ROCSCIENCE

RSSeismic

Verification Manual

Version 1.000

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Introduction

RSSeismic is a one-dimensional site response analysis program for performing:

- 1-D nonlinear time domain analyses with and without pore water pressure generation
- 1-D equivalent linear frequency domain analyses including convolution and deconvolution
- 1-D linear time and frequency domain analyses

This verification manual presents example problems solved using *RSSeismic* and alternative methodologies, with comparisons provided to demonstrate the consistency and accuracy of the results.

1. Nonlinear Analysis (MKZ Soil Model with Masing Re/Unloading Behavior)

Verification of Example 5 from the *DEEPSOIL* User Manual

1.1. Problem Description

Nonlinear and equivalent-linear site response analyses are carried out using *RSSeismic* and *DEEPSOIL* for the ChiChi input motion with different types of fitting procedures that are adopted for the nonlinear dynamic curves: D (Damping Only), MR (Modulus Reduction Only), and MRD (Modulus Reduction and Damping). The MKZ model with Masing type of re/unloading formation is used for dynamic curves defined for each layer. Frequency independent damping was used in the nonlinear analysis where the damping matrix was not recalculated at each step of the analysis. For the nonlinear (time-domain) analysis, a flexible step control with maximum strain increment of 0.005% is assumed along with a time history interpretation method of zero-padded in frequency domain. The equivalent-linear (frequency-domain) analysis assumed 15 iterations, an effective shear strain ratio (SSR) of 0.65 and a frequency-independent complex shear modulus formulation. Table 1.1 summarizes the layer properties. Soil profile with plots of key geotechnical properties using each fitting procedure is presented in Figure 1.1, Figure 1.2 and Figure 1.3.

Table 1.1: Layer Properties

Layer	Depth (m)	Soil Model	Unit Weight (kN/m^3)	Shear Wave Velocity, V_s (m/s)
1	0 – 4	MKZ	20	250
2	4 – 8	MKZ	20	250
3	8 - 12	MKZ	20	250
4	12 – 16	MKZ	20	250
5	16 – 20	MKZ	20	250
Bedrock	-	Elastic Halfspace (2% Damping Ratio)	25	760

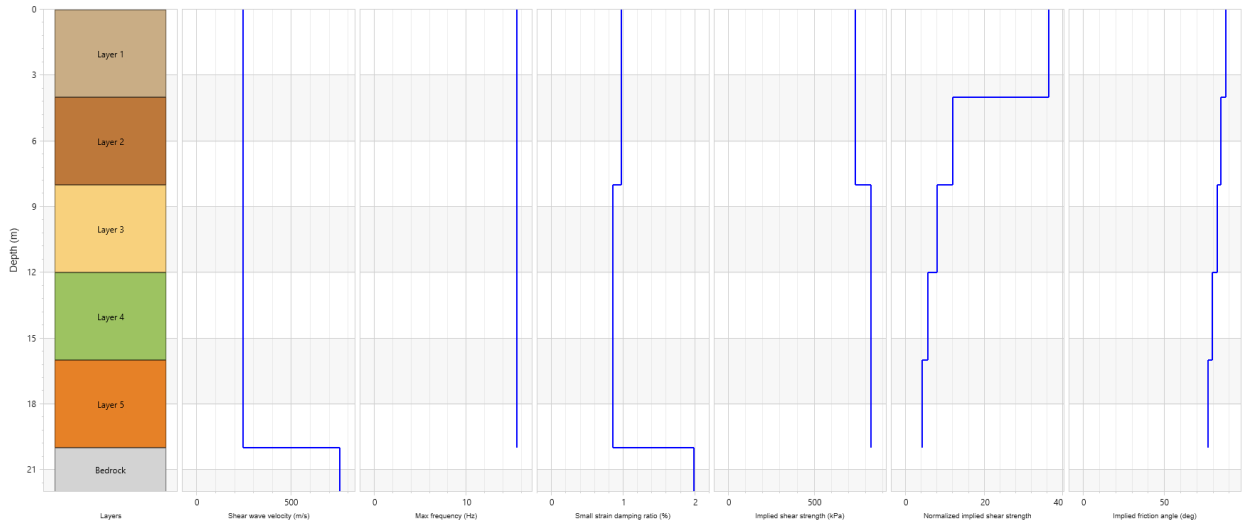

Figure 1.1: Soil Profile with Plots of Key Geotechnical Properties Using D Fitting Procedure

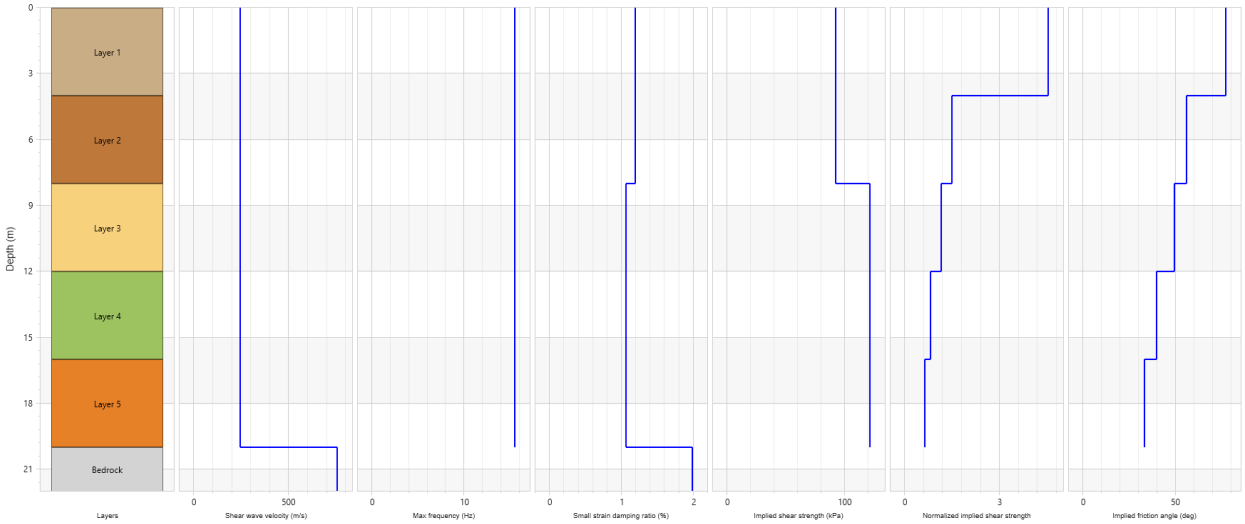

Figure 1.2: Soil Profile with Key Geotechnical Properties Using MR Fitting Procedure

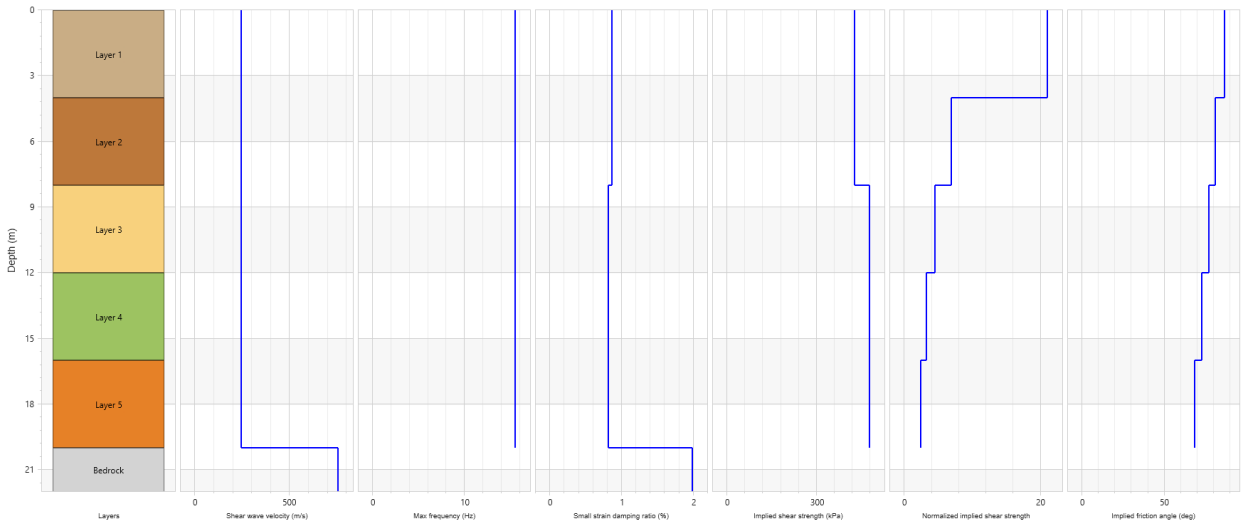

Figure 1.3: Soil Profile with Key Geotechnical Properties Using MRD Fitting Procedure

1.2. Results

The 5% damped spectral acceleration and Fourier amplitude spectrum computed at ground surface for each analysis and fitting procedure are presented in Figure 1.4 and Figure 1.5. The analysis results from *RSSeismic* closely match those obtained from *DEEPSOIL*.

