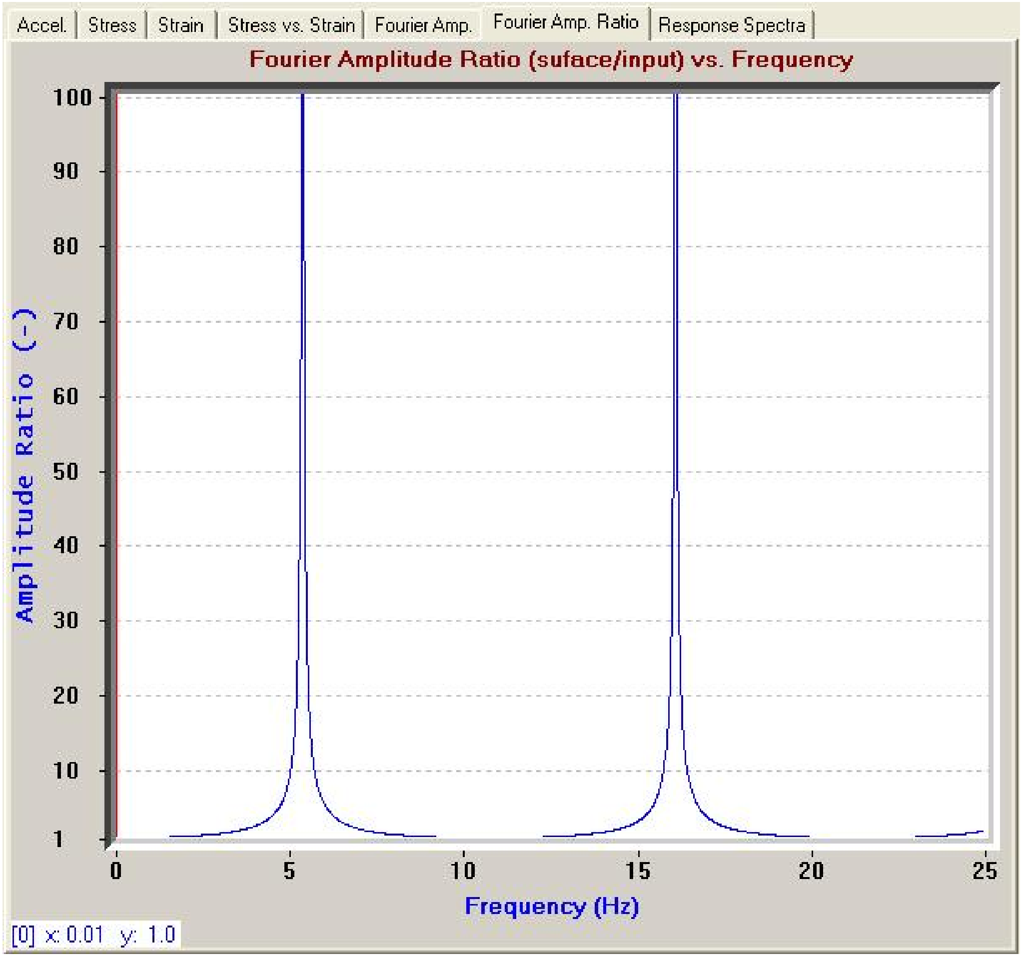
Upon completion of analysis, the user will be prompted by an informational message from Deepsoil indicating that the output data has been automatically exported to “ExportData.txt” in the user-specified working directory. Click “OK” to continue. If the file already exists, you will be prompted to either overwrite the existing file or to specify a new filename. Upon completion of this step, you are able to navigate the output window.

The output window displays acceleration, strain, and stress time histories, in addition to stress vs. strain curves, Fourier amplitude spectrum, Fourier amplification ratio, and response spectra.

Compare your results with the figures shown below. The results should be exactly the same (note the scales). Note that we have zoomed in on the plot of the Fourier amplification ratio. You may do this by performing a “Ctrl + Left-Mouse Drag” over the area to which you would like to zoom. Pressing “t” will zoom out one step.




Accel.
Stress
Strain
Stress vs. Strain
Fourier Amp.
Fourier Amp. Ratio
Response Spectra
Response Spectra vs. Period (Damping = 5)
PSA (g)
22
20
18
16
14
12
10
8
6
4
3
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
Period (sec)
[14] x: 0.1500 y: 9.78

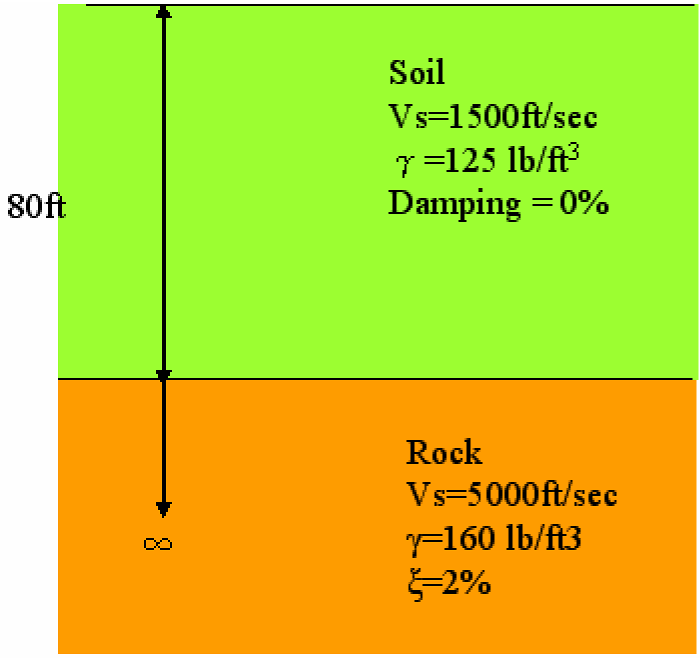


Note that resonance occurs at natural frequencies and therefore results in significant amplification of the motion at such frequencies.

3.2 *Example 2 Linear Frequency Domain Analysis / Undamped Elastic Layer, Elastic Rock*

Example 2 (“Ex2_Lin_Freq_Undamped_Elastic.dp”) is similar to Example 1; the only differences being that the soil column is now 80 feet thick and the bedrock is elastic instead of rigid. As such, the steps of the analysis are the same as those outlined in Example 1 except where noted below.

.



STEP 1/6

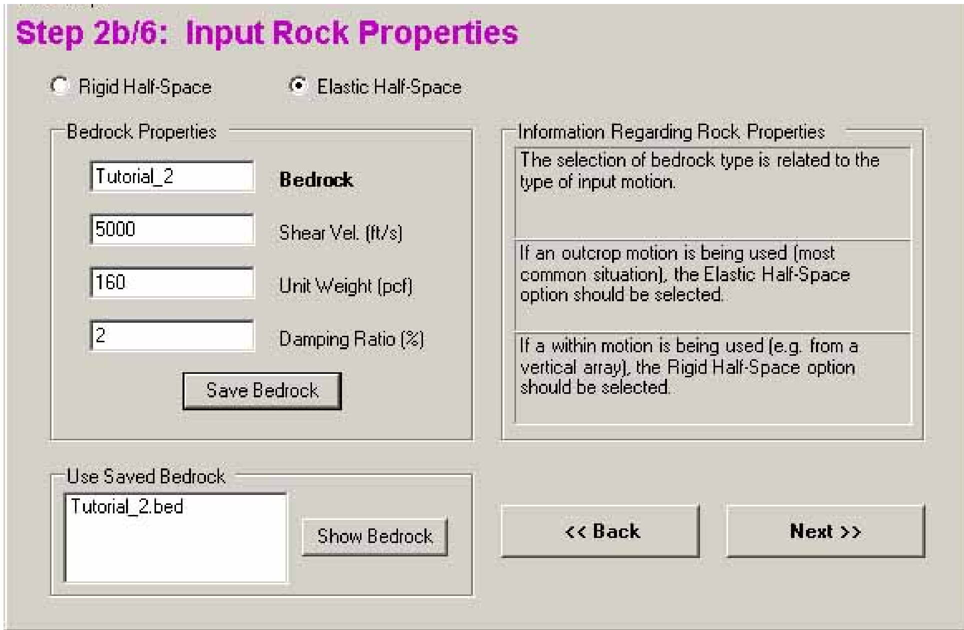
All options are the same as in Example 1. Press the “Next” button to proceed to the soil profile window.

STEP 2/6

Enter “80” for the thickness of the layer in the soil properties spreadsheet. All other values are the same as given in Example 1. Press the “Next” button to continue.

STEP 2b/6

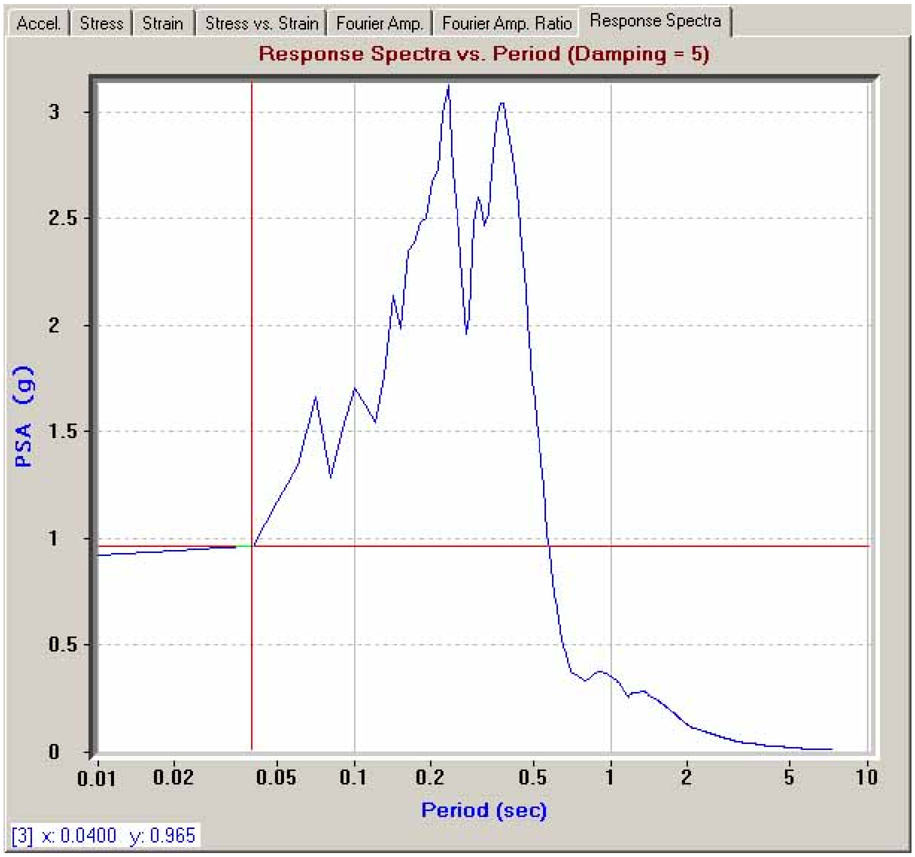
In this step, we will define the elastic properties of the bedrock. Select the “Elastic Half-Space” option to define the elastic bedrock properties. Enter the input for the Shear Velocity, Unit Weight, and Damping Ratio as 5000 ft/sec, 160 pcf, and 2% respectively. You can also save the bedrock properties by giving the bedrock a name and then clicking the “Save” button at the right upper corner of the “Half-space” form. Press the “Next” button to proceed to Step 3/6.

