NRC ELSRAP

(U.S. Nuclear Regulatory Commission Equivalent Linear Site Response Analysis Program)

Version 1.0

User Manual

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1 Introduction

U.S. Nuclear Regulatory Commission (NRC) staff in the Office of Research have developed an equivalent linear site response analysis program titled NRC ELSRAP using the computer software MATLAB. The purpose of this program is to assist NRC staff in efficiently performing confirmatory analyses that are consistent with the Electric Power Research Institute (EPRI) Seismic Evaluation Guidance Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic. It is highly recommended that the methodologies outlined in the SPID be understood prior to using NRC ELRAP.

NRC ELSRAP runs within the MATLAB environment and provides the user with a graphical user interface for entering parameters required for site response analyses. This user interface is presented in Figure 1. NRC ELSRAP implements tools for incorporating aleatory and epistemic uncertainty in site response analyses for the calculation of site specific amplification functions used to develop hazard consistant soil curves. The implementation of epistemic uncertainty is consistent with the logic tree presented by the Electric Power Research Institute in the SPID document shown in Figure 2.

NRC ELSRAP implements random vibration theory (RVT) within the equivalent linear method and requires the input motion to be developed using a point source seismologic model (e.g. a Brune single corner model). NRC ELSRAP uses the Vanmarcke peak factor (Vanmarcke 1975) in its RVT calculations.

This manual provides you with an explanation of the input variables. Site response and seismologic theory used to perform the calculations within NRC ELSRAP are not presented.

1.1 Requests for Additional Information

If you have questions that are not addressed in this user manual, please submit requests for additional information (RAIs) to Scott Stovall (scott.stovall@nrc.gov) and Thomas Weaver (thomas.weaver@nrc.gov).