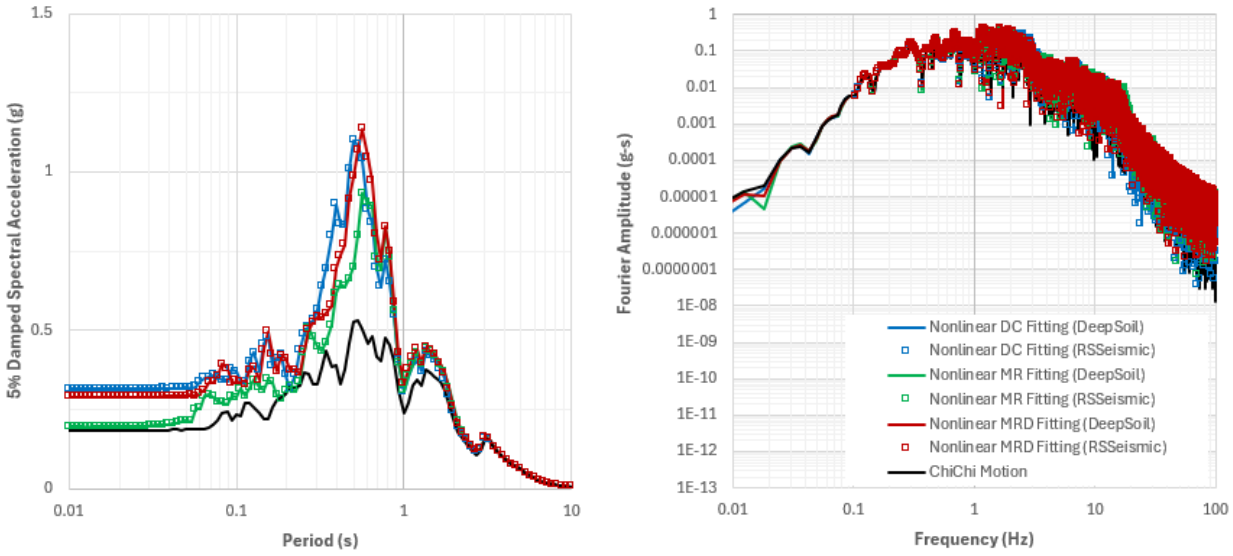

Figure 1.4: Comparison of 5% Damped Spectral Acceleration and Fourier Amplitude Spectrum computed at Ground Surface for Nonlinear Analysis using DC, MR and MRD fitting procedures along with those for the ChiChi Input Motion

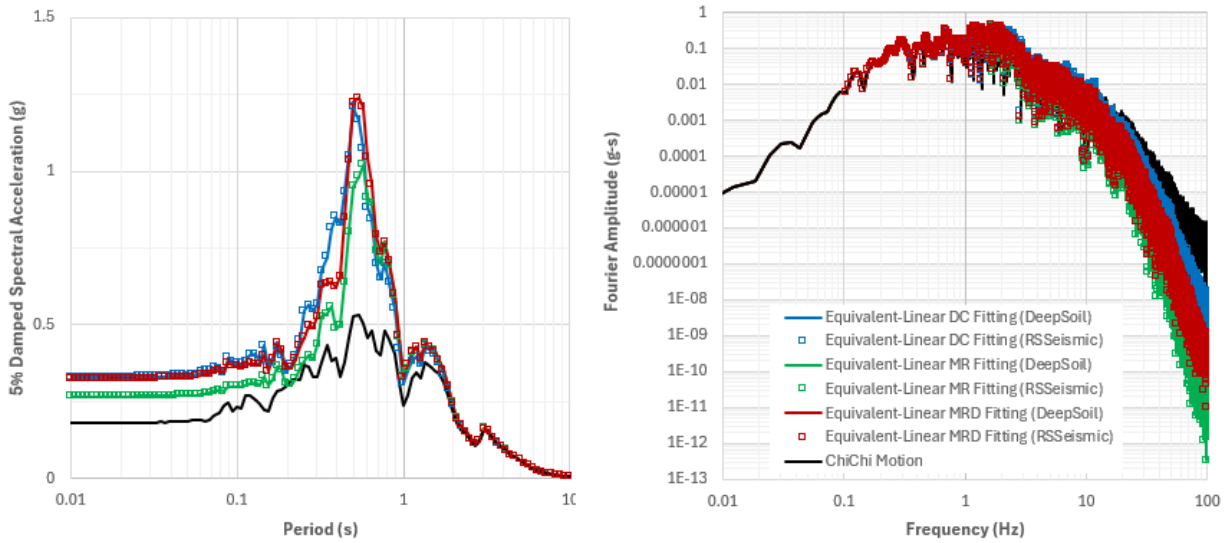

Figure 1.5: Comparison of 5% Damped Spectral Acceleration and Fourier Amplitude Spectrum computed at Ground Surface for Equivalent-Linear Analysis using DC, MR and MRD fitting procedures along with those for the ChiChi Input Motion

2. Nonlinear Analysis / Multi-Layer, GQ/H, Elastic Rock, Pore Pressure Generation and Dissipation

Verification of Example 8 from the *DEEPSOIL* User Manual

2.1. Problem Description

Nonlinear analysis was conducted as effective stress analyses by accounting for the generation and dissipation of pore water pressure (PWP). The analyses were conducted using *RSSeismic* and *DEEPSOIL* for the Kobe input motion and the results are compared. A summary of the layer properties is presented in Table 2.1.

Figure 2.1 presents the soil profile plots of key geotechnical properties. Soil model properties are calculated assuming a friction angle of 30˚. Stress-strain behavior of rockfill material is assumed to follow Non-Masing Re/Unloading Formulation, and backbone formulation is computed using GQ/H soil model fitted to the Darendeli (2001) reference curve assuming an overconsolidation ratio (OCR) of 1.0 and plasticity index (PI) of 0.0%. The coefficient of earth pressure at rest (K_0) required for calculation of the reference curve is calculated using the Jaky (1948) equation as follows:

$$K_o = [1 - \sin(\phi)] * OCR^{\sin(\phi)} \qquad (2.1)$$

The modulus reduction and damping curve fitting (MRDF) with UIUC Reduction Factor is used to capture the Non-Masing behavior and the GQ/H Model is fitted for a shear strain range up to 0.05% considering the Modulus Reduction Curve under the condition that the shear stresses reach 95% of the target shear strength at shear strain of 10%. The GMP PWP model for sand layer is assumed for all soil layers with the properties shown in Table 2.2. The bedrock is defined as an elastic halfspace with shear wave velocity (V_s) of 5000 ft/s, unit weight of 160 pcf and damping ratio (D_{min}) of 2%.

Frequency independent damping was used in the nonlinear analysis where the damping matrix was not recalculated at each step of the analysis. For the nonlinear (time-domain) analysis, a flexible step control with maximum strain increment of 0.005% is assumed along with a time history interpretation method of zero-padded in frequency domain.