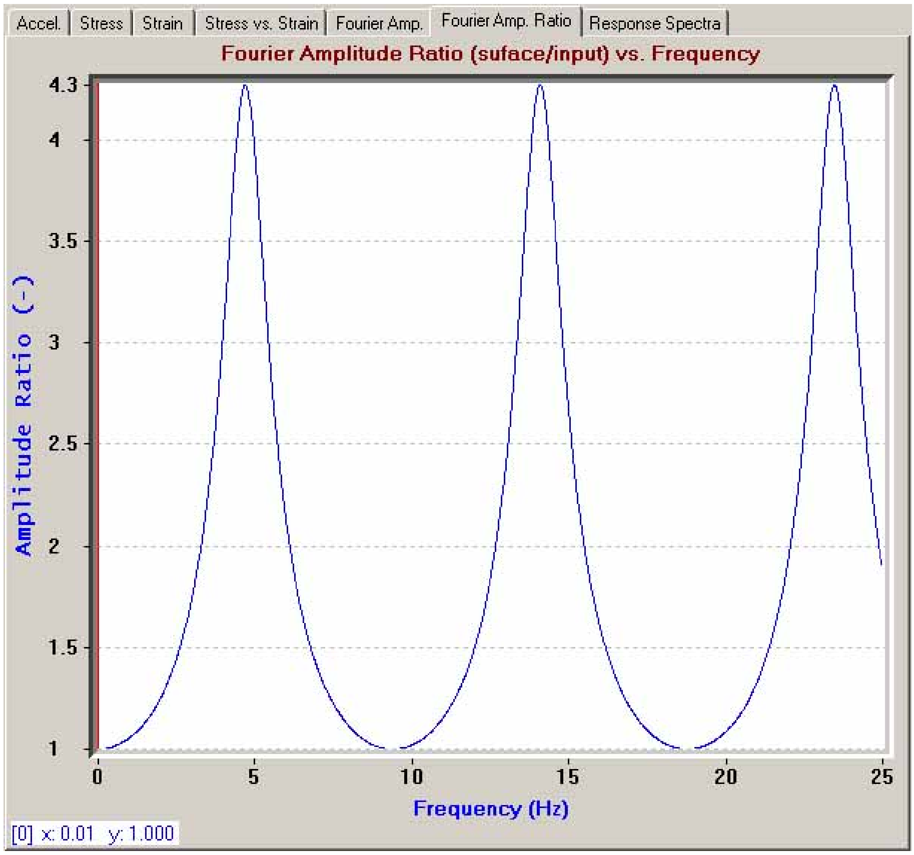


For the remaining steps, all options should be selected to be the same as in Example 1 (Input Motion→"loma_gilroy.txt"; Frequency Independent Complex Shear Modulus; FFT).

After you have checked that all options are the same as in Example 1, click the "Analyze" button to begin the analysis.

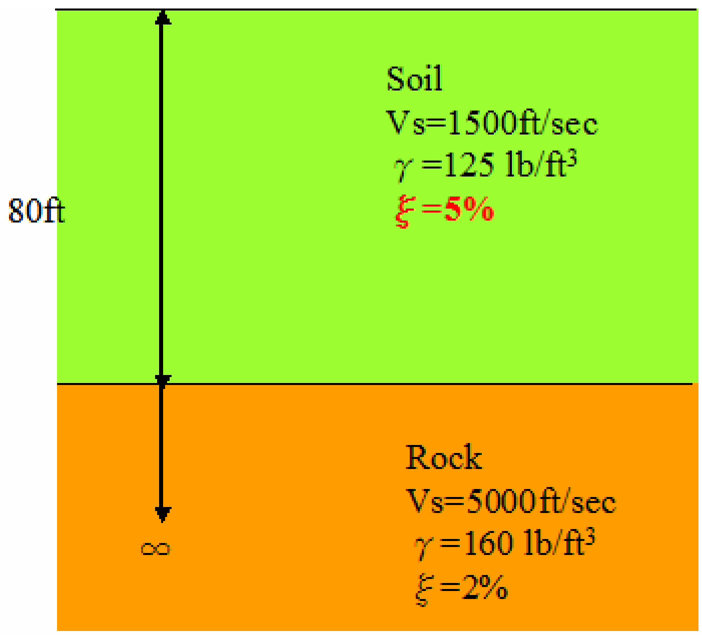
Check your analysis results with the figures shown on the following page. The first figure shows the calculated surface response spectrum. The elastic bedrock absorbs a significant amount of energy compared to the rigid bedrock and results in lower resonance.


Accel.
Stress
Strain
Stress vs. Strain
Fourier Amp.
Fourier Amp. Ratio
Response Spectra
Response Spectra vs. Period (Damping = 5)
PSA (g)
3
2.5
2
1.5
1
0.5
0
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
Period (sec)
[3] x: 0.0400 y: 0.965


Accel.
Stress
Strain
Stress vs. Strain
Fourier Amp.
Fourier Amp. Ratio
Response Spectra
Fourier Amplitude Ratio (suface/input) vs. Frequency
Amplitude Ratio (-)
4.3
4
3.5
3
2.5
2
1.5
1
0
5
10
15
20
25
Frequency (Hz)
[0] x: 0.01 y: 1.000

3.3 *Example 3 Linear Frequency Domain Analysis / Damped Elastic layer, Elastic rock*

Examples 1 and 2 assume that the soil layer has zero damping. This assumption is unrealistic because soils are known to exhibit damping even at very small strains. Example 3 (“Ex3_Lin_Freq_Damped_Elastic.dp”) is similar to Example 2; the only difference being that the soil is damped instead of undamped. As such, the steps of the analysis are the same as those outlined in Example 2 except where noted below.



STEP 1/6

All options for Step 1/6 are exactly the same as those in Example 2.

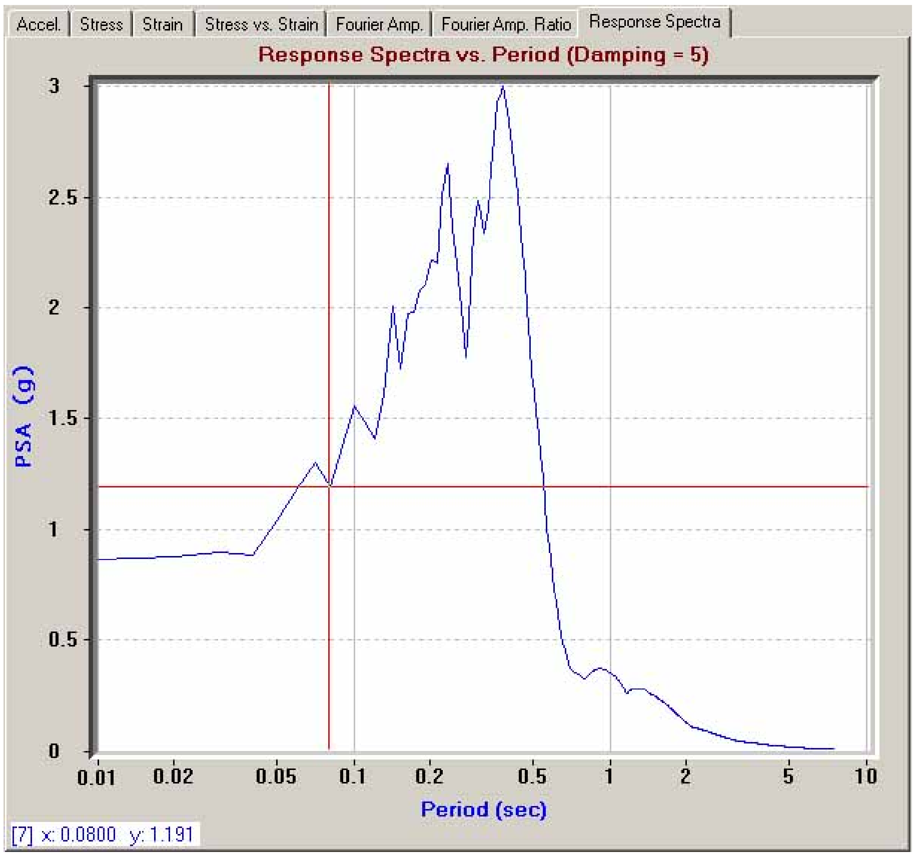
STEP 2/6

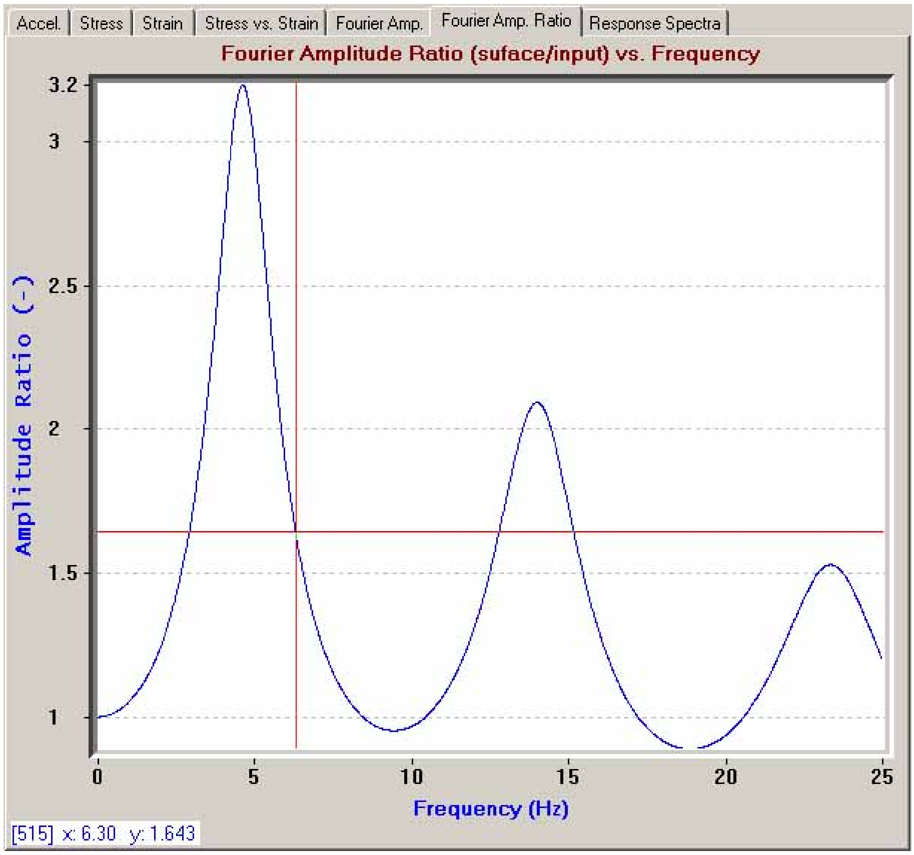
Damping of 5% is imposed on the soil layer. Enter “5” into the “Damping Ratio” column of the soil properties spreadsheet. Press the “Next” button to proceed to Step 2b/6.

Layer No.	Name	Thickness (ft)	Unit Weight (pcf)	Shear Vel. (ft/sec)	Damping Ratio (%)
1		80	125	1500	5

Select all other options to be the same as Example 2 (Input Motion→loma_gilroy.txt; Frequency Independent Complex Shear Modulus; FFT). After you have checked that all options are the same as in Example 2, click the “Analyze” button to begin the analysis.

The calculated surface response spectrum is shown in the figure on the following page. Note how the damping imposed on the soil results in lower resonance.




Accel.
Stress
Strain
Stress vs. Strain
Fourier Amp.
Fourier Amp. Ratio
Response Spectra
Fourier Amplitude Ratio (suface/input) vs. Frequency
Amplitude Ratio (-)
3.2
3
2.5
2
1.5
1
0
5
10
15
20
25
Frequency (Hz)
[515] x: 6.30 y: 1.643

3.4 *Example 4 Equivalent Linear Frequency Domain Analysis / Single Layer, Elastic Rock*

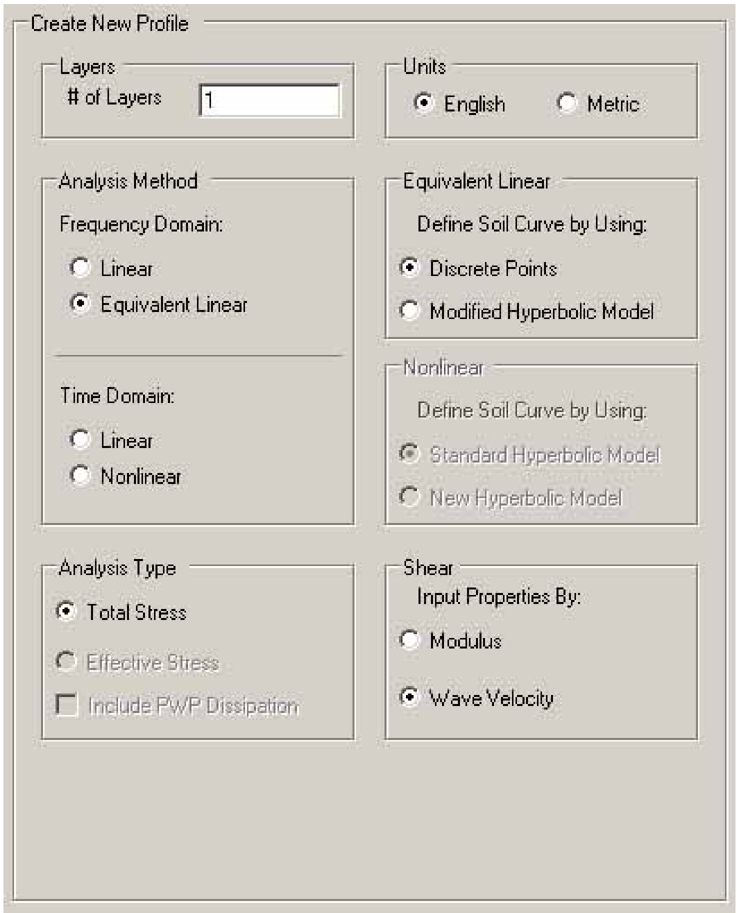
Example 4 (“Ex4_EQL_Single_Layer.dp”) considers an equivalent linear analysis. The profile is the same as that of Example 3 with the exception that the material properties will be changed.