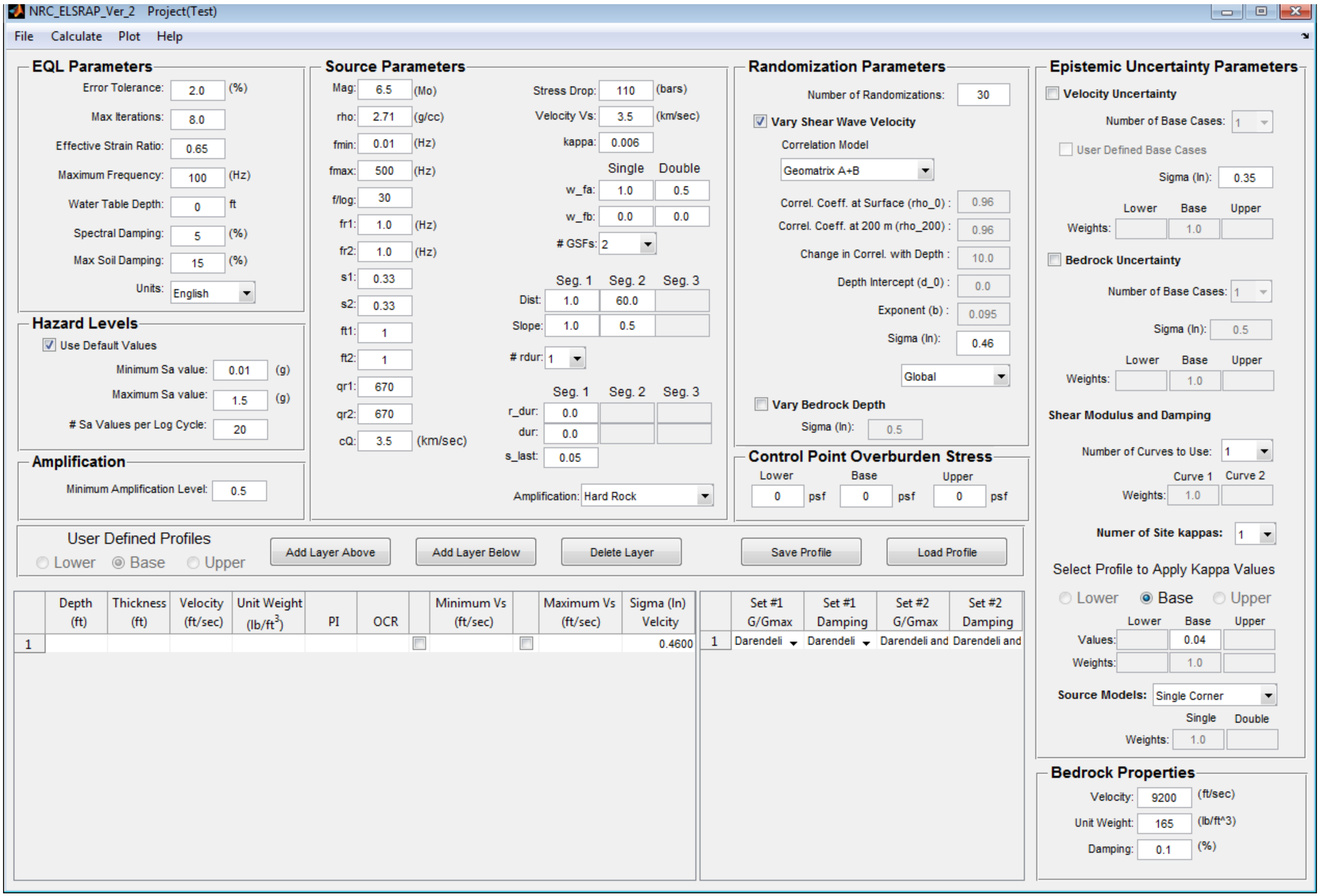

Figure 1. NRC ELSRAP user interface

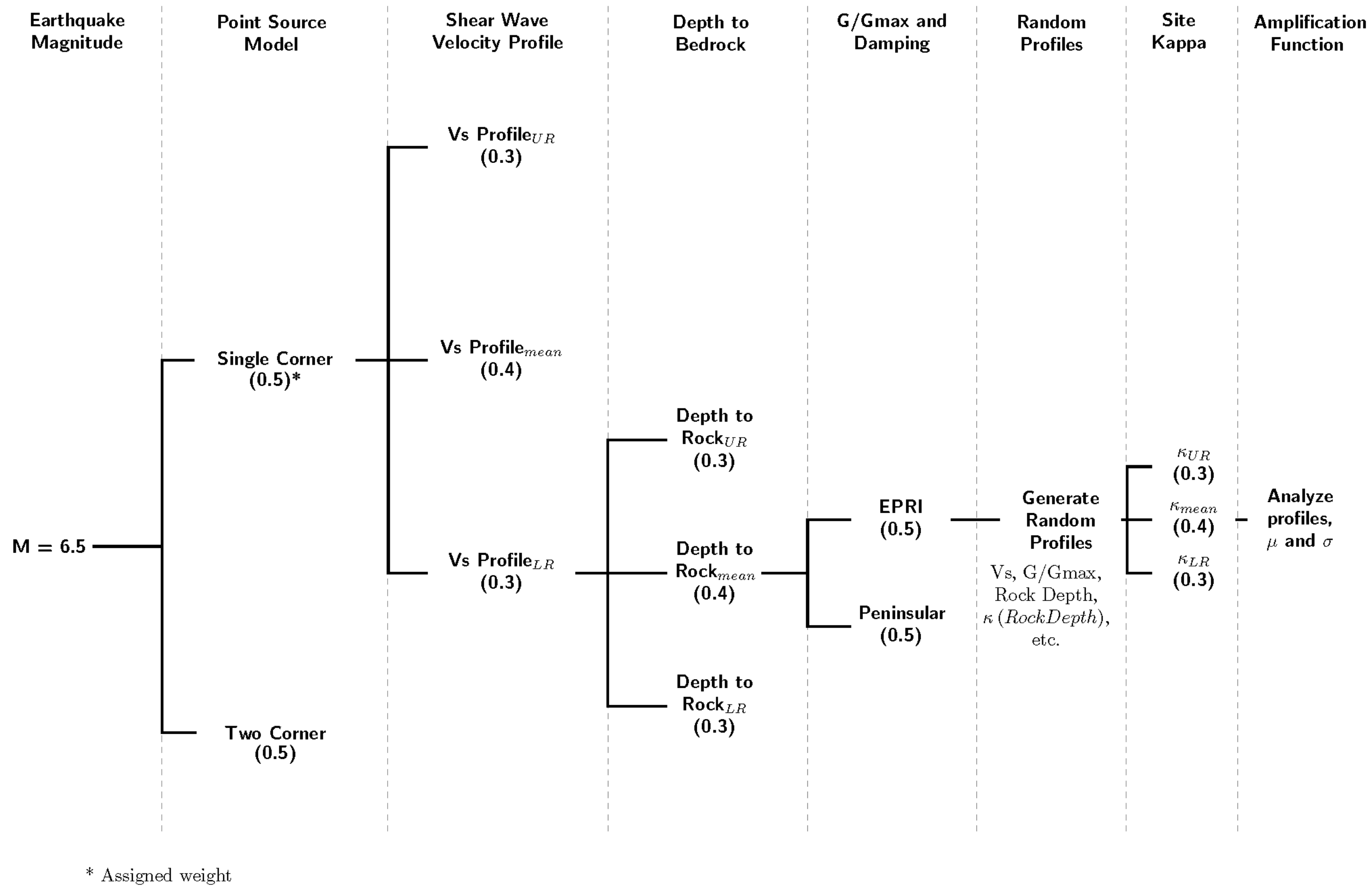

Figure 2. Logic tree illustrating the process for capturing uncertainty in site specific amplification functions (EPRI 2012).

2 Program Input

The program's Graphic User Interface (GUI) is constructed of individual panels each containing the necessary input parameters required to perform their associated function. When a new project is created, each panel will contain default values for each parameter. The default values are typical values used in analyses but the user needs to be aware of their meaning in order to appropriately execute their site response analyses. The following sections explain each panel along with their associated input parameters.

2.1 EQL Parameters

EQL parameters are general input parameters for the Equivalent Linear (EQL) analysis. These input parameters are shown in Figure 3 and decribed below.

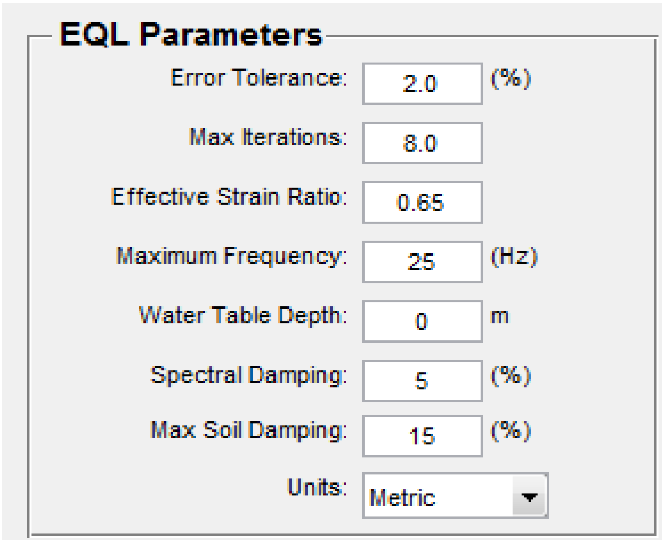

Figure 3. EQL Parameter inputs

Error Tolerance: As the equivalent linear process proceeds, strains at the middle of each soil layer are calculated. The calculated error is the difference in strain between the current iteration and the previous iteration divided by the current strain.

Max Iterations: The maximum number of iterations performed in the equivalent linear analysis. This can result in your maximum strain error being greater than the error tolerance.

Effective Strain Ratio: The effective strain ratio is used to obtain the effective strain, and the effective strain is used to update the shear modulus and damping used for the site response analysis. The effective strain is calculated by multiplying the effective strain ratio by the peak strain at the middle of each layer. A value of 0.65 is commonly used. Other values have been recommended that correspond to the earthquake magnitude.

Maximum Frequency: The maximum frequency in the EQL Parameters section is used to determine the sublayer thickness for the input soil profile. The thickness of the sublayers is calculated using the following equation.

$$t = \frac{V_s}{4f_{max}}$$

Where t is the sublayer thickness, V_s is the layer shear wave velocity, and f_{max} is the maximum frequency.

Water Table Depth: This is the depth below the reference surface (typically ground surface), and is used to calculate effective stresses for use in some shear modulus reduction relationships.

Spectral Damping: This is the damping value used to calculate the response spectrum of a single degree of freedom oscillator. A value of 5% is typically used.

Max Soil Damping: This value is used to limit the amount of hysteretic damping at large strains. According to the SPID, this value should be set at 15%.

Units: English or metric units can be used for inputs to the analysis. Exceptions to this are the source parameters which must always be entered in the specified units shown in the source parameters section.

2.2 Source Parameters

The source parameters are inputs required to calculate the input motion Fourier amplitude spectrum. The procedure described by Boore (2003) is used to calculate this spectrum. The source parameter inputs are shown in **Error! Reference source not found.** and described below.

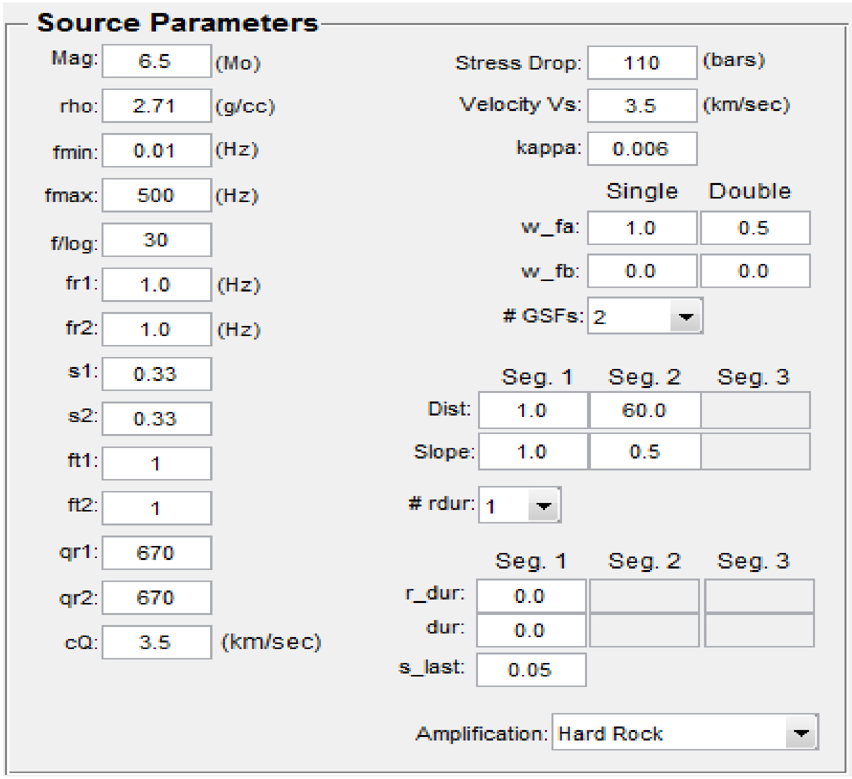

Figure 4. Source Parameters inputs

Mag: Moment magnitude of the earthquake.

rho: Mass density of the material where the seismic source is located.

fmin: The minimum frequency for the calculations (both the input Fourier amplitude spectrum and site response calculations).

fmax: The maximum frequency for the calculations (both the input Fourier amplitude spectrum and site response calculations).

f/log: The number of frequencies per log cycle at which the Fourier amplitude spectrum and site response will be calculated.

fr1, fr2, s1, s2, ft1, ft2, qr1, and qr2 : These are inputs used to define the relationship between the attenuation parameter Q and frequency. Attenuation can be modeled as a three segment piecewise function. An example of this three segment function is shown in Figure 5**Error! Reference source not found.**, and the associated input values are fr1 = 0.1, fr2 = 1.0, s1 = -2.03, s2 = 0.93, ft1 = 0.2, ft2 = 0.6, qr1 = 286, qr2 = 88. Often, sufficient data is only available to define a single segment of the relationship between attenuation and frequency. When defining a single segment, fr1 = fr2 = ft1 = ft2, s1 = s2, and qr1 = qr2.

cQ: Shear wave velocity used in determination of path effects.