Table 2.1: Layer Properties

Layer	Depth (ft)	Soil Model	Unit Weight (pcf)	Shear Wave Velocity, V_s (ft/s)	PWP Model
1	0 – 10	GQ/H	125	1000	Sand – GMP
2	10 – 25	GQ/H	125	1500	Sand – GMP
3	25 – 40	GQ/H	125	1500	Sand – GMP
4	40 – 60	GQ/H	125	2000	Sand – GMP
5	60 – 80	GQ/H	125	2000	Sand – GMP
Bedrock	-	Elastic Halfspace (2% Damping Ratio)	160	5000	-

Table 2.2: GMP PWP Model for Sand Layer Properties

Property	Value
Maximum normalized excess pore pressure, Max r_u	0.95
Coefficient of Consolidation, C_v (ft/s)	0.1
Pressure-Dependent Modifier, $C_{v\_exponent}$	0.0
Scale Factor, α	2.0
Relative Density, D_r (%)	95
Fines Content, FC (%)	15
Degradation Parameter, v	3.80

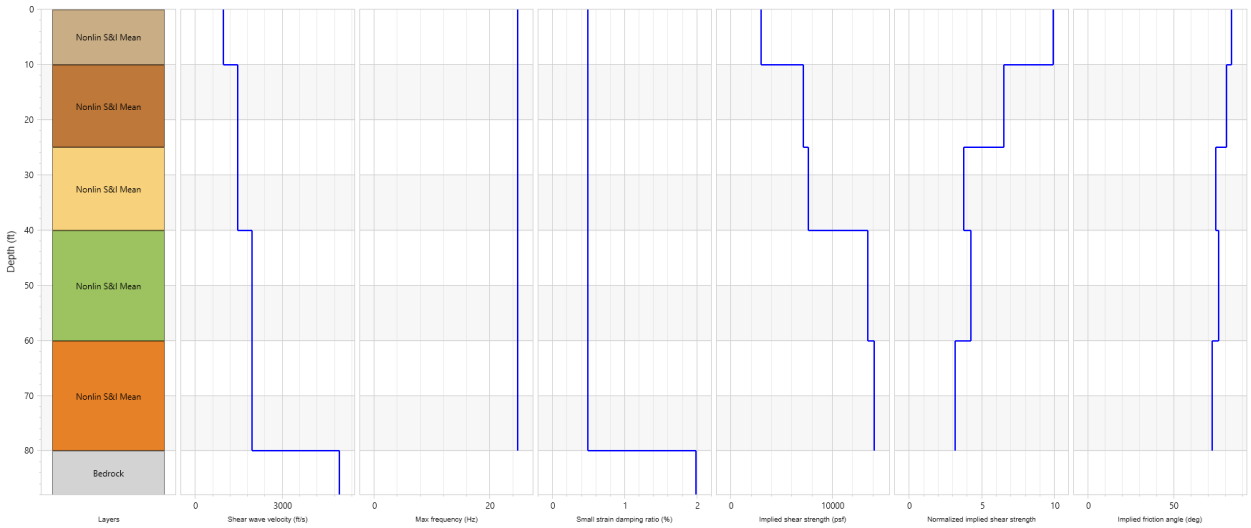

Figure 2.1: Soil Profile with Plots of Key Geotechnical Properties

2.2. Results

The results from *RSSeismic* and *DEEPSOIL* show good agreement, as shown in the profile plots (Figure 2.2), time history plots (Figure 2.3), stress-strain plots (Figure 2.4) and combined plots of 5% damped spectral acceleration, Fourier amplitude Spectrum (FAS) and Fourier Amplitude Ratio (FAS at layer divided by FAS at input motion)(Figure 2.5).