STEP 1/6

The input for Step 1/6 is similar to Example 3, with the following exceptions:

For “Analysis Type,” select the Frequency Domain – “Equivalent Linear” analysis. This will enable the “Equivalent Linear” options.

For an equivalent linear analysis, the G/G_{MAX} and damping ratio curves can be defined using either a) Discrete Points or b) the Modified Hyperbolic Model.



If Discrete points are selected, the G/G_{MAX} and damping ratio will be defined in discrete points at various strain levels. It is also possible to define the G/G_{MAX} and damping curve using the modified hyperbolic model. In that case, the user needs to define the nonlinear parameters for the soil model. DEEPSOIL will automatically develop corresponding G/G_{MAX} and damping ratio curves.

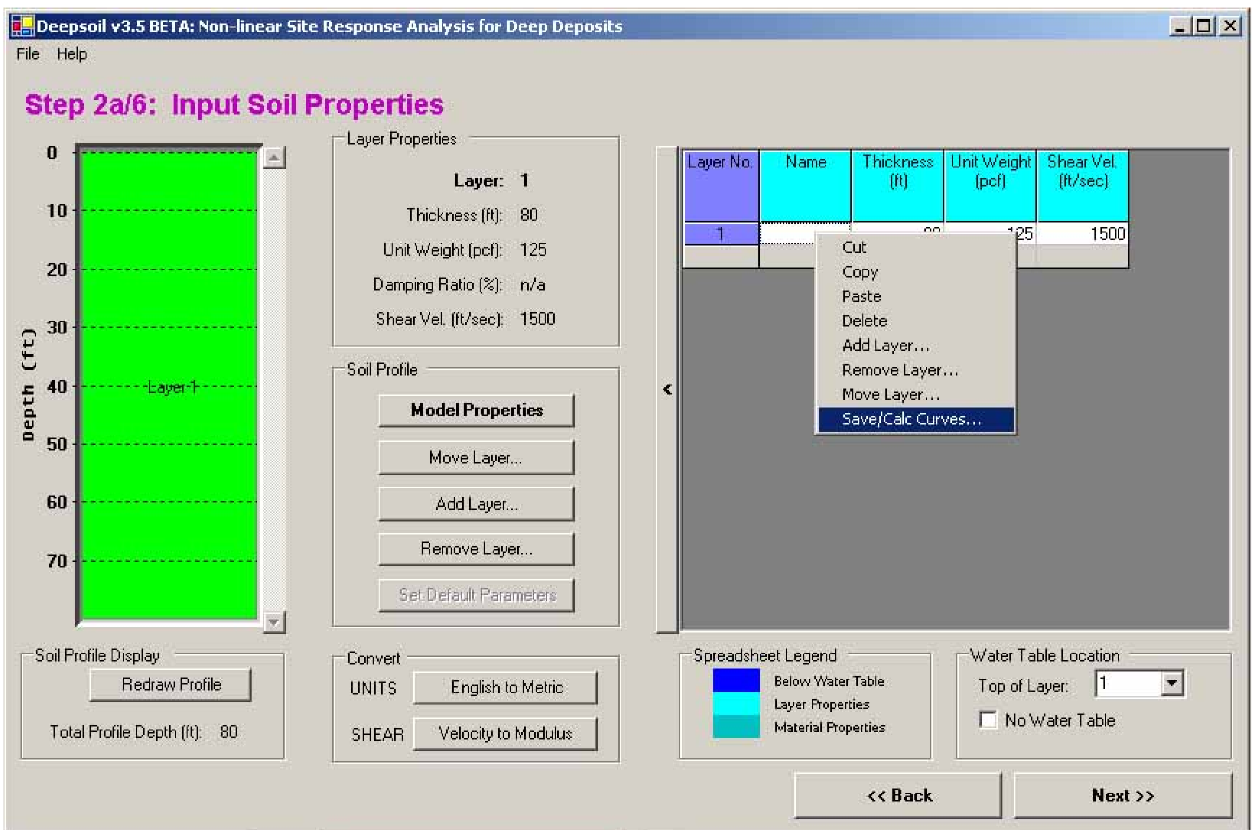
For this example, select “Discrete Points” and then press the “Next” button.

STEP 2/6

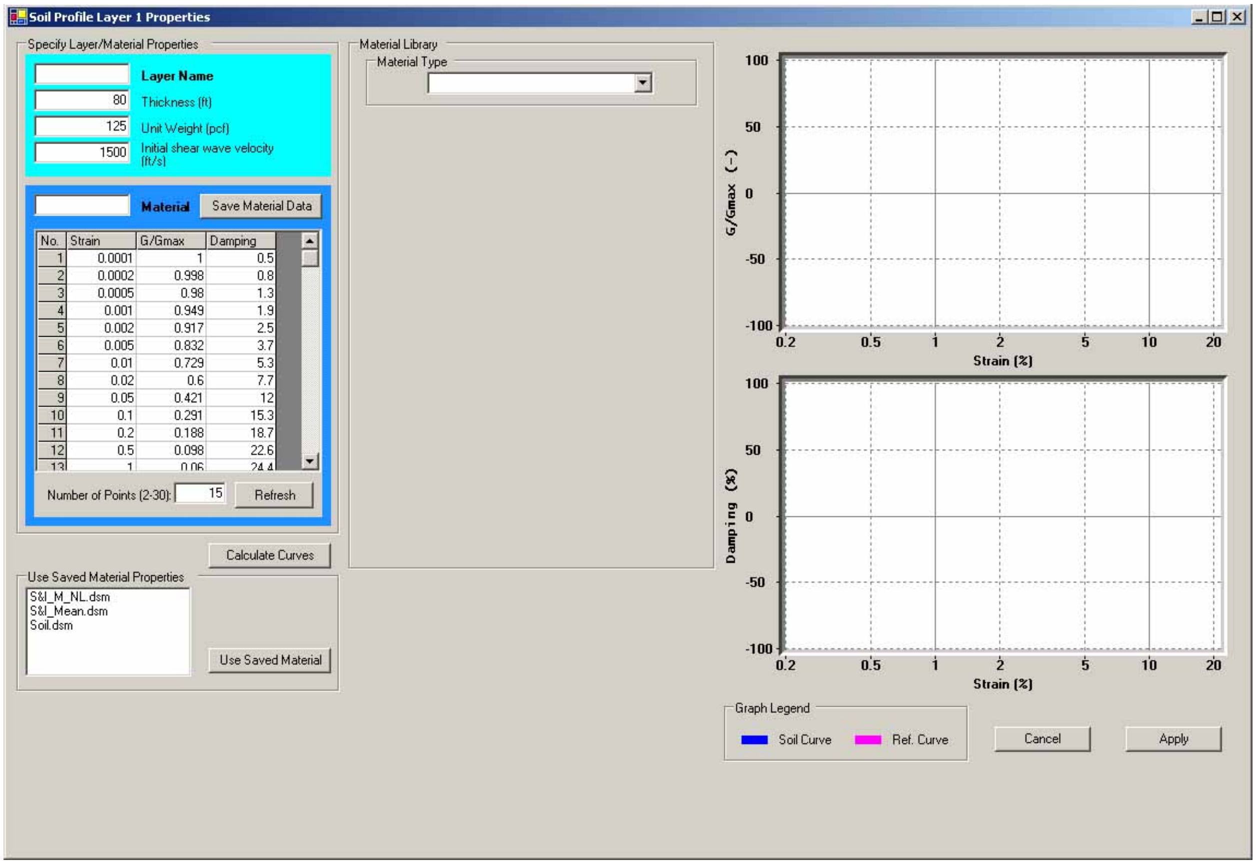
The user can go directly to the spreadsheet, the graphical soil column, or use the “Model Properties” button to define the soil curves. From the spreadsheet, left-click any cell of the layer for which you want to define the soil curve to select that layer. Next, right-click the same cell to bring up the spreadsheet pop-up menu. Select “Save/Calc Curves.”

From the graphical soil column, left-click the Layer name to bring up the soil column pop-up menu. Select “Save/Calc Curves.”

The “Model Properties” button will allow you to define the soil curves for whichever layer is currently selected as shown under Layer Properties.



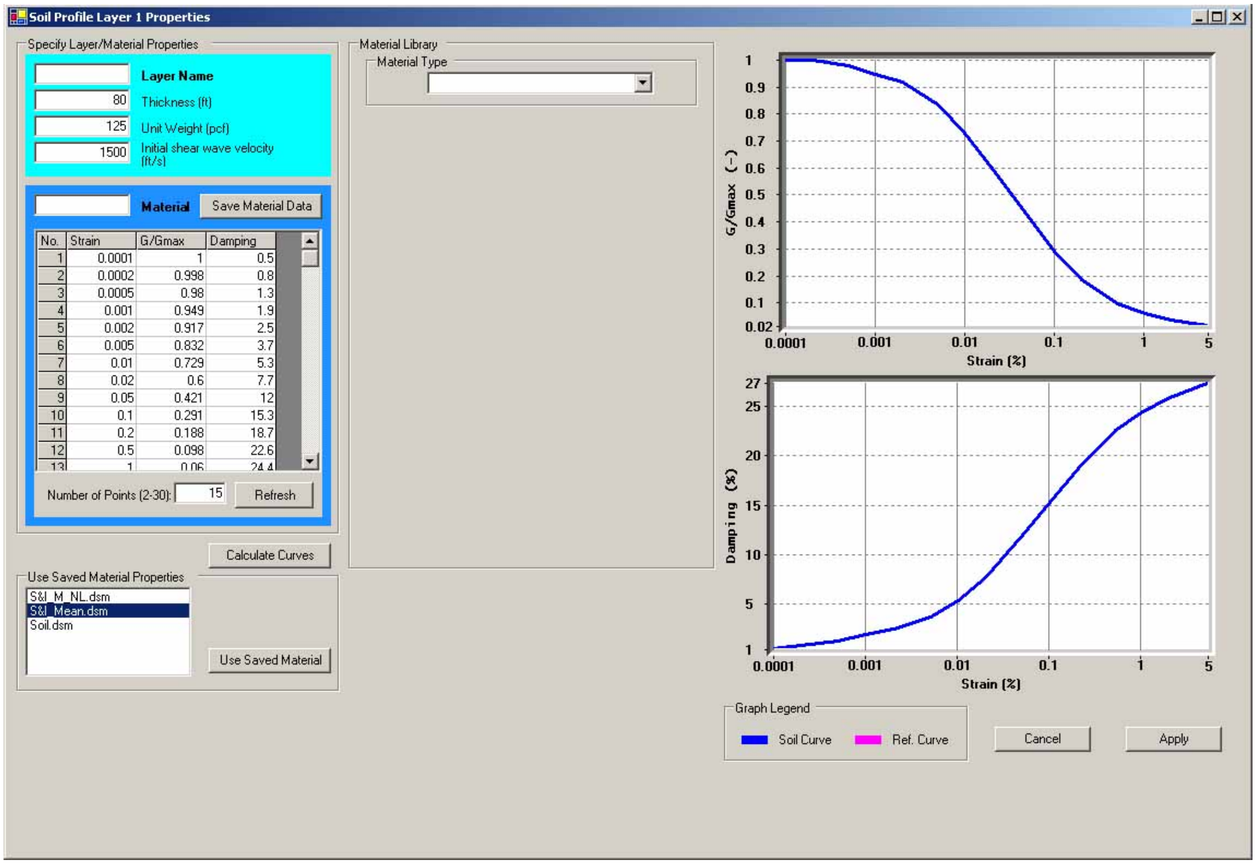
Pressing "Save/Calc Curves" or clicking the "Model Properties" button will open a new window:



The user can define the G/G_{MAX} and damping properties by first defining the number of data points. Note that the number of data points should be identical for G/G_{MAX} and damping. The strain and damping values should be entered as a percent [%].