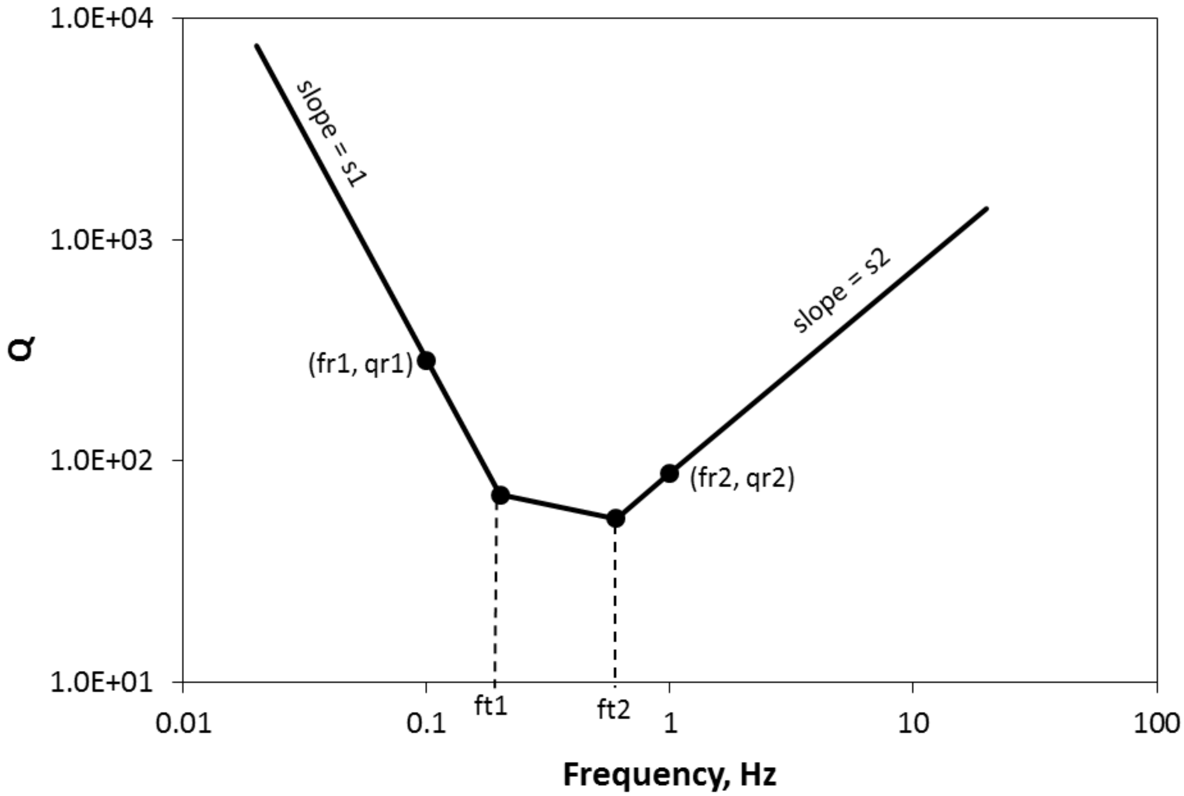

Figure 5. Definition of terms for a three segment attenuation function

Stress Drop: The stress drop associated with the earthquake source for which a Fourier amplitude is being calculated.

Velocity, Vs: shear wave velocity of the source material.

Kappa: A parameter used to account for small strain damping. This kappa value is associated with the reference rock input Fourier amplitude and response spectra. A value of 0.006 is typically assumed to be applicable for hard rock conditions in the Central and Eastern United States.

w_fa and w_fb: These values are used to calculate the duration of the ground motion at the source location. The source duration is calculated using the equation below.

$$T_{source} = \frac{1}{w\_fa} + \frac{1}{w\_fb}$$

When using a single corner model, w_fa is typically set equal to 1 and w_fb is 0. Atkinson and Boore (1995) recommended w_fa of 0.5 and w_fb of 0 for their double corner model which is used in ELSRAP.

 # GSFs: The number of line segments used to define geometrical spreading as a function of distance from the source. You can use 1 to 3 segments. An example of a 3 segment geometrical spreading function is shown in Figure 6. Each segment of the geometrical

spreading function is defined using the equation for Z(R) shown below, where Z(R) is the geometrical spreading term used to modify the source Fourier amplitude spectrum.

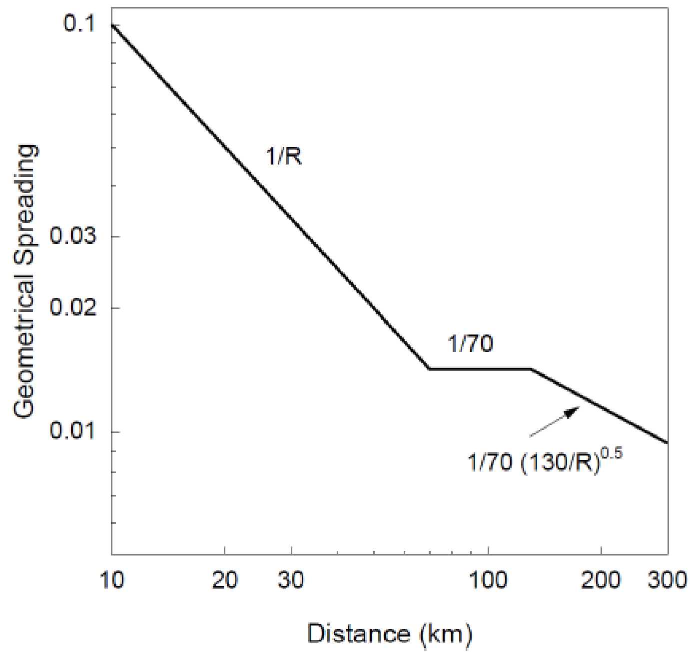

Figure 6. Three segment geometrical spreading relationship

$$Z(R) = \begin{cases} \left(\frac{R_1}{R}\right)^{n1} & R \le R_2 \\ Z(R_2)\left(\frac{R_2}{R}\right)^{n2} & R_2 \le R \le R_3 \\ \vdots & \\ Z(R_i)\left(\frac{R_i}{R}\right)^{n_i} & R_i \le R. \end{cases}$$

Dist and Slope: Dist corresponds to the values of R_1, R_2, and R_i in the equation above with R_1 being the distance for segment 1 and R_2 being the distance for segment 2. R1 is typically set equal to 1. Slope corresponds to the values of n_1, n_2 and n_i. The input values for the three segment geometrical spreading relationship show in Figure 6 are Dist: 1 km, 70 km, 120 km and Slope: 1, 0, and 0.5 for segments 1, 2, and 3, respectively.

#rdur: The path duration can be modeled using a multi segmented line. #rdur is the number of line segments used to define the relationship between duration of ground motion due to distance from the source and distance from the source.

r_dur, dur, slast: Each pair of r_dur and dur values for a segment correspond to the first point in the line segment. If only one line segment is used, r_dur and dur for segment 1 are typically

set equal to 0. The slope of the last line segment is defined by slast. Figure 7 shows a 4 segment relationship with r_dur values of 0, 10, 70, 130 km and dur values of 0, 0, 9.6, 7.8 seconds and slast of 0.04. The current version of ELSRAP limits you to 3 line segments. The SPID recommends a single slope which would be defined by 1 segment with r_dur = 0, dur = 0, and slast = 0.05.