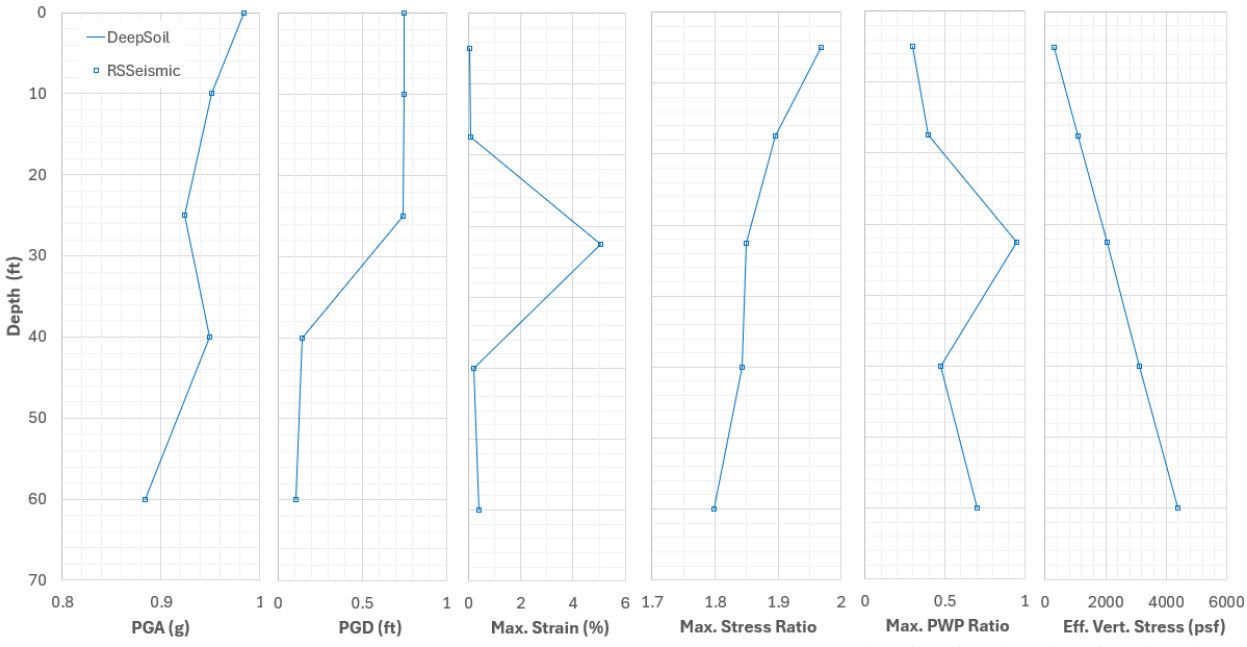

Figure 2.2: Comparison of Profile Plots

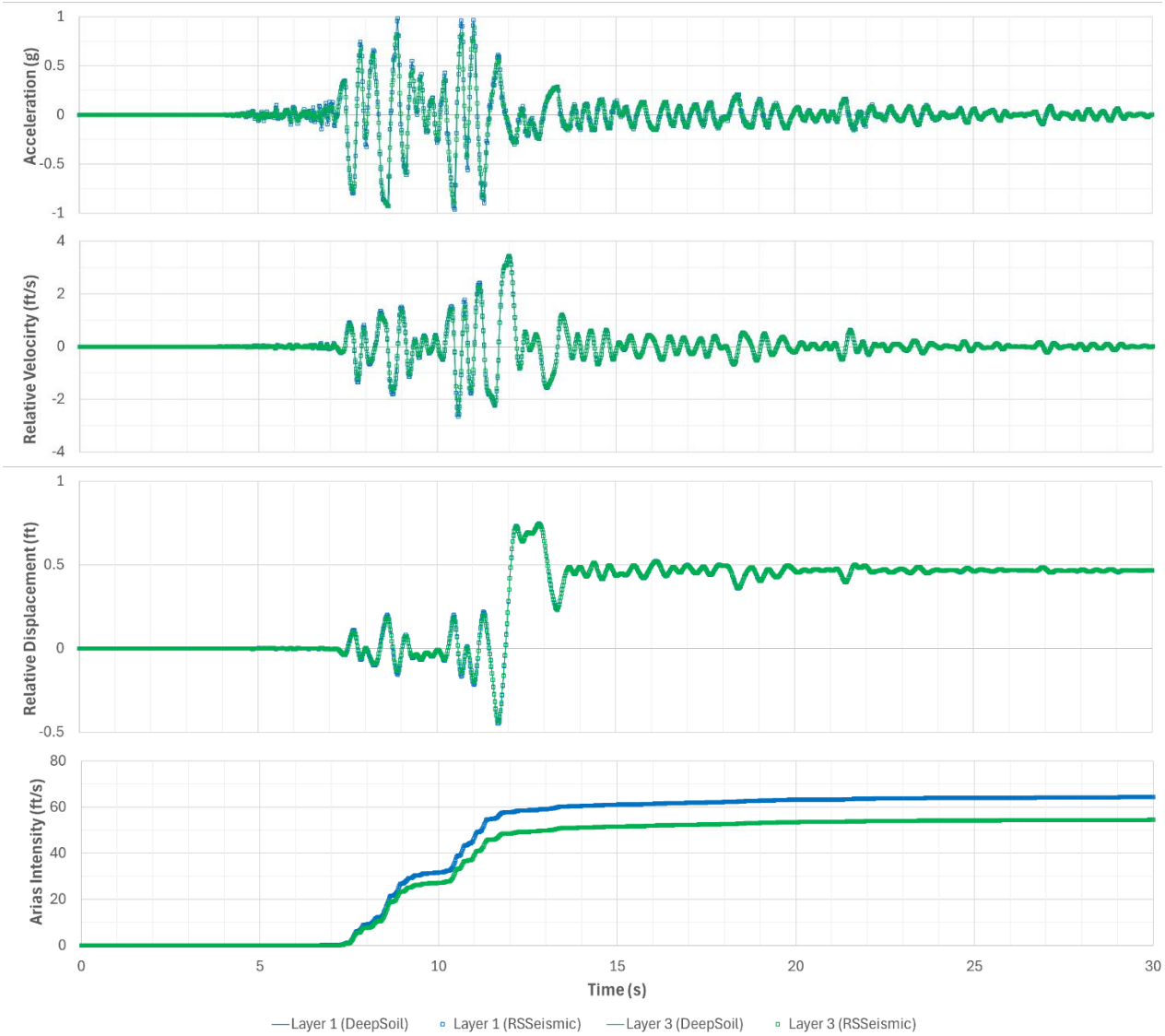

Figure 2.3: Comparison of Time History Plots at Layer 1 and 3 for the Kobe Motion

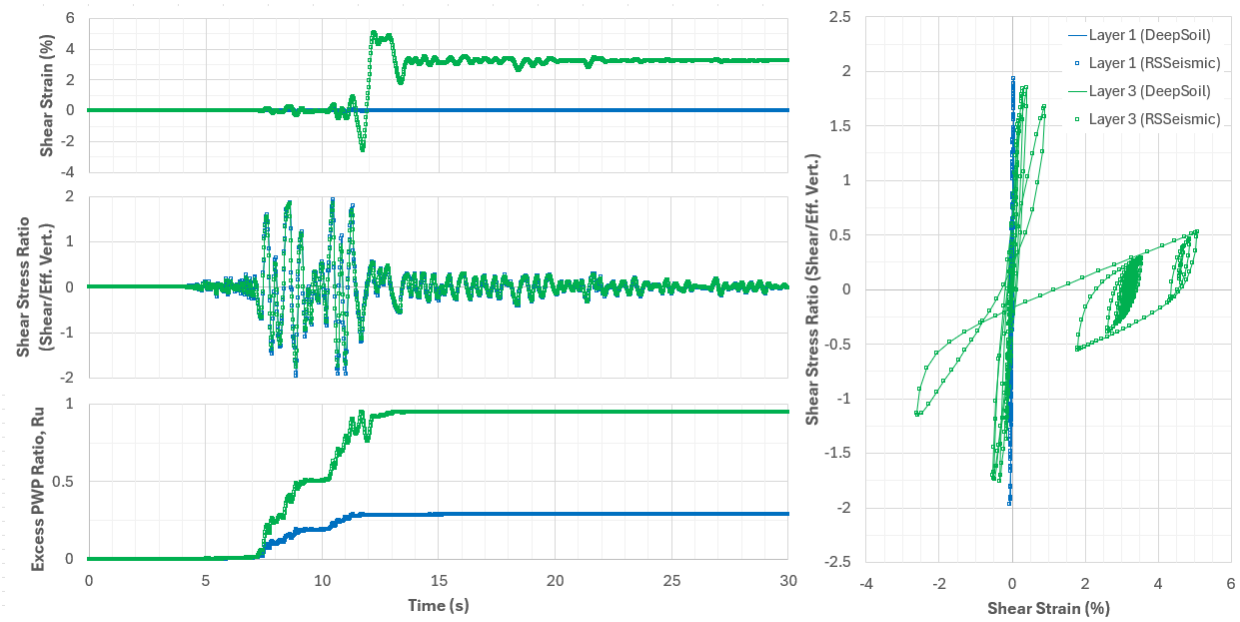

Figure 2.4: Comparison of Stress-Strain Plots at Layer 1 and 3 for the Kobe Motion

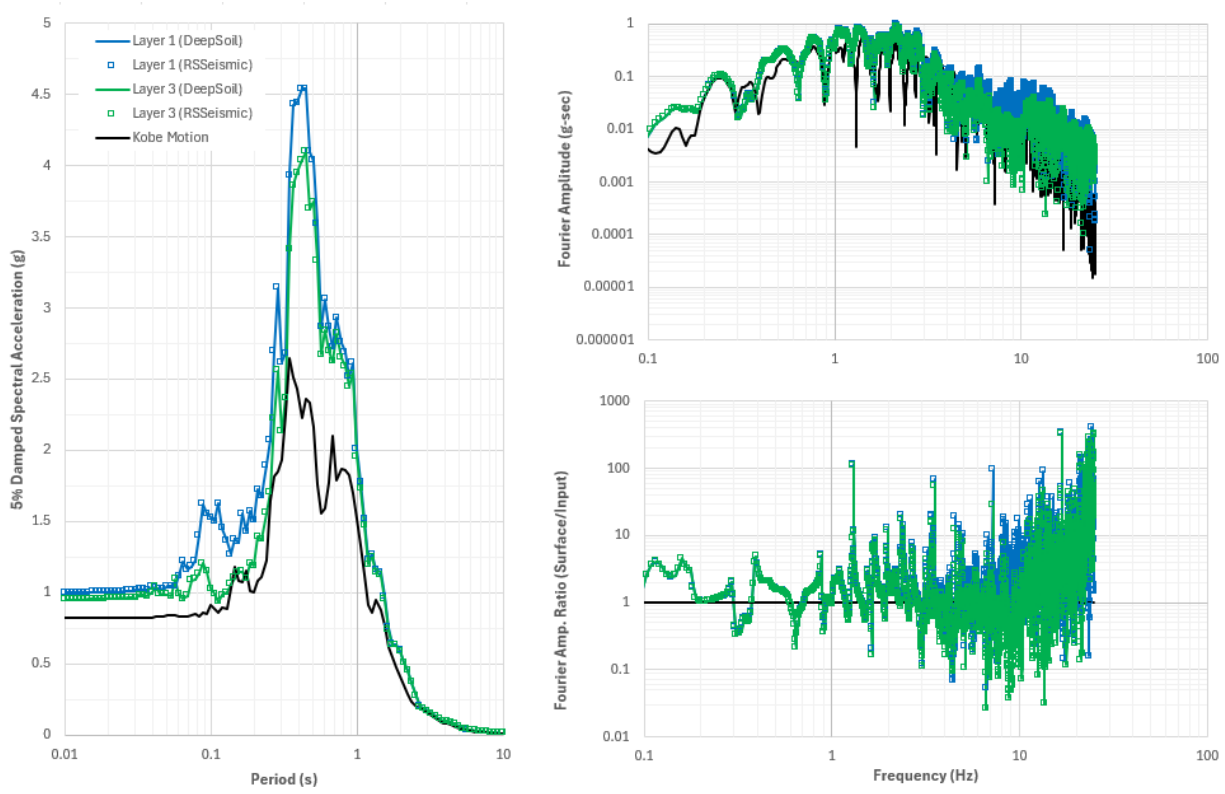

Figure 2.5: Comparison of 5% Damped Spectral Acceleration, Fourier Amplitude Spectrum (FAS) and Fourier Amplitude Ratio (FAS at layer divided by FAS at input motion) at Layer 1 and 3 for the Kobe motion

3. Nonlinear Analysis / Multi-Layer, MKZ, Rigid Rock, Treasure Island Profile

Verification of Example 10 from the *DEEPSOIL* User Manual

3.1. Problem Description

Nonlinear and equivalent-linear analyses were carried out on a soil profile of 100 m depth using *RSSeismic* and *DEEPSOIL* for the Kobe input motion, and the results are compared. The soil profile was divided into 53 soil layers and a rigid bedrock. The MKZ soil model with Masing Re/Unloading formulation is assumed to create the soil backbone curves. A summary of the layer properties is presented in Table 3.1. Figure 3.1 presents the soil profile with plots of key geotechnical properties. Two frequencies of Rayleigh Damping (0.8 Hz and 9 Hz) were used in the nonlinear analysis where the damping matrix was recalculated at each step of the analysis. For the nonlinear (time-domain) analysis, a flexible step control with maximum strain increment of 0.0005% is assumed along with a time history interpretation method of zero-padded in frequency domain. The equivalent-linear (frequency-domain) analysis assumed 15 iterations, an effective shear strain ratio (SSR) of 0.65 and a frequency-independent complex shear modulus formulation.