To save the data points, type a name to identify the properties and press "Save Material Data." Once saved, the newly saved file will appear in the "Use Saved Material Properties" listbox.

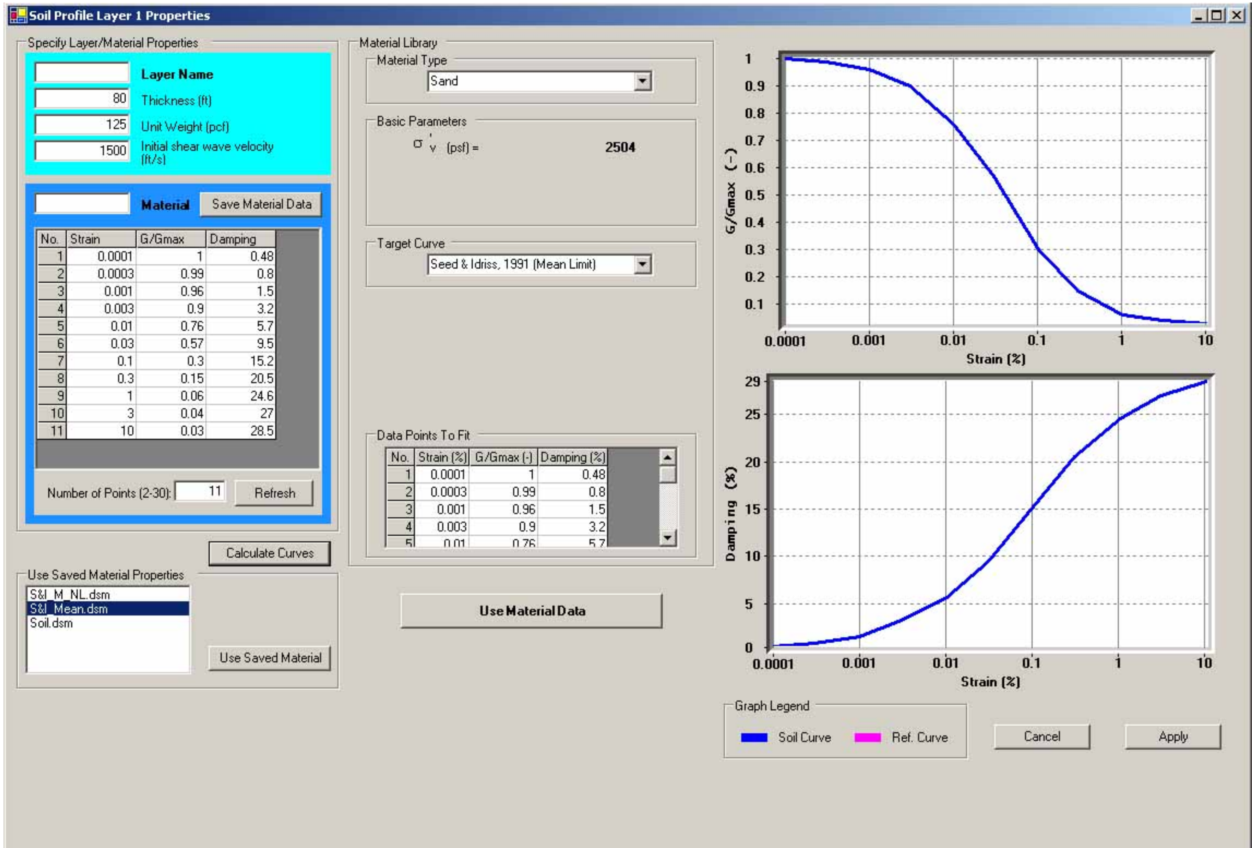
The user can also use pre-saved material properties by selecting the appropriate file from the list box and pressing the "Use Saved Material" button.



A Material Library is also available to the user to define the soil curves. We will use this method in this example. To use this method, the user must define a) the Material Type, and b) the Target Curve.

Click on the Material Type drop-down menu and select “Sand”. Two new items will appear: Basic Parameters and Target Curve. The Basic Parameters for this case simply displays the vertical stress at the midpoint of the layer. Now we must define the Target Curve.

Click on the Target Curve drop-down menu. A list of various models for sand will appear. Select the “Seed & Idriss, 1991 (Mean Limit)” item. The model soil curves will be plotted in red for your reference. In addition, a new item appears labeled: “Data Points to Fit.” These are the points which define the model curves. To use this model data, click the “Use Material Data” button. The discrete points of your soil model will be updated to match these points. Click “Calculate Curves” to verify that the models are the same.



Once you are satisfied with your soil curves, press the “Apply” button to apply the properties.

When you have finished checking the data, press the “Next” button to proceed.

STEP 2b/6

The entries for this step are the same as those specified in Example 3.

STEP 3/6

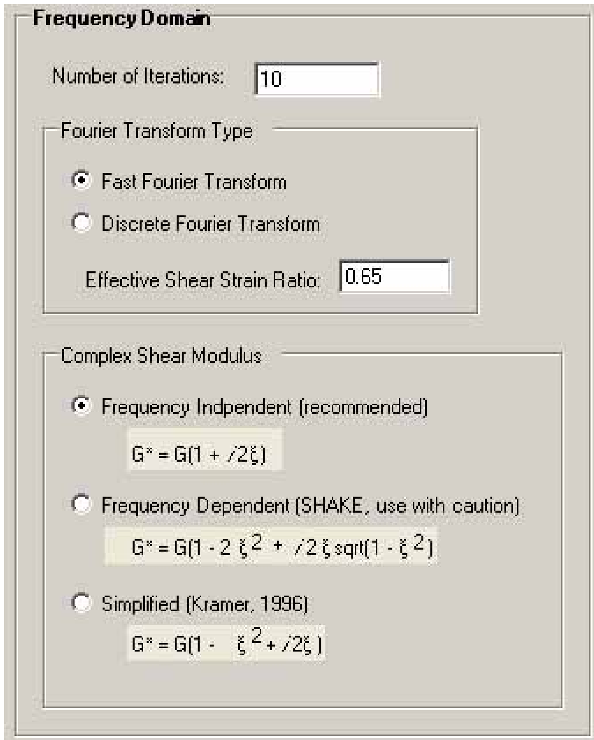
The third stage of analysis is the analysis control stage.

Equivalent linear analyses require a number of iterations to obtain more accurate results. The recommended number of iterations is 15. For the sake of accuracy, you should not choose less than 10 iterations. For this example, choose (at least) 10 iterations.

Select the Fast Fourier Transform (FFT).

The next step is selecting the effective shear strain ratio. The equivalent linear analysis selects shear modulus and damping ratio at a representative shear strain at an effective strain as a ratio of maximum shear strain. Enter an effective shear strain ratio of 0.65.

Select the Frequency Independent Complex Shear Modulus for use in this analysis.



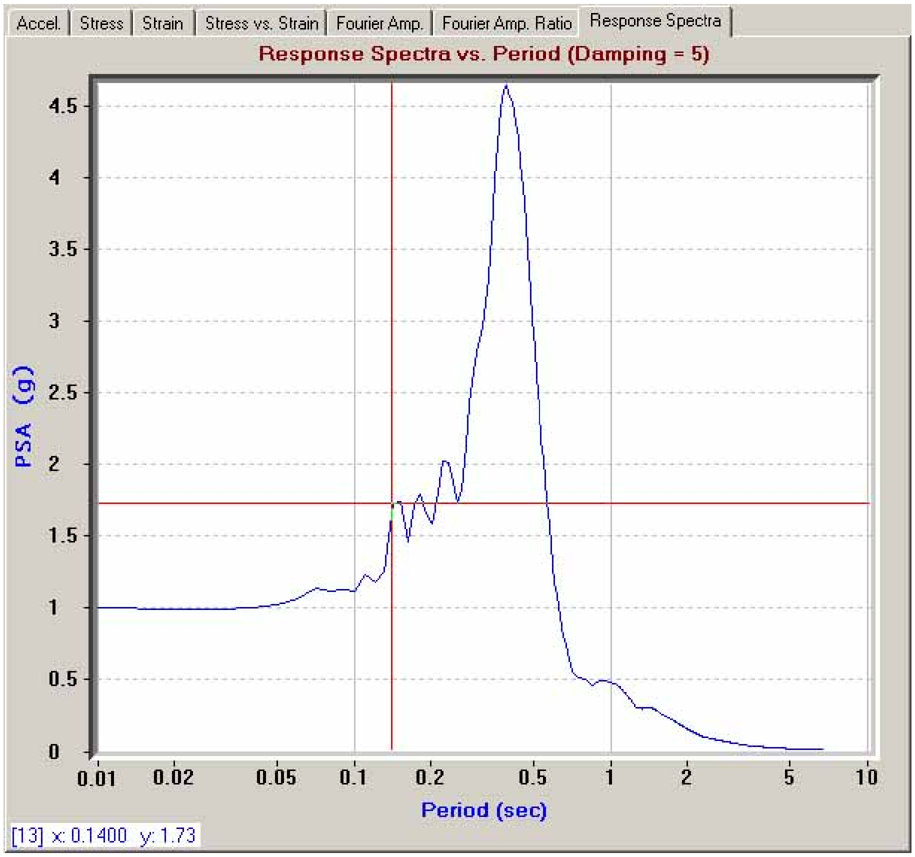
Finally, press the “Next” button to proceed to the input motion and output layer(s) selection window (Step 4/6).

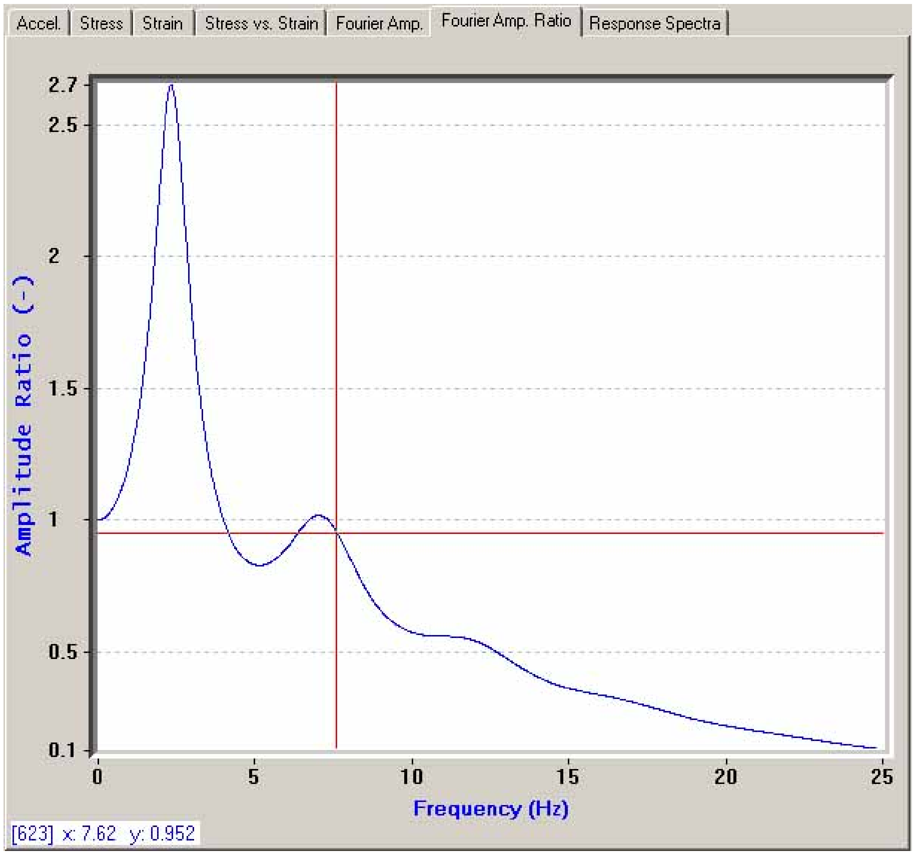
STEP 4/6

Similar to the previous examples, select “loma_gilroy.txt” as the input motion and select the desired layers for output. Layer 1 is automatically selected by default. Press the “Analyze” button to begin the analysis.