Amplification: ELSRAP uses the square root impedance method as described by Boore (2003) to account for amplification of the Fourier amplitude spectrum from the source depth to the bottom of the soil profile. The Hard Rock amplification function is based on a shear wave velocity profile consisting of 1 km thick rock with a shear wave velocity of 2830 m/s underlain by rock with a shear wave velocity of 3500 m/s. The Soft Rock amplification function is derived based on a general soft rock velocity profile presented by Boore (2003). Selecting none will result in an amplification of 1 at all frequencies. If an amplification function has been developed for an alternative velocity profile below the soil, the user can import an amplification function from a text file by selecting user defined.

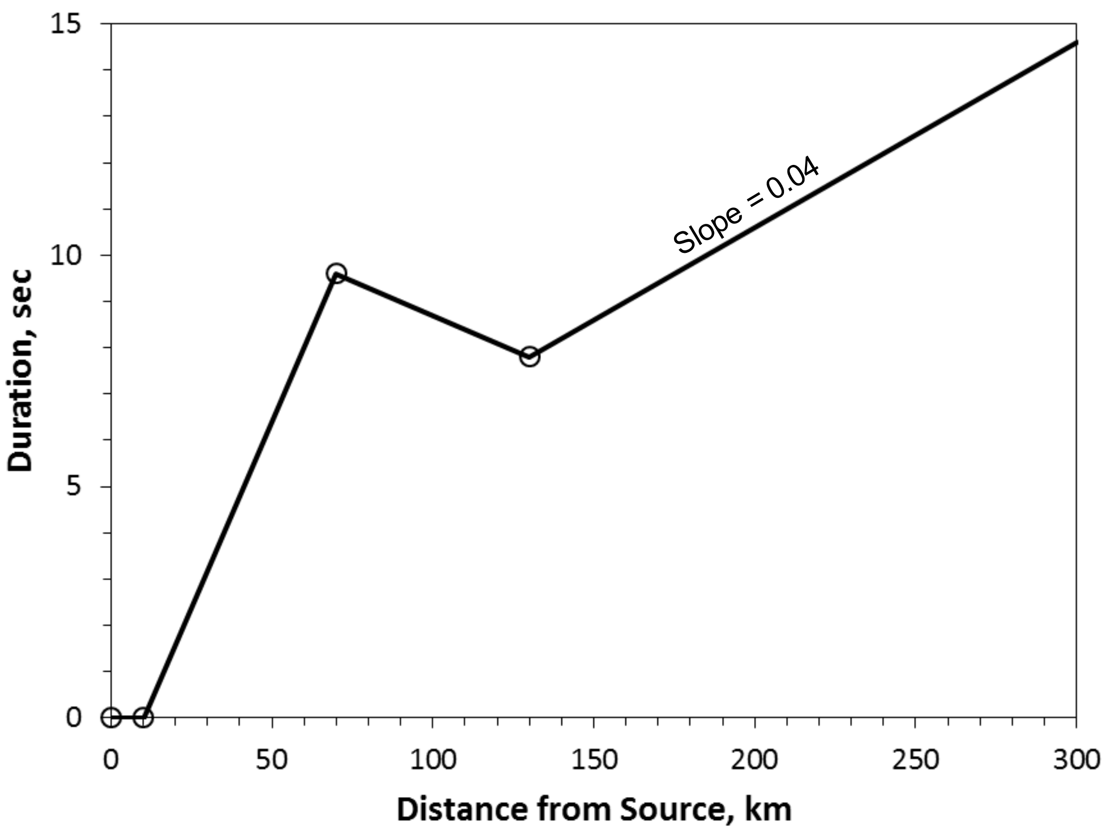

Figure 7. Relationship between distance from source and duration in addition to source duration

2.3 Randomization Parameters

The randomization parameters are used to define the aleatory uncertainty associated with each base case shear wave velocity profile and the depth to bedrock. The randomization parameters are shown in Figure 8.

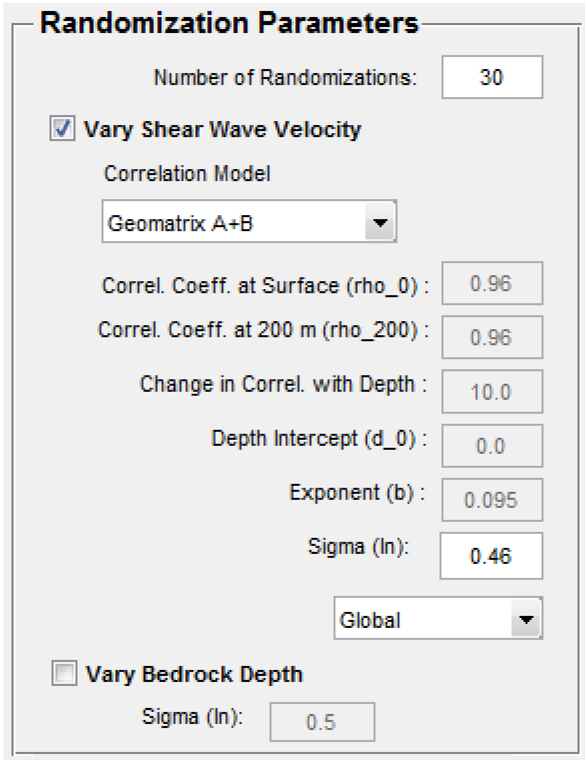

Figure 8. Randomization input parameters

Number of Randomizations: The number random profiles that will be used for calculating site response at the end of each branch of the logic tree. Each random profile can have the shear wave velocity varied and/or the depth to bedrock varied. There is a Vary Shear Wave Velocity checkbox and Vary Bedrock Depth checkbox, one of which must be selected in order to enter the number of randomizations you would like to analyze.

Vary Shear Wave Velocity: Selection of this checkbox allows you to analyze multiple randomly generated profiles for each branch of the logic tree associated with calculation of the median amplification function.

Correlation Model: This drop down menu provides you with options for the type of correlation model that is used for generating the shear wave velocity profiles. When selecting a correlation model, the correlation coefficient at the surface (rho_0), correlation coefficient at 200 m (rho_200), change in correlation with depth, depth intercept (d_0), exponent (b), and sigma (ln) are automatically inserted into the edit text boxes. The only value that can be modified after selecting a correlation model is the sigma (ln). If a user defined correlation model is selected, all of the above listed variables are specified by the user.

Global/Layer Specific: This drop down menu allows you to specify the standard deviation used in calculating random shear wave velocity profiles. If Global is selected, the sigma (ln) value entered for the correlation model will be used for all soil layers. If Layer Specific is selected, you need to input standard deviation values for each layer of the profile.

Vary Bedrock Depth: If you want the depth to bedrock to vary with each profile, this checkbox must be selected.

Sigma (ln): This editable input located below the vary bedrock depth checkbox is the standard deviation used to determine the depth to bedrock for each random velocity profile. The distribution of depth to bedrock is assumed to be lognormally distributed.

2.4 Epistemic Uncertainty

The epistemic uncertainty inputs are associated with the logic tree for calculating the median amplification function and associated standard deviation. The logic tree is divided into five main sections, velocity uncertainty for shear wave velocity profile base cases, Bedrock Uncertainty for depth to bedrock base cases, Shear Modulus and Damping which allows for assessing uncertainty associated with these curves, kappa, and type of source model. The epistemic uncertainty inputs are show in Figure 9.