Table 3.1: Layer Properties

Layer	Depth (m)	Soil Model	Unit Weight (kN/m^3)	Shear Wave Velocity, V_s (m/s)
1 – 53	0 – 100	MKZ	17.3 – 20.1	134 – 1900
Bedrock	-	Rigid Halfspace	-	-

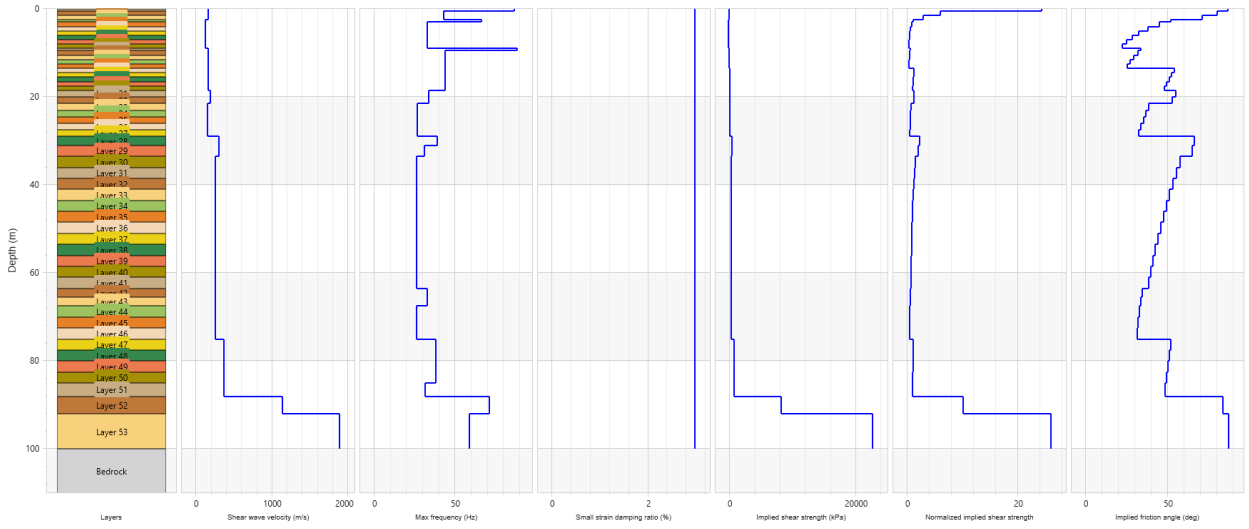

Figure 3.1: Soil Profile with Plots of Key Geotechnical Properties

3.2. Results

The results from *RSSeismic* and *DEEPSOIL* show good agreement, as shown in the time history plots (Figure 3.2), and 5% damped spectral acceleration spectra (Figure 3.3).

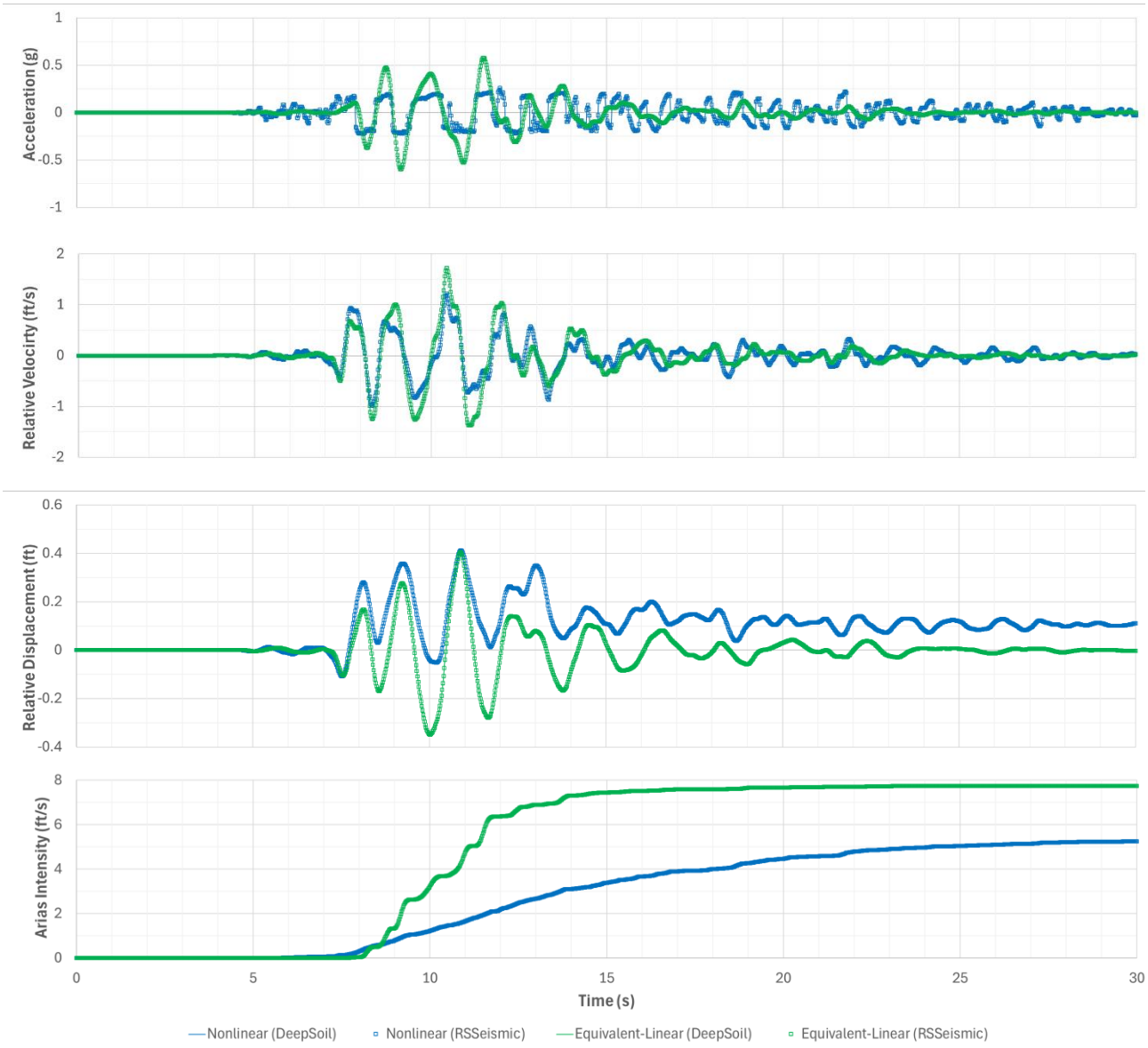

Figure 3.2: Comparison of Time History Plots at the Ground Surface for Nonlinear and Equivalent-Linear Analyses for the Kobe Motion