STEP 6/6

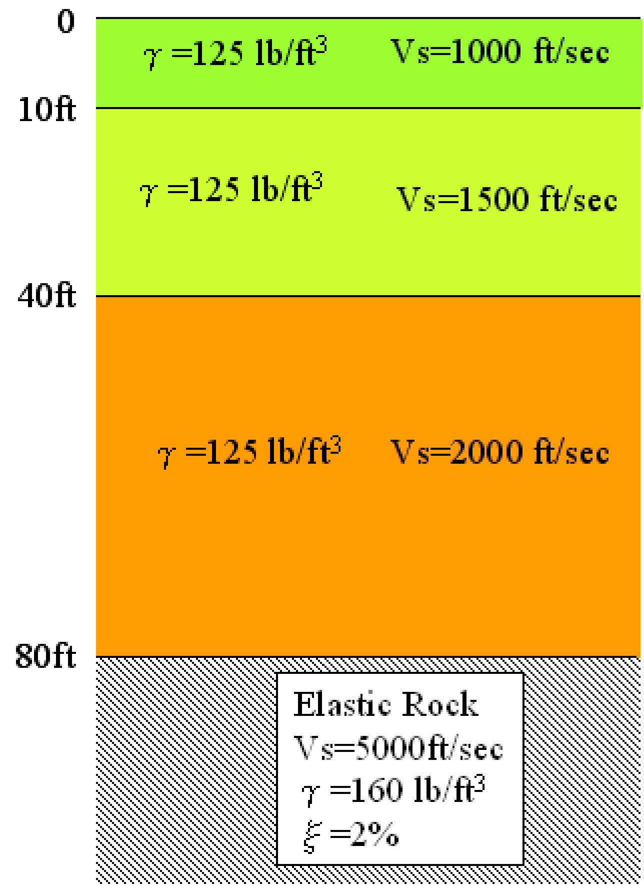
The figures below show the computed response spectrum at the surface. Check that your results match those presented in the figures.


Accel.
Stress
Strain
Stress vs. Strain
Fourier Amp.
Fourier Amp. Ratio
Response Spectra
Response Spectra vs. Period (Damping = 5)
PSA (g)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
Period (sec)
[13] x: 0.1400 y: 1.73


Accel.
Stress
Strain
Stress vs. Strain
Fourier Amp.
Fourier Amp. Ratio
Response Spectra
Amplitude Ratio (-)
2.7
2.5
2
1.5
1
0.5
0.1
0
5
10
15
20
25
Frequency (Hz)
[623] x: 7.62 y: 0.952

3.5 *Example 5 Equivalent Linear Frequency Domain Analysis / Multi Layer, Elastic Rock*

Example 5 (“Ex5_EQL_Multi_Layer.dp”) considers an equivalent linear analysis for a multi-layer profile. This example will show you how to modify a previously saved profile by adding and removing layers.



STEP 1/6

Press the “Open Existing Profile” button and browse for Example 4. It should be located in the “Examples” diredtory. Once you find the appropriate directory, open Example 4 (“Ex4_EQL_Single_Layer.dp”).

Press “Next” to proceed to Step 2/6.

STEP 2/6

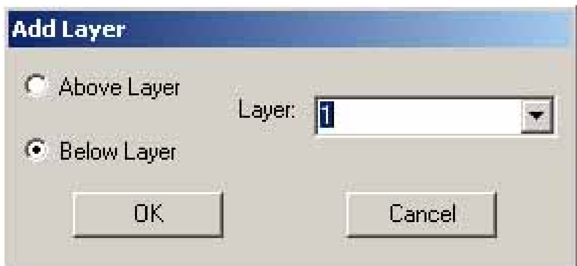
As you can see, all of the information for Layer 1 corresponds to Example 4. We will now modify this data and add two additional layers to the profile. First, change the Thickness and Shear Wave Velocity of Layer 1 to 10 ft and 1000 ft/sec, respectively.

There are two methods of adding a layer to the profile. We will use the first method to add the first layer, and the second method to add the second layer.

To add a layer to the profile by the first method, first select Layer 1 by left-clicking any of the cells in that row. Now, right-click to bring up the soil properties pop-up menu and select "Add Layer" from the list of commands. A new "Add Layer" window will appear.

In the "Add Layer" window, select the "Add layer below" option and select Layer 1 from the drop-down list. After pressing "OK," the "Soil Profile Layer Properties" window will appear which we used previously to calculate the soil curves.

In this window, enter the Thickness (30 ft), Unit Weight (125 pcf), and Shear Wave Velocity (1500 ft/sec) of the soil layer. Also apply the "Seed & Idriss, 1991 (Mean Limit)" curves for the layer as was done in Example 4. Once you have entered the appropriate data, click the "Apply" button.



To add the third layer, left-click one of the cells corresponding to Layer 2. Now click the "Add Layer" button in the Soil Profile group located in the middle of the form. Repeat the same process outlined above. Be sure that you check your input in the spreadsheet to confirm that it matches with this tutorial.

Layer No.	Name	Thickness (ft)	Unit Weight (pcf)	Shear Vel. (ft/sec)
1		10	125	1000
2		30	125	1500
3		40	125	2000

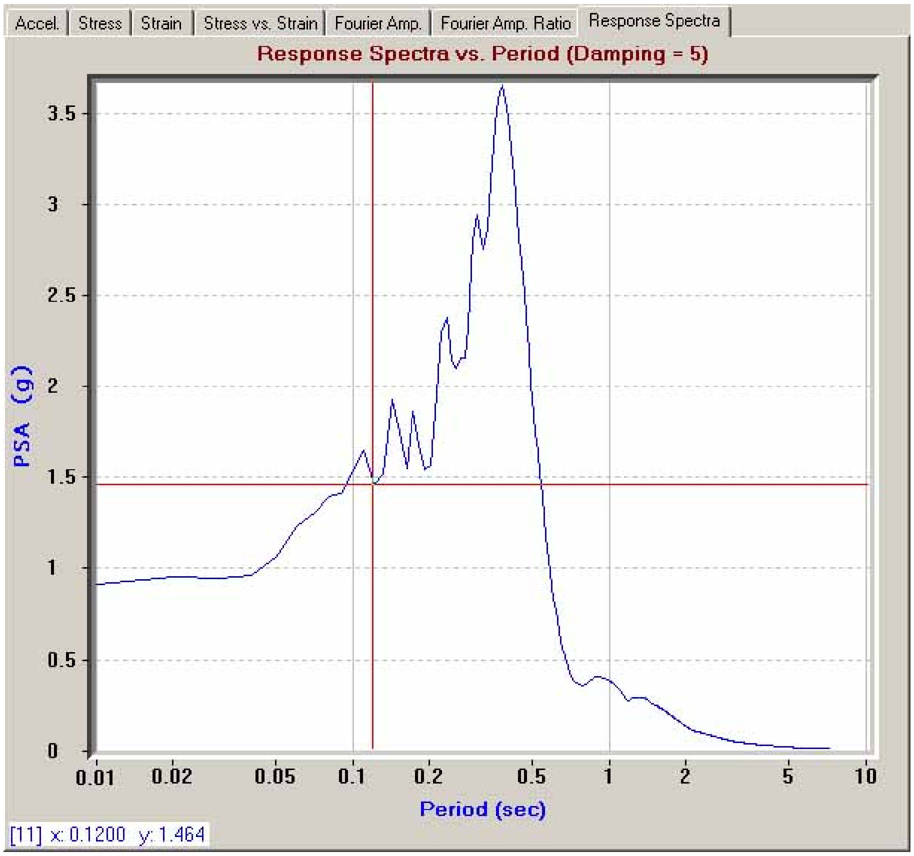
For Step 2b/6 and Step 3/6, keep all other options the same as Example 4.

STEP 4/6

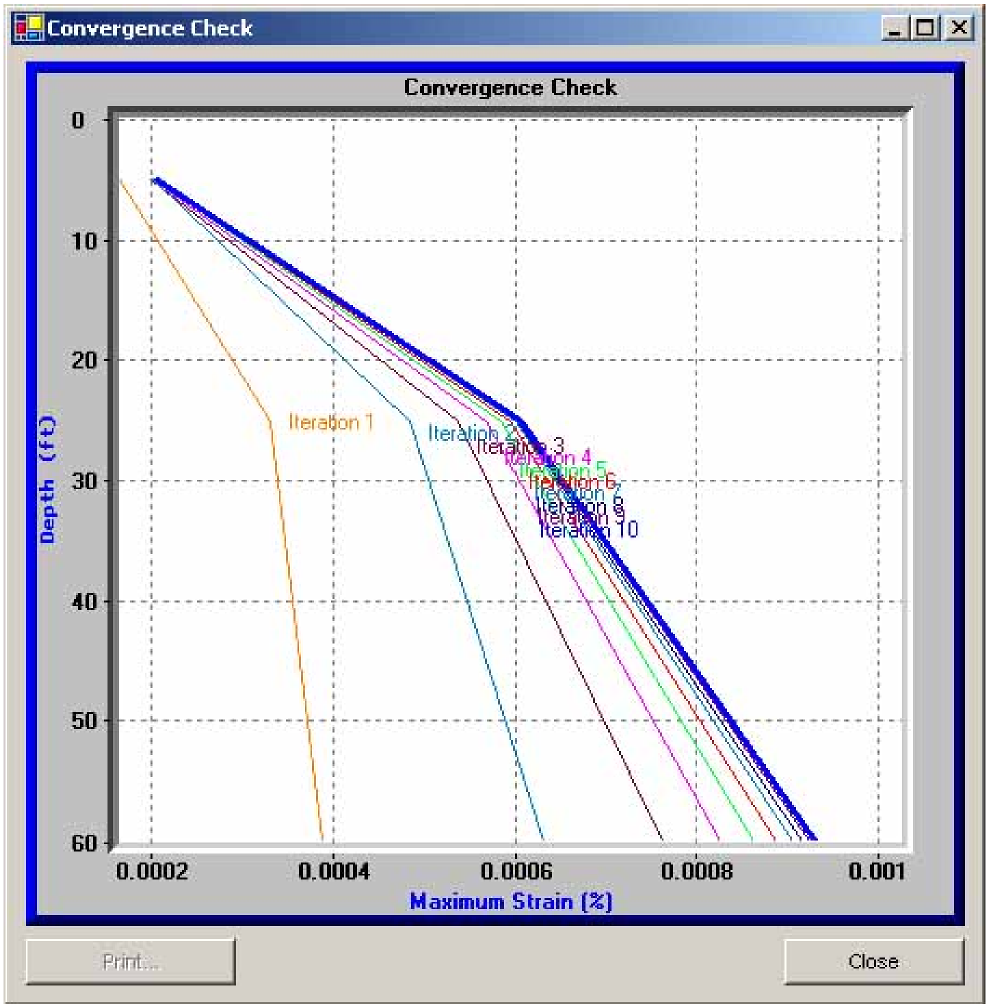
Keep all other selected options the same as in Example 4, including the input motion ("loma_gilroy.txt"). If you like, you may select to analyze Layers 2 and 3 (Layer 1 is selected by default) by checking each layer's corresponding checkbox located to the left of the input motion plot. Once you have checked your input and specified which layers are to be analyzed, press the "Analyze" button to run the analysis.

STEP 6/6

The figure below shows the computed surface acceleration. Check that your results match with those shown.



DEEPSOIL also allows checking the convergence of the equivalent linear analysis. You may do so by pressing the “Check Convergence” button located near the lower left corner of the form.