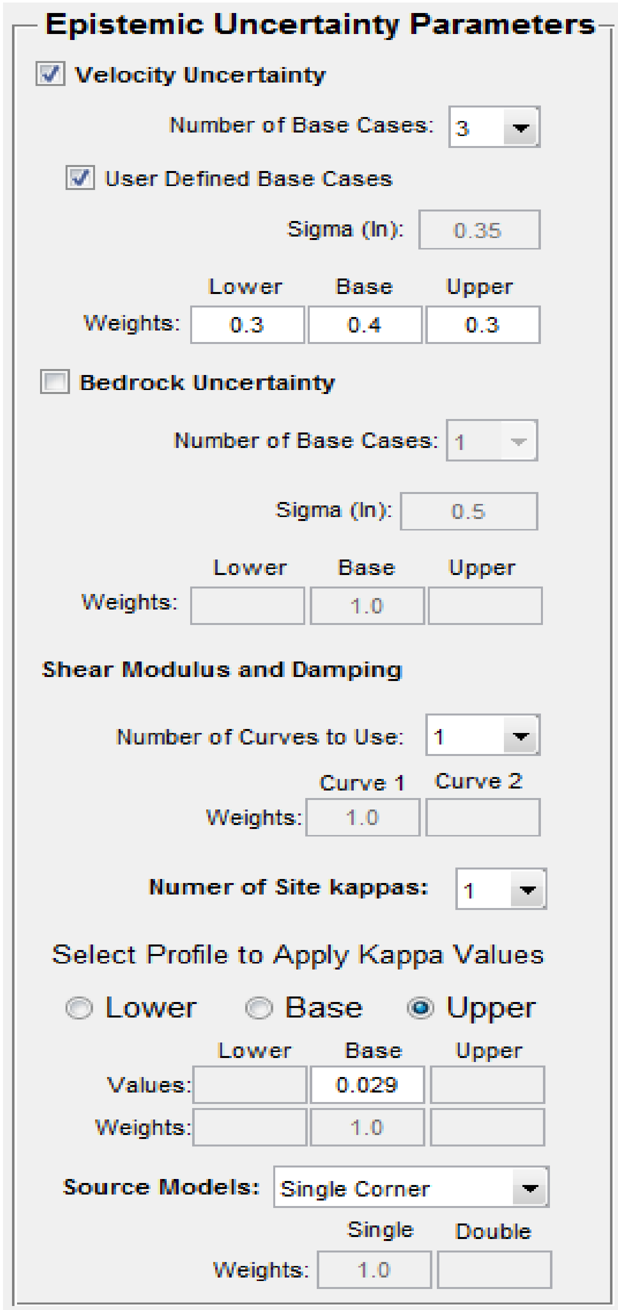

Figure 9. Epistemic uncertainty input parameters

Velocity Uncertainty: select this checkbox if you want to use more than 1 base case shear wave velocity profile.

Number of Base Cases: Number of base case velocity profiles that will be used in the logic tree. The program can use up to 3 base case profiles.

User Defined Base Cases: Select this checkbox if you want to input specific velocity profiles for the lower and upper base case profiles. If selected, the random profiles for the lower and upper base case profiles must be entered by the user. If this checkbox is not selected, the lower and upper velocity profiles will be automatically generated by subtracting or adding $1.3\sigma_{ln}$ (Velocity Sigma (ln)) to the base case profile.

Velocity Sigma (ln): The natural log standard deviation used to generate the lower and upper velocity profiles when the user defined base case checkbox is not selected.

Velocity Weights: These are the weights used in the logic tree for calculating the median amplification function. When the lower and upper base case velocity profiles are calculated by the program, the weights should be set to 0.3, 0.4, and 0.3 for the lower, base (median), and upper base cases, respectively. These weights are appropriate for the 10^{th}, 50^{th}, and 90^{th} percentile velocity profiles. If user defined lower and upper velocity profiles are used, the user should estimate the percentile for which the lower and upper profiles are associated and choose weights accordingly.

Bedrock Uncertainty: Select this checkbox if there should be multiple base case depths to bedrock.

Bedrock Number of Base Cases: Allows you to select up to 3 base cases for the depth to bedrock. The number chosen will be applied to each base velocity profile.

Bedrock Sigma (ln): The lognormal standard deviation used to calculate the lower and upper base case depth to bedrock.

Bedrock Weights: Similar to the weights for velocity, if three base cases are used, the weights should be set equal to 0.3, 0.4, and 0.3 for the lower, base (median), and upper base cases, respectively.

Number of Curves to Use: A set of shear modulus and damping curves are associated with the input profile(s). An additional set of curves can be used to account for uncertainty in the shear modulus reduction and damping relationships. When Number of Curves to Use is set to 2, the user is allowed to define a second set of curves for the input profile(s).

Shear Modulus and Damping Weights: If one set of curves are used, the Curve 1 weight is set equal to 1. Typically when 2 curves are used, weights are set equal to 0.5. However, an alternate weighting scheme could be employed if justified.

Number of Site kappas: Site kappa allows you to account for small strain energy dissipation due to wave scattering and other phenomenon. The SPID provides guidelines for estimating site kappa based on the shear wave velocity profile. The number of site kappas can range from

1 to 3. The user is required to input kappa values for each velocity base case. If there are three velocity base cases, and the user has selected 3 kappas, then the user will need to input lower, base, and upper kappa values for each base profile. This means the user will need to select the radio button associated with the individual base profile and enter the appropriate lower, base, and upper kappa values for that profile.

Values and Weights: The lower and upper kappa values typically correspond to the 10th and 90th percentiles, respectively. Therefore, weights should be 0.3, 0.4, and 0.3 for this case.

Source Models: Allows you to select the type of source model(s) that will be used for the analyses. You can select single corner, double corner, or both. The double corner model is the Atkinson and Boore 1995 two corner model.

Source Model Weights: If a single corner or double corner model are selected, a weight of 1 is automatically input into the appropriate weight box. If both source models are used, the weights are automatically set equal to 0.5.

2.5 User Defined Profiles

The user must input at least a base profile for analyses to be completed. The user is required to input the thickness, velocity, and unit weight of each layer (Figure 10). PI and OCR are only required for specific shear modulus and damping curves (e.g. Darendeli and Stokoe, and Ishibashi and Zhang). If the checkbox to the left of Minimum Vs or Maximum Vs is selected, values must be entered in the appropriate columns. If Layer Specific has been selected in the Randomization Parameters section, standard deviations must be entered in each row of the Sigma (ln) Velocity column. Shear modulus and damping curves must be selected for each layer, and user defined curves may be imported. If the user has selected User Defined Base Cases, the Lower and Upper radio buttons can be selected so that these profiles can be entered. Note that the profile does not include the properties for the bedrock half space. These properties are entered in the Bedrock Properties section

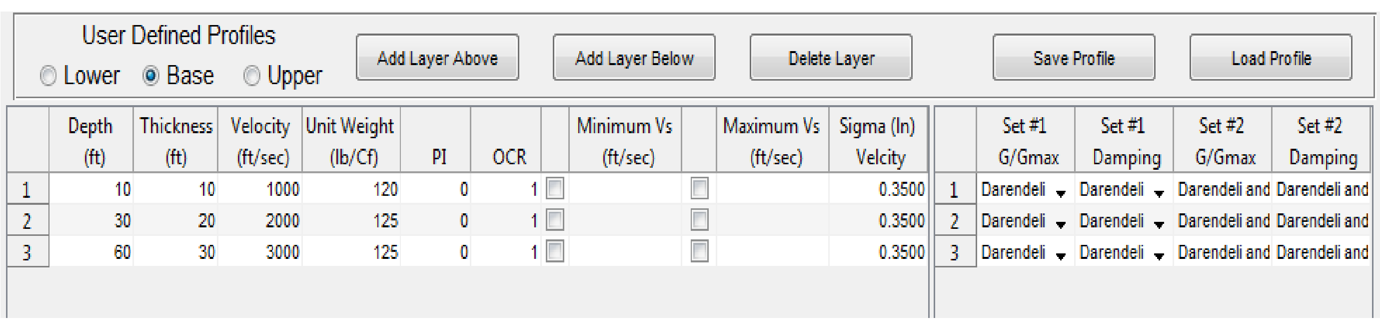

Figure 10. User Defined Profiles inputs

2.6 Control Point Overburden Stress

Initlal overburden stresses can be applied to each base profiles using the Control Point Overburden Stress panel.