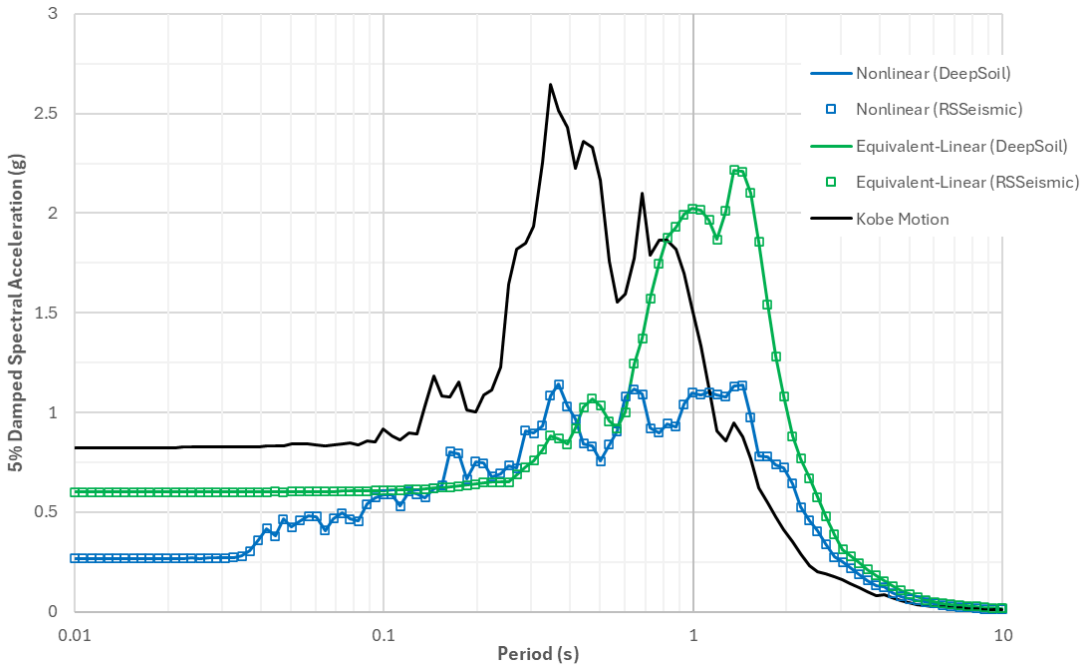

Figure 3.3: Comparison of 5% Damped Spectral Acceleration at Ground Surface for Nonlinear and Equivalent-Linear Analyses for the Kobe Motion

4. Nonlinear Analysis / Multi-Layer, MKZ, Elastic Rock, MRDF

Verification of Example 11 from the *DEEPSOIL* User Manual

4.1. Problem Description

Nonlinear and equivalent-linear analyses were carried out on a soil profile of 435.5 ft depth using *RSSeismic* and *DEEPSOIL* for the Kobe input motion, and the results are compared. The soil profile was divided into 80 soil layers and an elastic bedrock. The MKZ soil model with Non-Masing Re/Unloading Formulation is assumed to create the soil backbone curves. A summary of the layer properties is presented in Table 4.1. Figure 4.1 presents the soil profile with plots of key geotechnical properties. Two frequencies of Rayleigh Damping (1 Hz and 5 Hz) were used in the nonlinear analysis where the damping matrix was not recalculated at each step of the analysis. For the nonlinear (time-domain) analysis, a flexible step control with maximum strain increment of 0.001% is assumed along with a time history interpretation method of zero-padded in frequency domain. The equivalent-linear (frequency-domain) analysis assumed 15 iterations, an effective shear strain ratio (SSR) of 0.65 and a frequency-independent complex shear modulus formulation.

Table 4.1: Layer Properties

Layer	Depth (ft)	Soil Model	Unit Weight (pcf)	Shear Wave Velocity, V_s (ft/s)
1 – 80	0 – 435.5	MKZ	120 – 130	469 – 1616
Bedrock	-	Elastic Halfspace (0% Damping Ratio)	137	2492

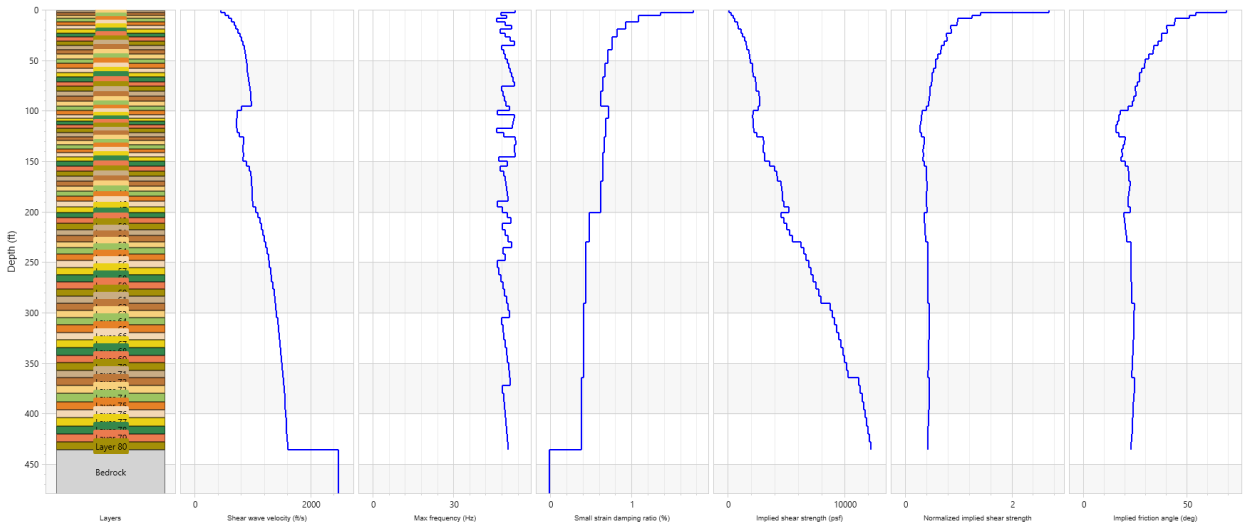

Figure 4.1: Soil Profile with Plots of Key Geotechnical Properties

4.2. Results

The results from *RSSeismic* and *DEEPSOIL* show good agreement, as shown in the time history plots (Figure 4.2), and 5% damped spectral acceleration spectra (Figure 4.3).

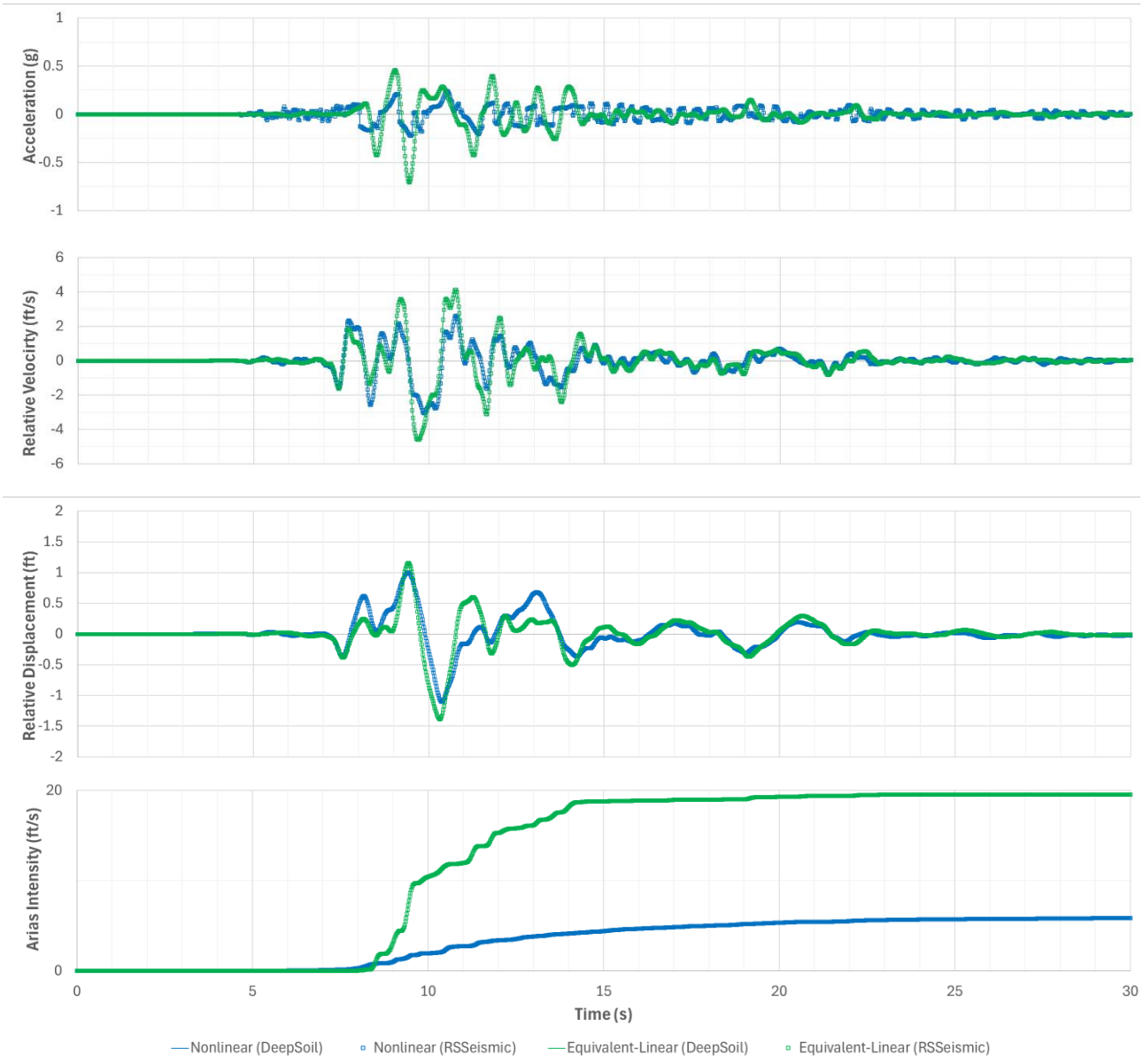

Figure 4.2: Comparison of Time History Plots at the Ground Surface for Nonlinear and Equivalent-Linear Analyses for the Kobe Motion