Convergence Check
Convergence Check
Depth (ft)
0
10
20
30
40
50
60
0.0002
0.0004
0.0006
0.0008
0.001
Maximum Strain (%)
Iteration 1
Iteration 2
Iteration 3
Iteration 4
Iteration 5
Iteration 6
Iteration 10
Print...
Close

3.6 *Example 6 Non-linear Analysis / Multi Layer, Elastic Rock*

Example 6 (“Ex6_Nonlin_Multi_Layer.dp”) of this tutorial considers a Non-Linear analysis. The profile is the same as that of Example 5.

In a non-linear analysis, the thickness of each layer has to be changed. This is because the thickness controls the maximum frequency that can be propagated by the layer. The greater is the thickness of the layer, the lower the maximum frequency that can be propagated by the same layer.

The equation that correlates the maximum frequency with soil thickness is as follows:

$$h = Vs/4f_{max}$$

Where h = thickness of the soil layer, Vs=shear wave velocity of the layer, and f_{max} is the maximum frequency that can be propagated.

It is a common practice to set the maximum frequency to 25 Hz in a non-linear site response analysis. This example will also use f_{max} = 25Hz.

Simple calculations reveal that h for the layers should be 10 ft, 15 ft, and 20 ft for layers 1, 2, and 3 respectively. The first layer does not need to be changed, whereas the subsequent layers need to be subdivided into 2 thinner layers.

Now let's actually develop the input file for this example.

STEP 1/6

Open Example 5 (“Ex5_EQL_Multi_Layer.dp”).

Change the “Analysis Type” from “Equivalent Linear” to “Non-Linear.” Press the “Next” button to proceed to the soil properties input form.

STEP 2/6

Note that the basic properties of the layers (Thickness, unit weight, and shear velocity) are preserved.

Layer No.	Name	Thickness (ft)	Unit Weight (pcf)	Shear Vel. (ft/sec)	Damping Ratio (%)	Ref. Strain	Ref. Stress (MPa)	Beta	s	b	d
1		10	125	1000							
2		30	125	1500							
3		40	125	2000							

Subdivide Layers 2 and 3 into 2 thinner layers with each having a thickness equal to half of the original layer.

Layer No.	Name	Thickness (ft)	Unit Weight (pcf)	Shear Vel. (ft/sec)	Damping Ratio (%)	Ref. Strain	Ref. Stress (MPa)	Beta	s	b	d
1	Nonlin S&I	10	125	1000							
2	Nonlin S&I	15	125	1500							
3	Nonlin S&I	15	125	1500							
4	Nonlin S&I	20	125	2000							
5	Nonlin S&I	20	125	2000							

For each layer, bring up the soil properties pop-up menu and select “Save/Calc Curves.”

The default non-linear parameters are given as “S&I_M_NL.dsm” Find the file in the “Saved Materials” list box and press “Use Saved Material” to apply the material data to the layer.

Find the “Seed & Idriss, 1991 (Mean Limit)” curves in the Material Library as was done in previous examples. Now, press “Calculate Curves” to display the soil curves. Compare the calculated curves to the Seed and Idriss mean cohesionless curves. The Seed and Idriss curves, which are the reference curves, will be shown in red.

To match the Seed and Idriss curves, the material constants need to be changed. The soil model incorporated in DEEPSOIL is the extended modified hyperbolic model:

$$\tau = \frac{G_{mo}\gamma}{1+\beta\left(\frac{G_{mo}}{\tau_{mo}}\gamma\right)^{s}} = \frac{G_{mo}\gamma}{1+\beta\left(\frac{\gamma}{\gamma_{r}}\right)^{s}}$$

$$\gamma_r = REF.strain\left(\frac{\sigma_v'}{REF.stress}\right)^{b} \qquad \xi = \frac{Damping\ ratio}{(\sigma_v')^{d}}$$

The parameters that control the shape of the backbone curve are β (beta), s, and γ_r.

The curve can be made confining pressure dependent by selecting the reference stress and the “b”-parameter. Select b = 0 to make the curve pressure independent. Note that γ_r = reference effective strain for b = 0 or σ_v' = reference stress.

The small strain damping properties can also be made pressure dependent by introducing the “d”-parameter. The “d”-parameter in the equation is the small strain damping in the user interface. Select d = 0 to make the curve pressure independent.

Try various combinations to get a good match with the Seed and Idriss reference curves.

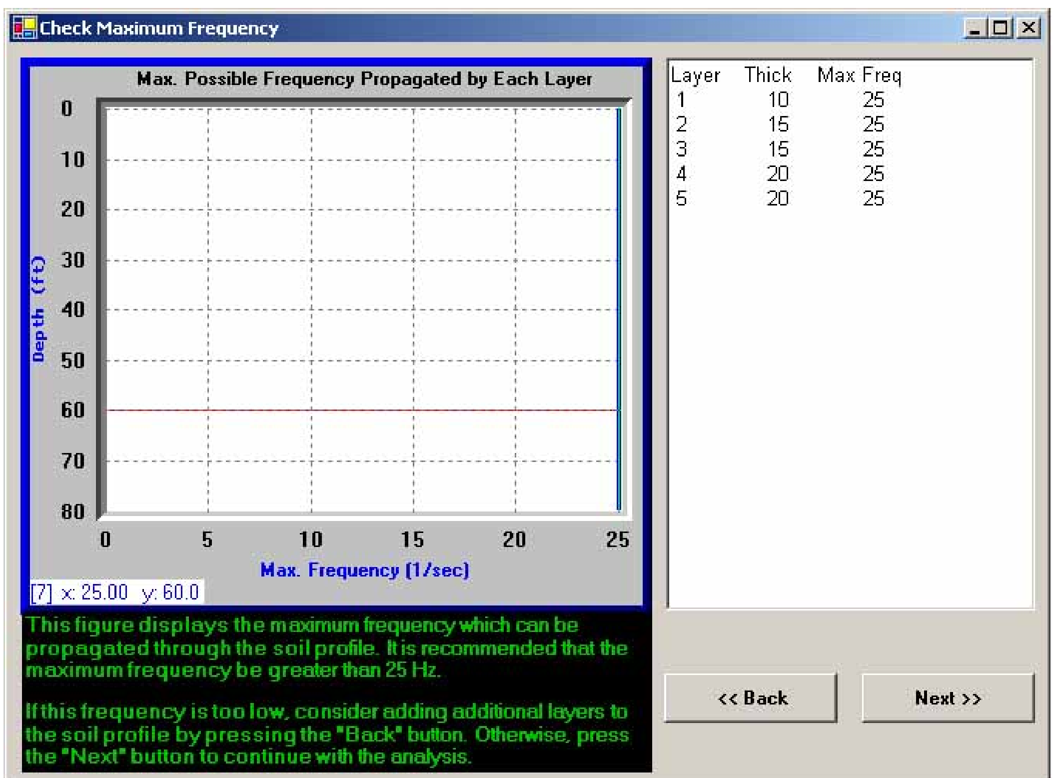
Once a satisfactory match is obtained, save the material in the material library. Then assign the selected parameters for all other layers.

For the purposes of this example, use the “S&I_M_NL.dsm” saved material for all layers.

After all of the input parameters have been specified, the spreadsheet should look like this:

Layer No.	Name	Thickness (ft)	Unit Weight (pcf)	Shear Vel. (ft/sec)	Damping Ratio (%)	Ref. Strain	Ref. Stress (MPa)	Beta	s	b	d
1	Nonlin S&I	10	125	1000	0.5	0.03	0.18	0.8	0.7	0	0
2	Nonlin S&I	15	125	1500	0.5	0.03	0.18	0.8	0.7	0	0
3	Nonlin S&I	15	125	1500	0.5	0.03	0.18	0.8	0.7	0	0
4	Nonlin S&I	20	125	2000	0.5	0.03	0.18	0.8	0.7	0	0
5	Nonlin S&I	20	125	2000	0.5	0.03	0.18	0.8	0.7	0	0

For nonlinear analyses, DEEPSOIL will automatically check the maximum frequency of each layer. The Maximum Frequency vs. Depth will be plotted with a table of corresponding values given on the right. This check is to ensure that the maximum cut-off frequency is always greater than or equal to 25 Hz.



After checking the results, press the “Next” button to continue to Step 2b/6 of the analysis.

<u>STEP 2b/6</u>

The values to be entered in this step are the same as in Example 4.

STEP 3/6

The third stage of the analysis is the analysis control stage. In a time domain analysis, the user must specify a step control scheme. Choose either a “Flexible” (default) or “Fixed” sub-incrementation scheme. The “Flexible” sub-incrementation scheme subdivides a time interval into small steps if the calculated strain increment is higher than the user-defined maximum strain increment. The “Fixed” scheme sub-divides all time intervals into user-defined sub-increments.

For the purpose of this tutorial, select the “Flexible” sub-incrementation scheme. Press the “Next” button to continue.

STEP 4/6

This stage of analysis requires selection of the input ground motion and layers to be analyzed for output. As in previous examples, select “loma_gilroy.txt” as the input motion. You may select the additional layers to be analyzed as well. Layer 1 is selected by default.

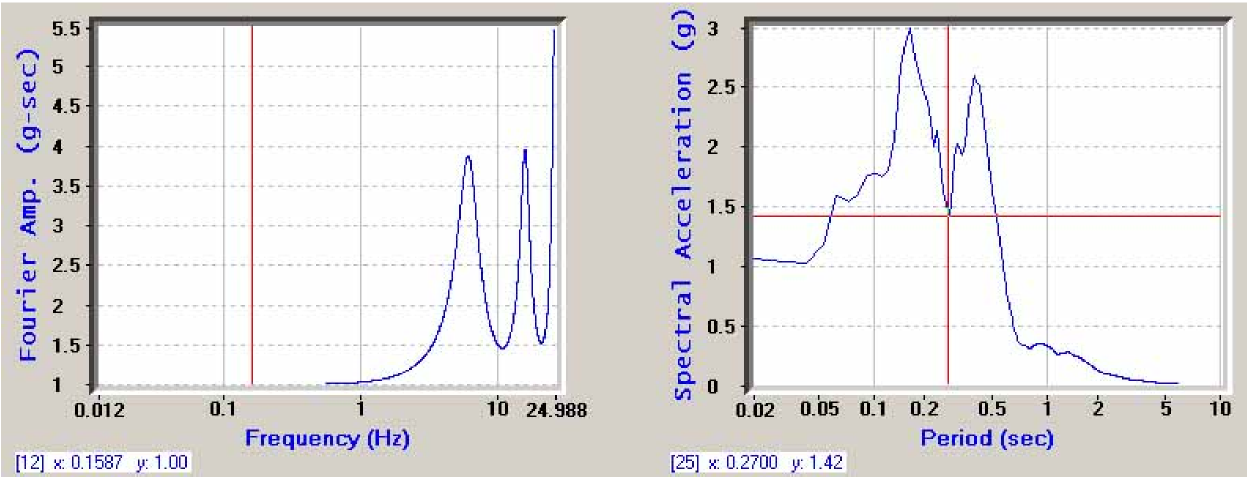
Press the “Next” button to continue to the fifth stage of analysis.

STEP 5/6

The fifth stage of analysis requires selection of the appropriate Rayleigh damping coefficients.

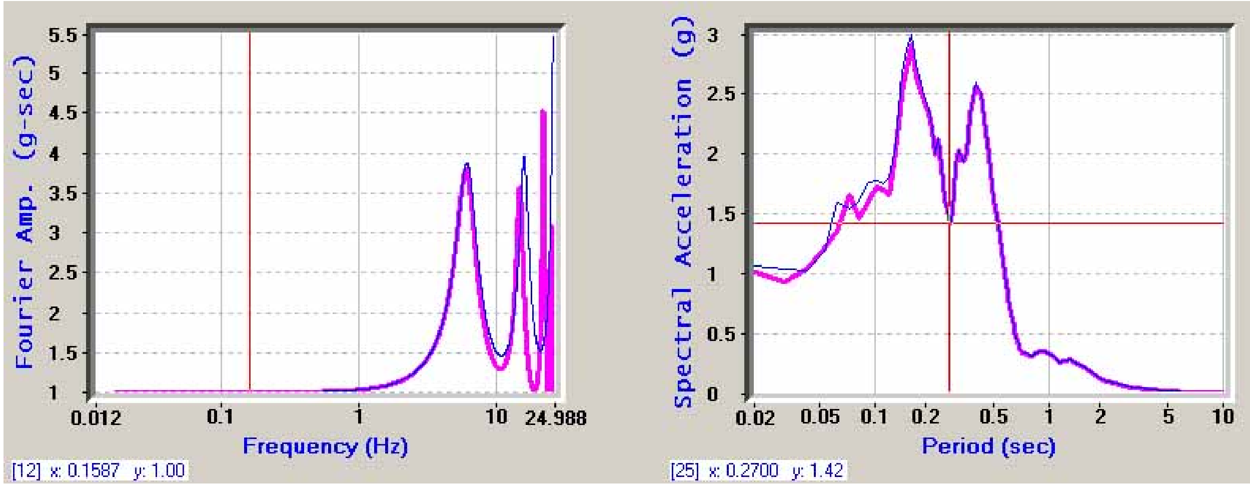
The purpose of this stage of analysis is to reduce frequency dependent damping introduced due to the viscous damping formulation. This stage allows selection of optimum coefficients by comparing the linear time domain solution with the linear frequency domain solution (Note: the linear frequency domain solution uses frequency independent damping).