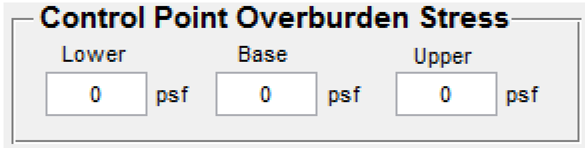

Figure 11. Control Point Overburden Inputs

2.7 Bedrock Properties

The bedrock properties (Figure 12) require a shear wave velocity, unit weight, and damping value. It is assumed that this bedrock half space behaves linearly elastic.

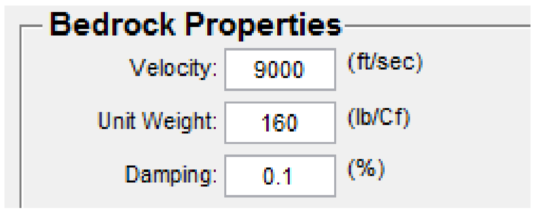

Figure 12. Bedrock Properties

2.8 Hazard Levels

Amplification functions are calculated at specified bedrock input motion levels, typically peak bedrock acceleration levels. The range and number of acceleration levels are chosen so that the soil hazard curve can be obtained with reasonable accuracy for annual exceedance frequencies of interest.

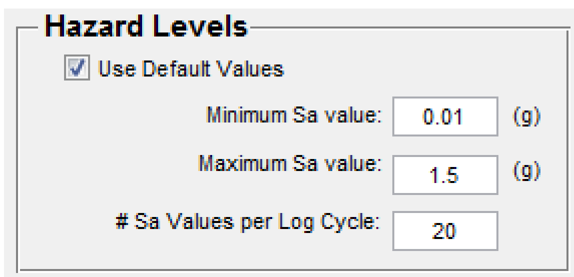

Figure 13. Hazard Levels

Use Default Values: When this checkbox is selected (Figure 13), input motions for site response analyses have peak ground acceleration of 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.75, 1.0, 1.25, 1.5, 2.1 g. When the checkbox is not selected, minimum and maximum spectral accelerations (peak ground acceleration values) must be entered.

Minimum Sa value: The minimum spectral acceleration (pga) for an input motion.

Maximum Sa value: The maximum spectral acceleration (pga) for the input motion.

 # Sa Values per Log Cycle: This input determines how many input motion levels will be used to drive the soil column. With a minimum Sa value of 0.1 and a maximum Sa value of 1.0 and a number of Sa values per log cycle of 5, the input motions for the site response analyses will have pga values of 0.1, 0.16, 0.25, 0.40, 0.63, and 1.0 g.

2.9 Amplification

This option allows the user to specify a minimum amplification value. At relatively high frequencies and high input levels, the amplification function tends to decrease. Because the equivalent linear process applies the same damping to all frequencies, the high frequency motion may be overdamped and produce artificially low amplification values. To mitigate this, the SPID recommends that the amplification function not be allowed to be lower than 0.5 (Figure 14).

Figure 14. Input to specify the minimum amplification value

3 Menus

The program menus as shown in Figure 15 allow you to open and save project data, perform site response and hazard calculations, plot select results, and access the program user manual. Each menu option is described in more detail below.

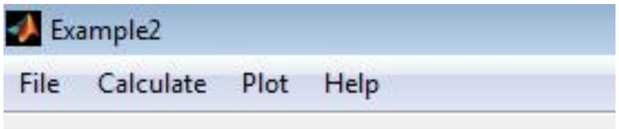

Figure 15. ELSRAP menu

3.1 File

The file menu has the following options as illustrated in Figure 16: New Project, Open Project, Save Project, Save Project As, Export Data, Unlock Project, and Exit.

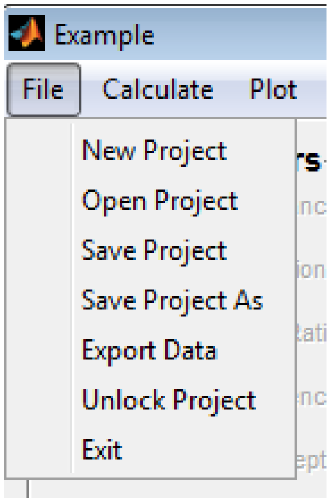

Figure 16. File menu options

The operations performed by each of these menu options is described below.

New Project: Selection of this option will create the needed folders for a new project. When selecting New Project, you will be prompted to input a File Name. This will create a new folder with the given name in the existing Projects folder. In addition, the following folders will be created as subfolders to the newly created folder: Curves, Profiles, and RockCurves.

Within the Curves folder, there are two files and two additional folders. The files contain the list of shear modulus degradation and damping curves that are available for site response analyses and the folders contain text files with the shear modulus degradation and damping relationships. User defined curves added in the program will be stored in these folders and will only be accessible for this project.

The Profiles folder is initially empty. Profiles can be saved to this folder using the Save Profile button located above the shear modulus degradation and damping curve selection section. Note that you do not have to save a profile. The profile information you input will be saved when you save the project. Saving profiles may be beneficial if you anticipate using the same profile in multiple projects.

The RockCurves folder is where the rock hazard curves must be located. Although creating a new project generates a folder for rock hazard curves, no rock hazard curves are automatically placed in this folder. You must put the rock hazard curves in this folder. Note that the rock hazard curves are for oscillators with natural frequencies of: 0.5, 1, 2.5, 5, 10, 25, and 100 Hz. The file names for these rock hazard curves are: RHC0.5.txt, RHC1.txt, RHC2.5.txt, RHC5.txt, RHC10.txt, RHC25.txt, and RHC100.txt.

Open Project: This will load all saved data associated with a previously saved project including calculated results.

Save Project: Once a project has been created, you can save your input and calculated results using the Save Project option.

Save Project As: This allows you to save your project under a new name. When using this option, all project folders and results from the current project are copied into a new project folder under the new project name.

Export Data: Creates and Excel file with having the same name as the project name. The following data is written to the Excel file: The median amplification and standard deviation as a function of frequency for each hazard level (input pga), The median amplification and standard deviation as a function of spectral acceleration for select oscillator frequencies, rock hazard curves, soil hazard curves, and the GMRS along with the 1E-4 and 1E-5 soil uniform hazard spectra.

Unlock Project: After performing site response calculations, you are not able to edit the user input fields. If you desire to change input variables and re-run your analysis, you must select the Unlock Project menu option.

Exit: Closes the program.

3.2 Calculate

The calculate menu option shown in Figure 17 is used to generate the random profiles for the site response calculations, perform the site response calculations, and calculate soil hazard curves.

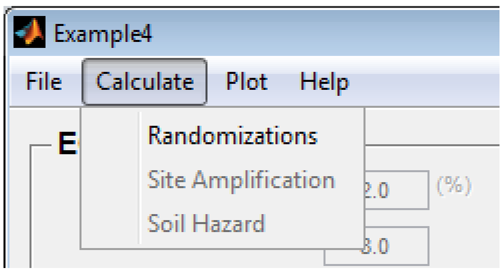

Figure 17. Calculate menu

Randomizations: Selection of this menu option will generate the velocity profiles that will be used for the site response analyses. This option is used if aleatory uncertainty will be incorporated into the analyses through the Randomization Parameters.

Site Amplification: This option is used to perform the site response calculations for each branch of the logic tree and for each random profile. Using the results of the site response calculations, site amplification functions and associated uncertainties are obtained.

Soil Hazard: After site amplification functions are calculated, this option is used to calculate the soil hazard curves and the ground motion response spectrum (GMRS).

3.3 Plot

The Plot menu allows you to graph select input and output data.

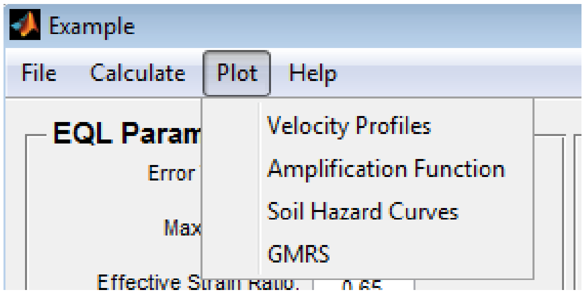

Figure 18. Plot menu

Velocity Profiles: Plots the velocity profiles associated with the site response analysis calculations. Each plot is labeled to identify the velocity profile (Figure 19). The labels used and meaning are provided in Table 1.