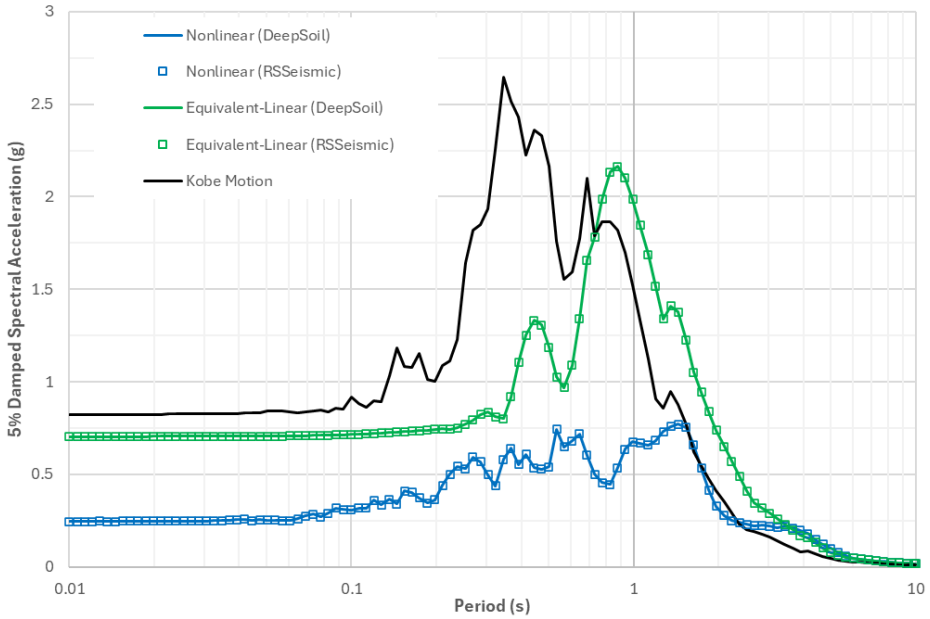

Figure 4.3: Comparison of 5% Damped Spectral Acceleration at Ground Surface for Nonlinear and Equivalent-Linear Analyses for the Kobe Motion

5. Nonlinear Analysis by Soil Profile with Various Soil Models at Different Layers

Verification of Example 14 from the *DEEPSOIL* User Manual

5.1. Problem Description

The site profile is extracted as a shear-beam from a 2-D finite element model of a centrifuge model for a concrete-face rockfill dam. The profile has a total depth of 352.2 m, consisting of 202.2 m of rockfill underlain by bedrock layers. Table 5.1 summarizes the layer properties. Note that the profile is divided into 58 soil layers where different soil models are applied at different layers. Figure 5.1 presents the soil profile with plots of key geotechnical properties. Nonlinear analysis is carried out using *RSSeismic* and *DEEPSOIL* for the ChiChi input motion and the results are compared.

Table 5.1: Layer Properties

Layer	Depth (m)	Soil Model	Unit Weight (kN/m^3)	Shear Wave Velocity, V_s (m/s)
Rockfill (1 – 42)	0 – 202.2	GQ/H	20.99	301.2 - 1098.7
Bedrock (43 – 58)	202.2 – 352.2	Linear	25.99	1500
Bedrock	-	Rigid Halfspace	-	-

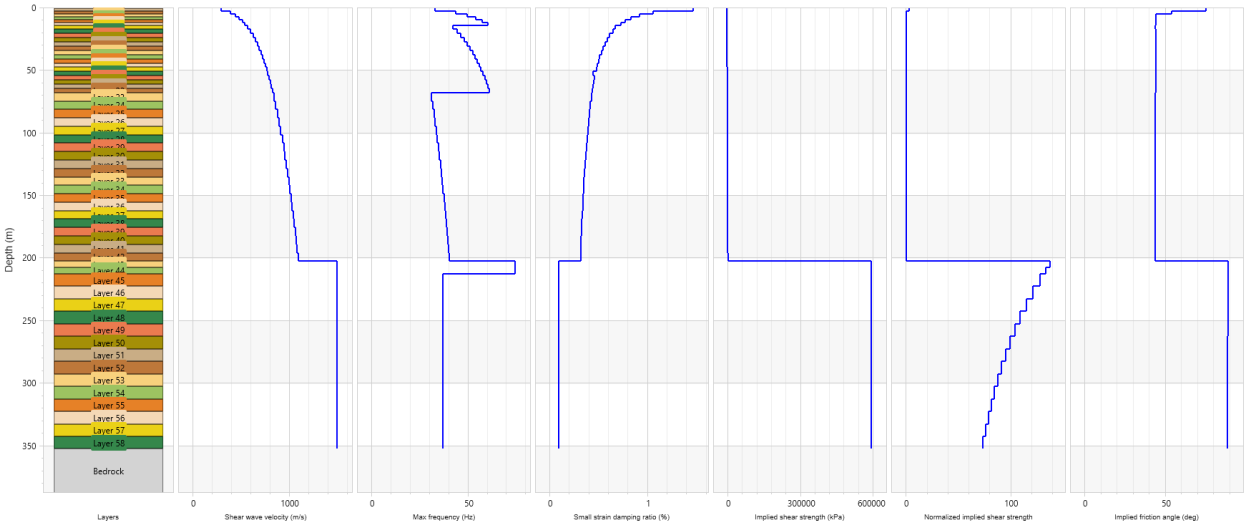

Figure 5.1: Soil Profile with Key Geotechnical Properties for Each Layer

Soil model properties for the rockfill layers 1 to 42 are calculated assuming a friction angle of 45°. Stress-strain behavior of rockfill material is assumed to follow Non-Masing Re/Unloading Formulation, and backbone formulation is computed using the GQ/H soil model fitted to the Darendeli (2001) reference curve assuming an overconsolidation ratio (OCR) of 1.0 and plasticity index (PI) of 0.0%. The coefficient

of earth pressure at rest (K_0) required for calculation of the reference curve is calculated based on the Jaky (1948) equation as follows:

$$K_o = [1 - \sin(\phi)] * OCR^{\sin(\phi)} \quad (5.1)$$

The modulus reduction and damping curve fitting (MRDF) with UIUC Reduction Factor is used to capture the Non-Masing behavior and GQ/H Model is fitted for a shear strain range up to 0.05% considering the Modulus Reduction Curve under the condition that the shear stresses reach 95% of the target shear strength at shear strain of 10%.

Soil model properties for the bedrock layers 43 to 58 are calculated assuming linear behaviour under earthquake excitation with shear wave velocity (V_s) of 1500 m/s and damping ratio (D_{min}) of 0.1%.

For the nonlinear (time-domain) analysis, a flexible step control with maximum strain increment of 0.005% is assumed along with a time history interpretation method of linear in time domain.

5.2. Results

The results from *RSSeismic* and *DEEPSOIL* compare well as shown in time history plots (Figure 5.2), stress-strain plots (Figure 5.3) and 5% damped spectral acceleration response spectra (Figure 5.4).