First, click the “Graph Lin. Freq. Domain” button. DEEPSOIL will display the Fourier amplification ratio and response spectrum plots corresponding to the linear frequency domain solution.



Next, choose modes/frequencies for the Rayleigh damping formulation. It is strongly recommended to use 2 modes/frequencies. The selection process is an iterative trial-and-error procedure to get the best match with the frequency domain solution.

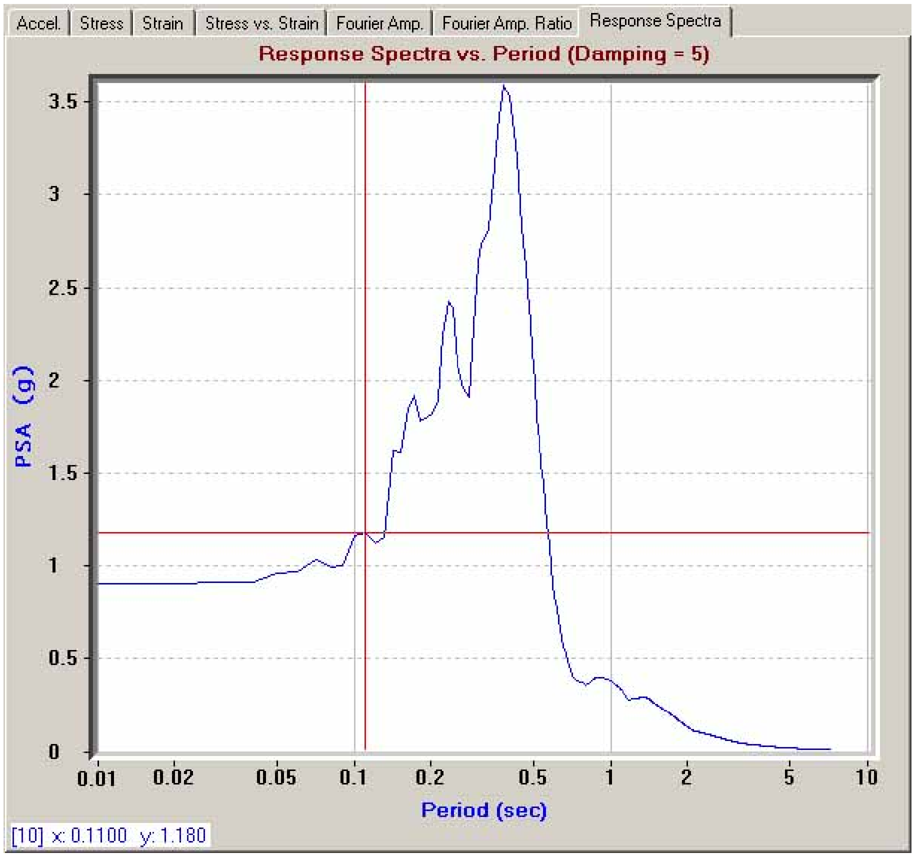
The default selections using 2 modes/frequencies are the 1st and 8th modes. Click the "Check with Lin. Time Domain" button to view the linear time domain solution. Using the default modes, a good match is obtained with the linear frequency domain solution.



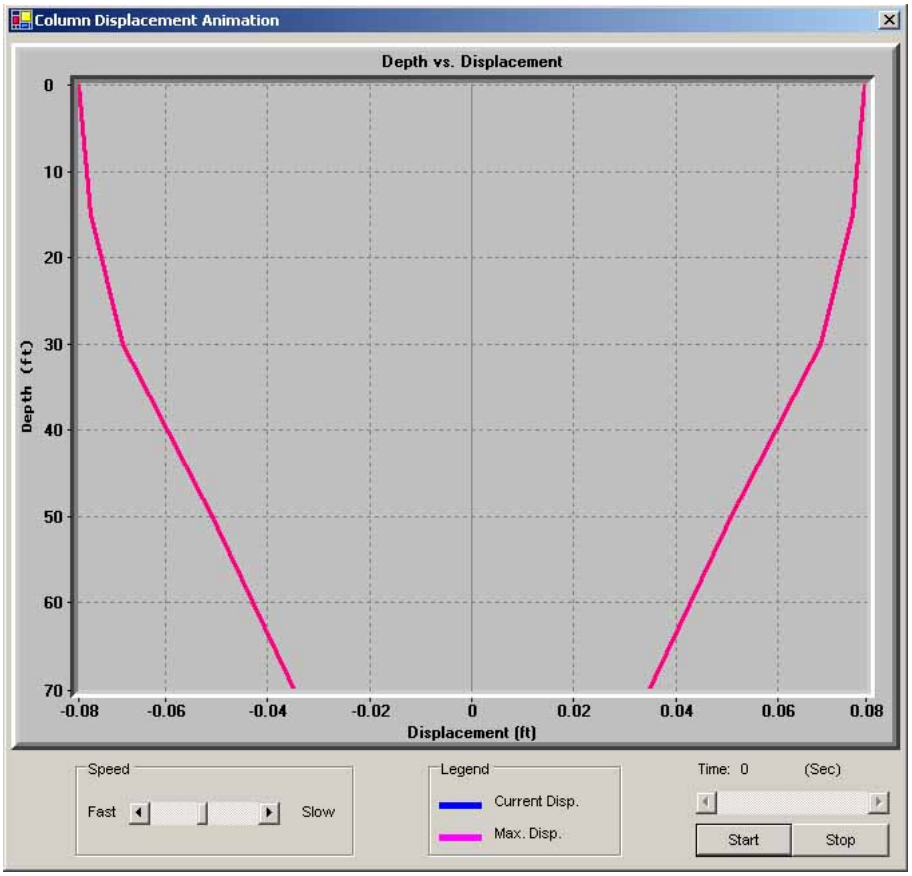
We have now optimized this analysis. Press the "Analyze" button to continue.

STEP 6/6

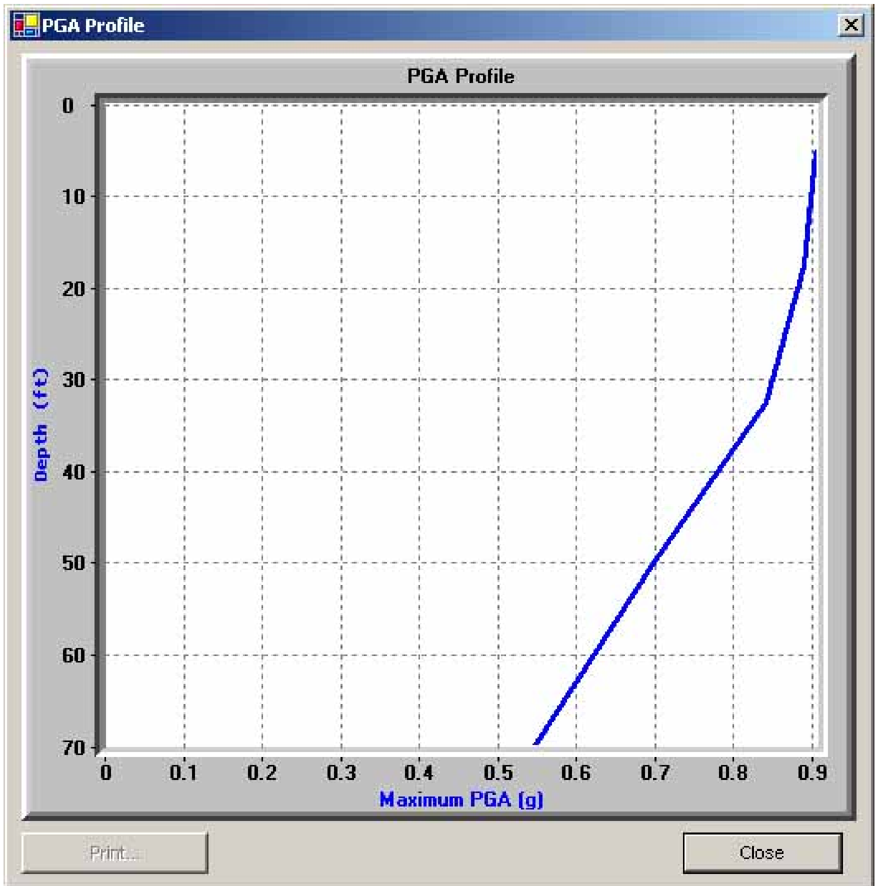
The figure shown on the following page is the calculated surface response spectrum for Layer 1. Check that your results match those shown in this tutorial.


Accel.
Stress
Strain
Stress vs. Strain
Fourier Amp.
Fourier Amp. Ratio
Response Spectra
Response Spectra vs. Period (Damping = 5)
PSA (g)
3.5
3
2.5
2
1.5
1
0.5
0
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
Period (sec)
[10] x: 0.1100 y: 1.180

In a non-linear analysis, it is also possible to animate the column displacement time histories. You can do so by clicking the “Column Displacement Animation” button.



The PGA profile can also be displayed by clicking the “PGA Profile” button.



PGA Profile
PGA Profile
0
10
20
30
40
50
60
70
Depth (ft)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Maximum PGA (g)
Print...
Close

3.7 *Example 7 Non-linear Analysis / Multi Layer, Elastic Rock, Pore Water Pressure Generation and Dissipation*

The final example ("Ex7_Nonlin_Multi_Layer_PWP.dp") of this tutorial considers the Non-Linear analysis of Example 6 as an effective stress analysis with generation and dissipation of pore water pressure. The steps in the analysis are the same as Example 6 except where noted below.

STEP 1/6

Open Example 6 ("Ex6_Nonlin_Multi_Layer.dp").

Change the "Analysis Type" from "Total Stress Analysis" to "Effective Stress Analysis." This will enable the option to "Include PWP Dissipation." Check the checkbox next to "Include PWP Dissipation" to allow for both pore water pressure generation and dissipation in the analysis.

When the "Include PWP Dissipation" option is selected, a new item appears labeled: "Boundary Conditions for Bottom of Profile." These options are used to specify whether the bottom of the profile is a fully-permeable or impermeable boundary. For the purposes of this example, select the "Fully Permeable" option.

Press the "Next" button to continue to the soil properties input form.

STEP 2/6

Note that the properties defined in Example 6 are preserved.

Using the horizontal scroll bar, we see that there are new parameters which must be defined for the pore water pressure generation and dissipation model.

Layer No.	b	d	PWP Model (1 = Sand) (2 = Clay) (3 = GMP)	f/s/Dr (%)	p/r/FC (%)	F/A/-	s/B/-	g/C/-	v/D/v	-/g/-	Cv (ft^2/sec)
1	0	0									
2	0	0									
3	0	0									
4	0	0									
5	0	0									

The first parameter that needs to be defined for each layer is the "PWP Model." The models that can be used in analysis are Sand (1), Clay (2), or GMP (3) which is another model which can be used for sands. Each layer may use a different PWP Model. For the purpose of this example, set each layer to use the Sand Model by entering 1 into each layer's corresponding cell.

The next parameter is “f/s/D_r (%).” The notation for the parameters including a “/” is that the first listed parameter is for the Sand Model, the second listed parameter is for the Clay Model, and the third listed parameter is for the GMP Model. So, in the case of “f/s/D_r (%),” “f” must be defined if the Sand Model is selected, “s” must be defined if the Clay Model is selected, or “D_r (%)” must be defined if the GMP Model is selected. (Note that the parameters are defined in Section 4.2)

Dashed parameters such as “-/g/-” indicate that a certain model has no input for this column. In the case of “-/g/-“, the Sand and GMP Models have no input for this column. You may leave the cell blank for the Sand and GMP Models.