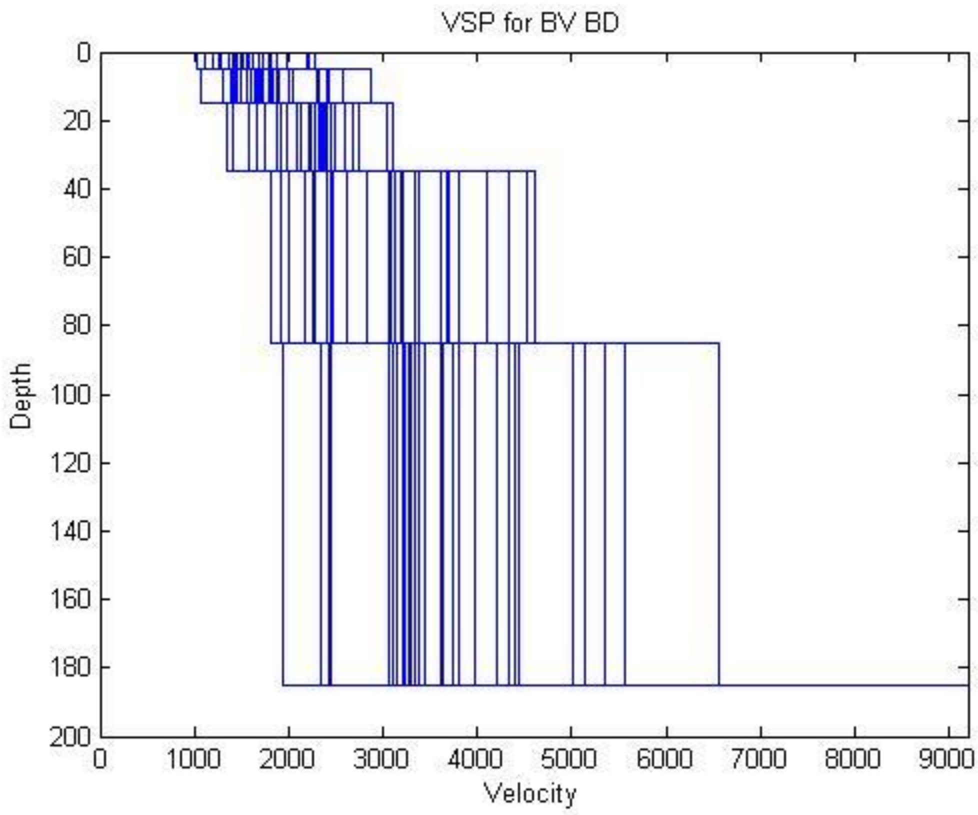

Figure 19. Base Velocity Randomizations

Table 1. Velocity Profile Label Definitions

Depth / Velocity	Lower Velocity	Base Velocity	Upper Velocity
Lower Depth	LV LD	BV LD	UV LD
Base Depth	LV BD	BV BD	UV BD
Upper Depth	LV UD	BV UD	UV UD

Amplification Function: Plots the median amplification function for the selected hazard input level. Note this menu is not enabled until site amplification has been run. Figure 20 displays how the user can select a single or multiple hazard levels to plot mean amplification curves (Figure 21.)

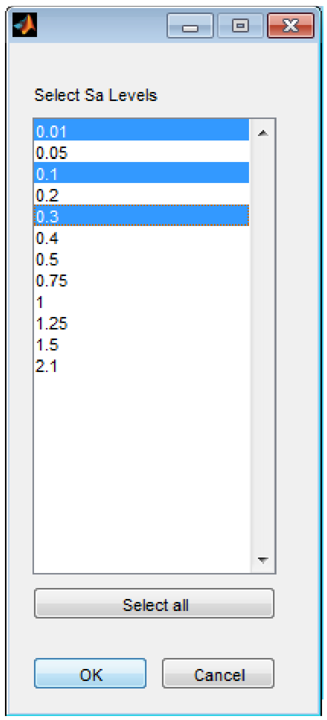

Figure 20. Selection of Mean Amplification Functions to Plot

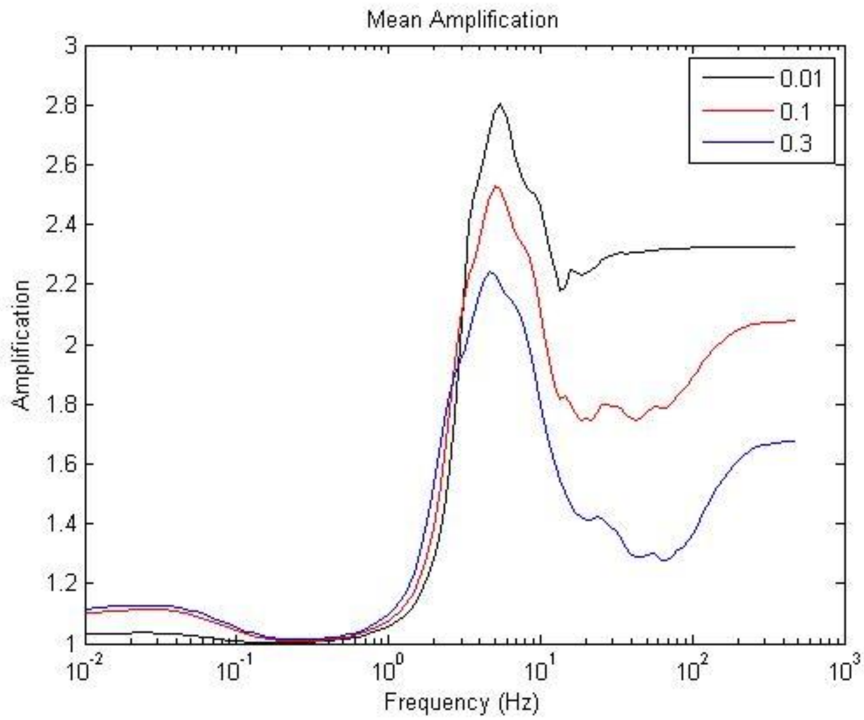

Figure 21. Mean Amplification Functions

Soil Hazard Curves: Plots the Rock hazard and resulting soil hazard curves for the following oscillator natural frequencies: 0.5, 1, 2.5, 5, 10, 25, and 100 Hz (Figure 22.) Note this menu is not enabled until soil hazard has been run.