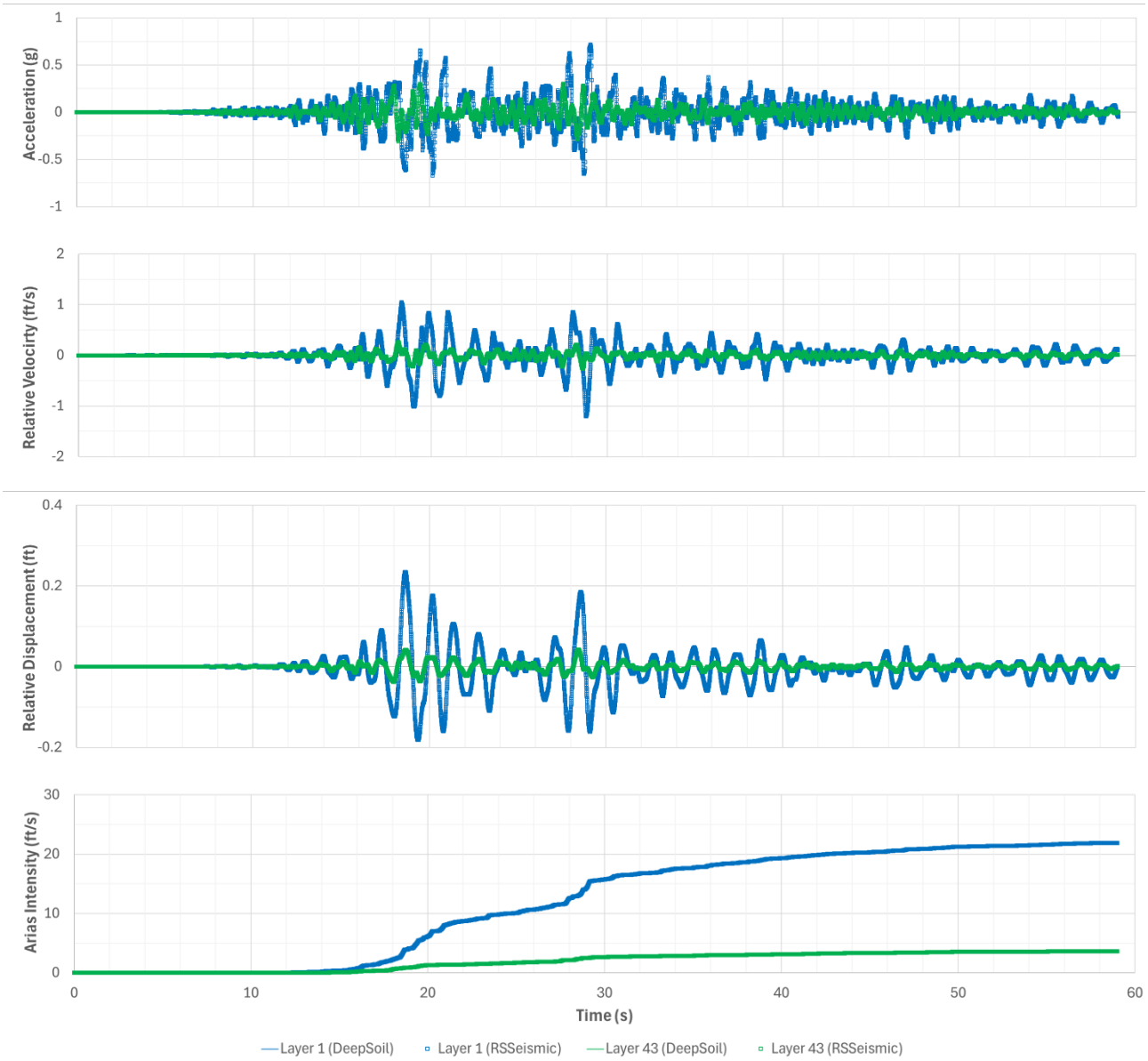

Figure 5.2: Comparison of Time History Plots at Layer 1 and 43 for the ChiChi Motion

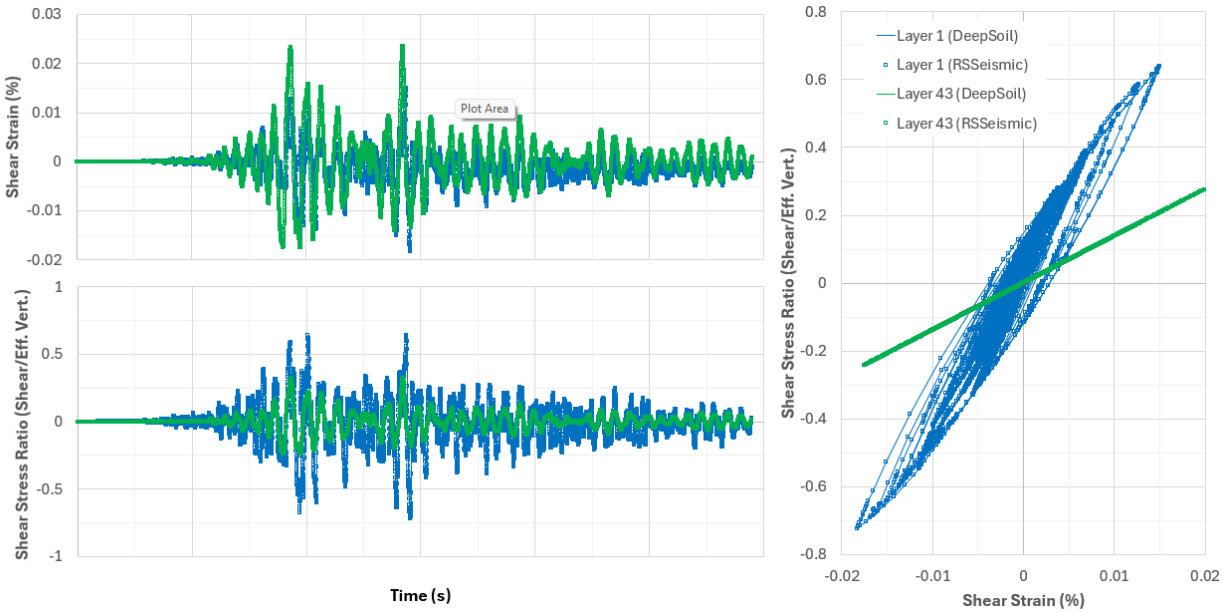

Figure 5.3: Comparison of Stress-Strain Plots at Layer 1 and 43 for the ChiChi Motion

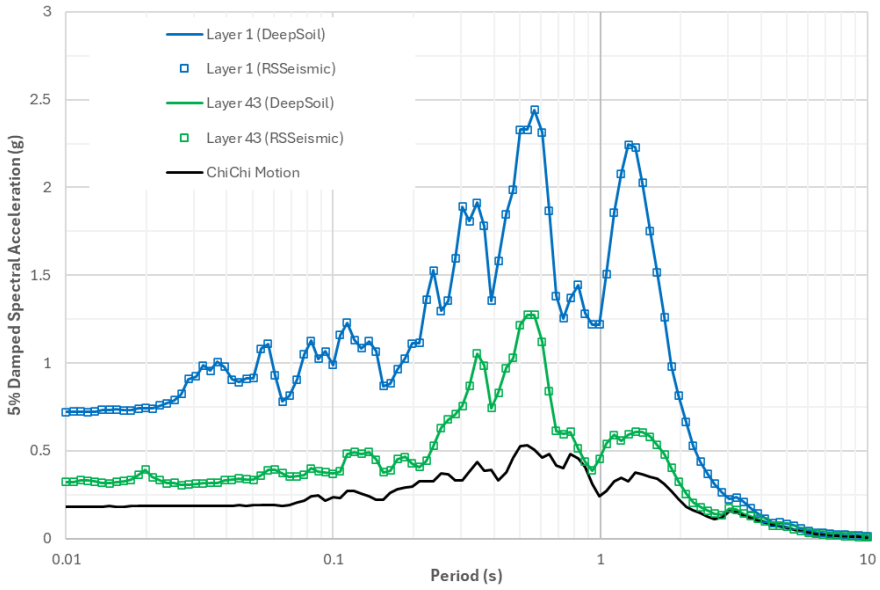

Figure 5.4: Comparison of 5% Damped Spectral Acceleration at Layer 1 and 43 for the ChiChi Motion

References

1. Darendeli, M. B. (2001). Development of a New Family of Normalized Modulus Reduction and Material Damping Curves, Department of Civil, Architectural and Environmental Engineering, The University of Texas, Austin, Texas.
2. Jaky, J. (1948). “Pressure in silos.” *Proc., 2nd Int. Conf. on Soil Mechanics and Foundation Engineering*, Rotterdam, The Netherland, 1, 103–107.