Let us define the parameters as follows:

f/s/D_r (%) → f = 1

p/r/FC (%) → p = 1

F/A/- → F = 0.73

s/B/- → s = 1

g/C/- → g = 0.02

v/D/v → v = 3.8

-/g/- → (None; leave blank)

C_v = 0.1

The spreadsheet should look like the following figure.

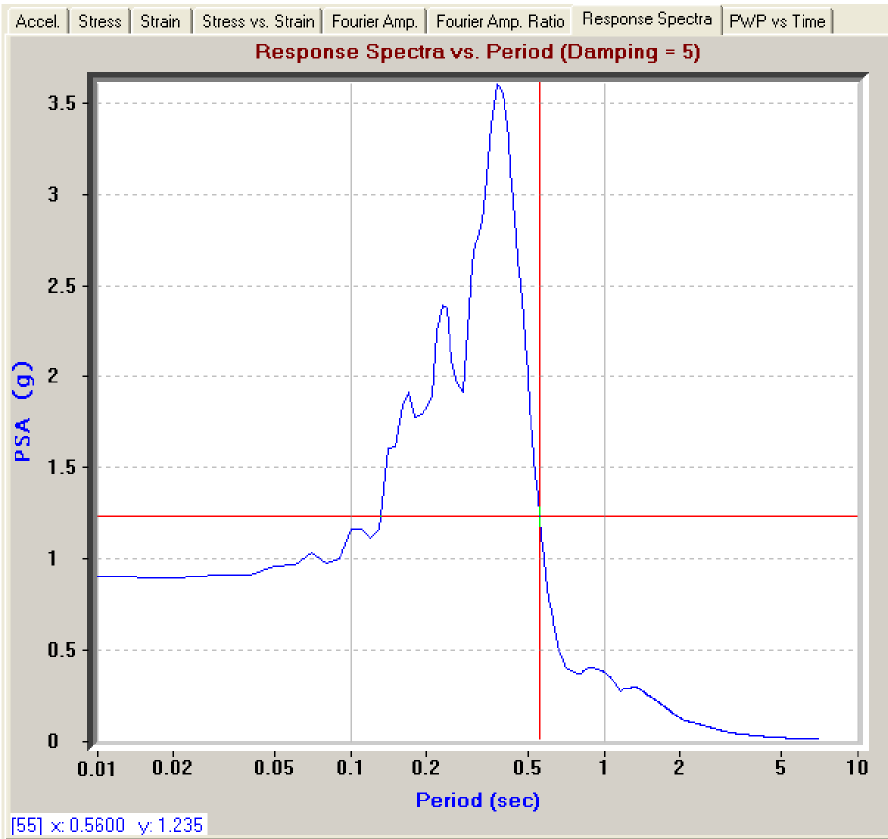
Layer No.	b	d	PWP Model (1 = Sand) (2 = Clay) (3 = GMP)	f/s/Dr (%)	p/r/FC (%)	F/A/-	s/B/-	g/C/-	v/D/v	-/g/-	Cv (ft^2/sec)
1	0	0	1	1	1	0.73	1	0.02	3.8		0.1
2	0	0	1	1	1	0.73	1	0.02	3.8		0.1
3	0	0	1	1	1	0.73	1	0.02	3.8		0.1
4	0	0	1	1	1	0.73	1	0.02	3.8		0.1
5	0	0	1	1	1	0.73	1	0.02	3.8		0.1

After checking your input, press the “Next” button to continue to the third stage of analysis.

The remaining steps of the analysis are exactly the same as in Example 6. Check that your input for Steps 3/6 – 5/6 are the same as in Example 6. In Step 4/6, be sure to select the “loma_gilroy.txt” input motion for analysis.

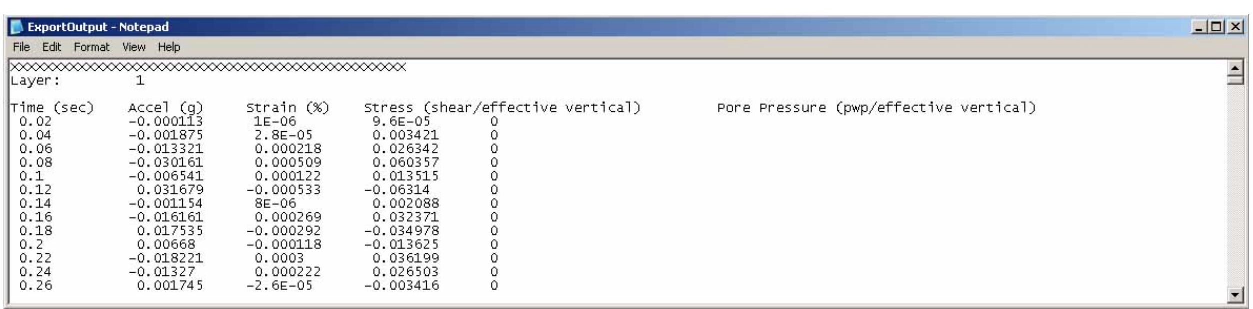
STEP 6/6

The figure shown on the following page is the calculated surface response spectrum for Layer 1. Check that your results match those shown in this tutorial.



Now let's take a look to see if any pore water pressure was generated in Layer 1 due to the input motion. You can do this by selecting the "PWP vs Time" tab for a quick visualization. For the purposes of this example, let's examine the exported output data. Use your "My Computer" to navigate to the folder you specified as your working directory when you started Deepsoil. If you kept the default directory suggested by Deepsoil, then navigate to the "Working\Saved Profiles" folder of the Deepsoil program path.

Open "ExportOutput.txt."


ExportOutput - Notepad

File Edit Format View Help

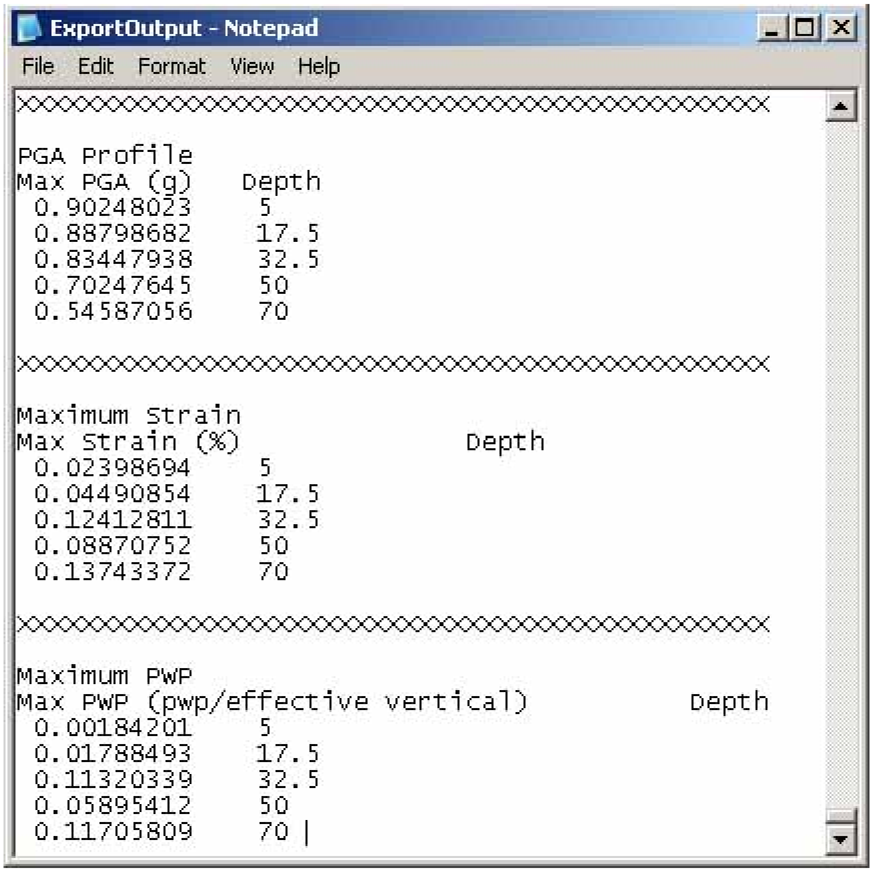
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Layer: 1

Time (sec)	Accel (g)	Strain (%)	Stress (shear/effective vertical)	Pore Pressure (pwp/effective vertical)
0.02	-0.000113	1E-06	9.6E-05	0
0.04	-0.001875	2.8E-05	0.003421	0
0.06	-0.013321	0.000218	0.026342	0
0.08	-0.030161	0.000509	0.060357	0
0.1	-0.006541	0.000122	0.013515	0
0.12	0.031679	-0.000533	-0.06314	0
0.14	-0.001154	8E-06	0.002088	0
0.16	-0.016161	0.000269	0.032371	0
0.18	0.017535	-0.000292	-0.034978	0
0.2	0.00668	-0.000118	-0.013625	0
0.22	-0.018221	0.0003	0.036199	0
0.24	-0.01327	0.000222	0.026503	0
0.26	0.001745	-2.6E-05	-0.003416	0

“ExportOutput.txt” contains all of the output data produced by DEEPSOIL. As can be seen from the figure above, the last column of data contains the pore water pressure in the layer at a given time. By inspecting the time history, we find that there was no significant development of pore pressure in Layer 1 through the entire motion. What about the other layers?

Scroll down to the very bottom of “ExportOutput.txt.” Here you will find data regarding the PGA, Maximum Strain, and Pore Water Pressure Profiles.


ExportOutput - Notepad

File Edit Format View Help

```
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

PGA Profile
Max PGA (g)    Depth
 0.90248023     5
 0.88798682     17.5
 0.83447938     32.5
 0.70247645     50
 0.54587056     70

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Maximum Strain
Max Strain (%)              Depth
 0.02398694     5
 0.04490854     17.5
 0.12412811     32.5
 0.08870752     50
 0.13743372     70

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Maximum PWP
Max PWP (pwp/effective vertical)          Depth
 0.00184201     5
 0.01788493     17.5
 0.11320339     32.5
 0.05895412     50
 0.11705809     70 |
```

As you can see from the results, almost no pore water pressure was generated in Layer 1, and the largest pressures were generated in Layer 5.

Using “ExportOutput.txt,” we can determine the generation of pore water pressures with time, and also quickly identify which layer experiences the maximum generation of pore water pressure.

UNIT 4 Appendices

4.1 *Dynaplot User Interface Navigation*

DynaPlot offers several user interface commands, which help you navigate through a plot. The table below lists the default mapping of keyboard and mouse commands to program actions. A client program may change this mapping according to its own requirements.

Please note, that the control needs to have the input focus (highlighted chart border) before it can accept any keystrokes.

a		Auto scale
b		Bimap mode on / off
c		Cursor on / off
	Tab	Second cursor / toggle cursors
	Left/right arrow key	Move cursor on selected curve
	Shift+left/right arrow key	Fast move cursor on selected curve
	Up/down arrow key	Next / previous curve
	f	Cursors floating / locked
Ctrl+arrow key		Pan and scroll
Ctrl+Shift+arrow key		Pan and scroll both y-axes
Ctrl+page up/down		Fast scroll
Ctrl+Shift+page up/down		Fast scroll both y-axes
Ctrl+Pos1/End		Fast pan
Ctrl+Shift+Pos1/End		Fast pan
Ctrl+left mouse button		Start mouse zoom
Ctrl+Shift+left mouse button		Start mouse zoom
	Ctrll+left mouse button up	Zoom
	Ctrll+Shift+left mouse button up	Zoom both y-axes
	Left mouse button up	Abort zoom operation
i		Copy bitmap to the clipboard
l		Legend on / off
o		Original Scale
p		Open properties dialog
t		Zoom out one step
y		Toggle active y-axis
z		Start kbd Zoom
	Arrow key	Move zoom rectangle
	Shift+Arrow key	Move zoom rectangle(scroll both y-axes)
	Alt+arrow key	Size zoom rectangle
	Enter	Zoom
	Shift+Enter	Zoom both y-axes
	Esc	Abort zoom operation

4.2 *References*

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