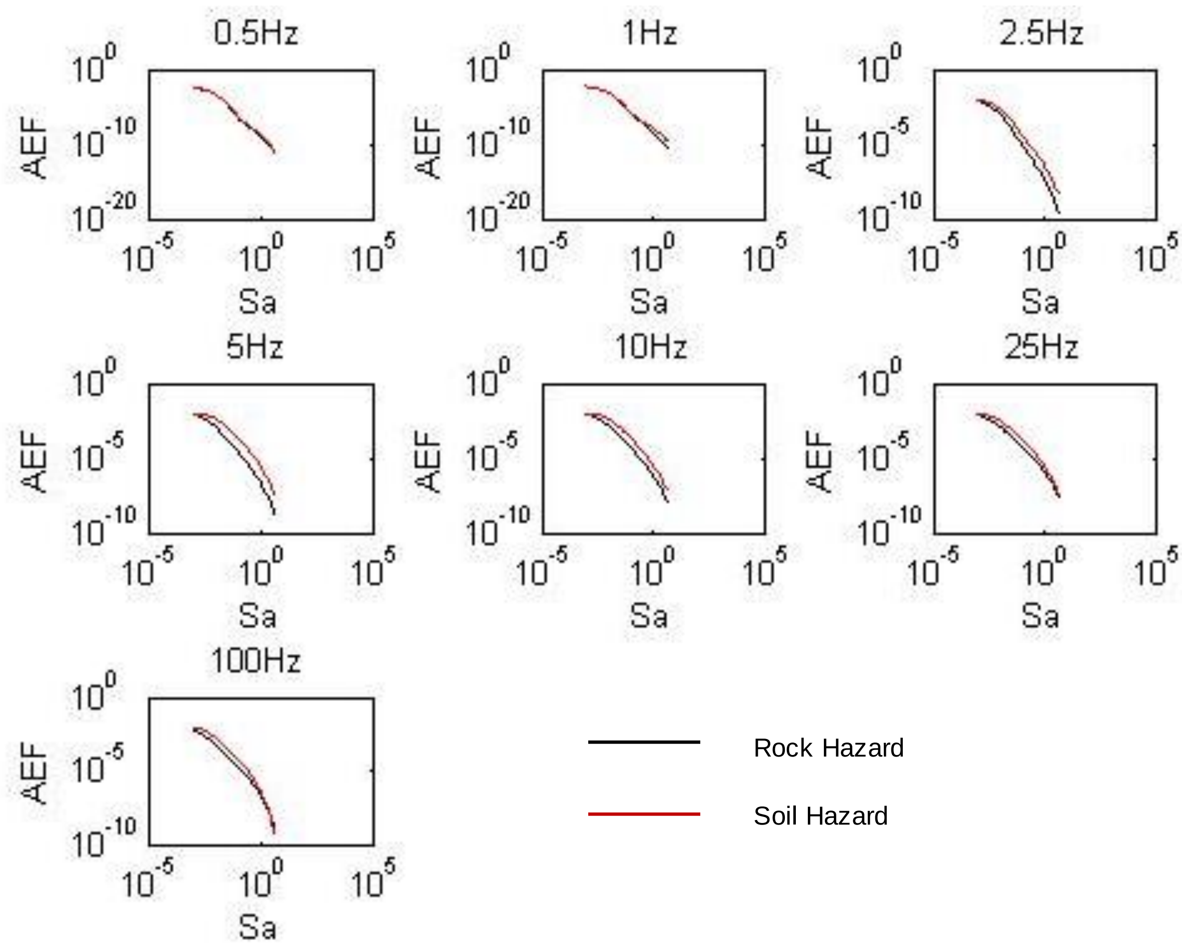

Figure 22. Rock and Soil Hazard Curves

GMRS: Plots the Ground Motion Response Spectrum (GMRS) using the calculated soil hazard curves. In addition, the soil uniform hazard spectrum for annual exceedance frequencies of 1E-4 and 1E-5 are plotted. Note this menu is not enabled until soil hazard has been run.

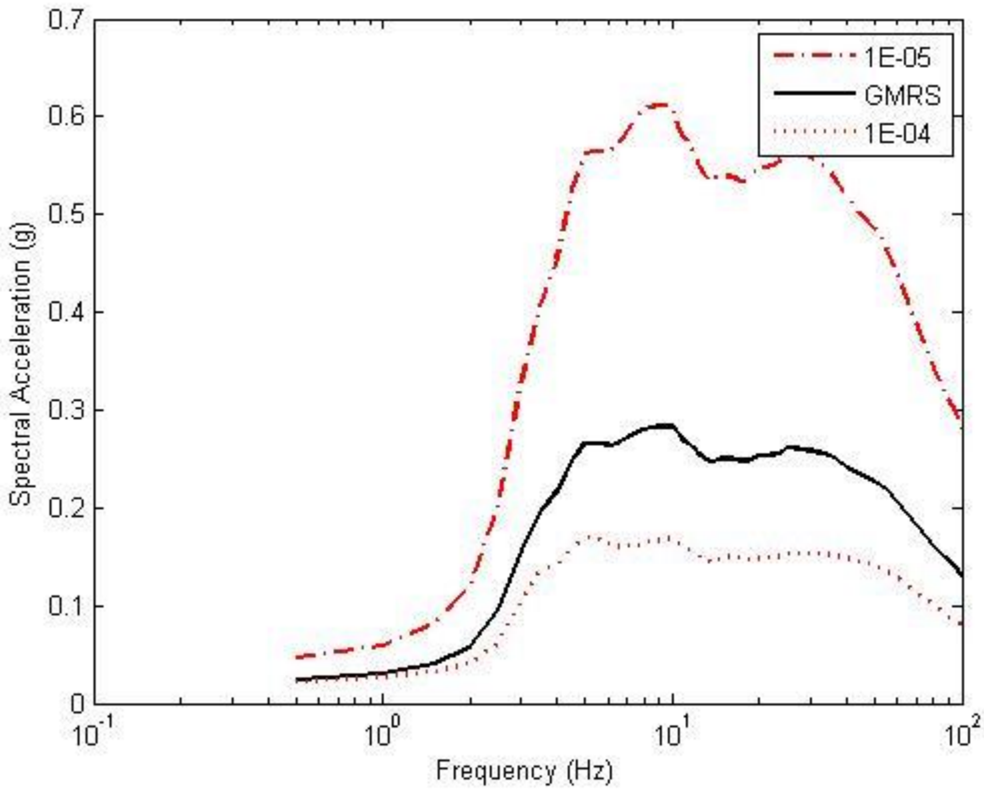

Figure 23. GMRS

4 Output Files

Results from the analyses are saved in output files located in the Results folder within the project folder. Data placed in the output files are described below.

AmpFuncCurv.mat: This file contains the median amplification and standard deviation associated with each oscillator natural frequency. The first column of the file is the median amplification for the 0.5 Hz oscillator and the second column is the standard deviation associated with the median amplification function values. Each row of the file corresponds to a spectral acceleration.

***ProjectName*.xls:** The following data is written to the Excel file: The median amplification and standard deviation as a function of frequency for each hazard level (input pga), The median amplification and standard deviation as a function of spectral acceleration for select oscillator frequencies, rock hazard curves, soil hazard curves, and the GMRS along with the 1E-4 and 1E-5 soil uniform hazard spectra.

GRMS.mat: The first column of this file contains the oscillator natural frequencies. The other columns contain spectral acceleration for the GRMS (column 2), and annual exceedance frequencies of 1E-4 (Column 3), and 1E-5 (Column 4).

HL*X*_MeanAmp.mat: This file contains the median amplification values and associated standard deviation for a given hazard level or input peak ground acceleration as a function of oscillator natural frequency for all branches of the logic tree, where X represents the given hazard level. Column 1 in this file is the amplification value and Column 2 is the standard deviation.

HL*X*_Source*X*_*XX*_*XX*_kappa*X*_Curves*X*.mat: This file contains results for one branch of the logic tree for a given hazard level (peak ground acceleration input level). Column 1 is the oscillator natural frequency, Column 2 is the median response spectral acceleration, Column 3 is the amplification, and Column 4 is the standard deviation. The first X in the file name is associated with the hazard level, the second X is associated with the input source type (e.g. single corner, double courner), the first XX is associated with the velocity profile (e.g. LV, BV, LV) and the second XX is associated with the depth to bedrock (e.g. LD, BD, UD), the X following kappa is for the lower, base, or upper kappa value used, and the X following Curves is for the set of shear modulus and damping curves used.

ReferenceRS.mat: This file contains the hard rock spectral accelerations (reference response spectra) for each hazard level (input peak ground acceleration). The first column is the oscillator natural frequency and the remaining columns are spectral accelerations for each hazard level. When using the default hazard levels, the reference response spectra are associated with input peak ground acceleration of 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.75, 1.0, 1.25, 1.5, and 2.1 g.

SaAll.mat: This file contains the soil spectral accelerations associated with the calculated annual exceedance frequencies for each oscillator.

SoilHazardCurves.mat: This file contains the soil annual exceedance frequencies. The spectral acceleration values associated with these exceedance frequencies are in the SaAll.mat file.

5 References

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Vanmarcke EH. (1975) On the distribution of the first-passage time for normal stationary random processes. Journal of Applied Mechanics; 42 (1): 215-220.