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SPECTIME USER'S GUIDE

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Prepared by

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Content

1. SPECTIME (Generation of Theoretical Earthquakes)

Seismic shake table users and other seismic researchers often need to develop one or more statistically independent time histories that have a specified required response spectrum (RRS). The ANCO program, SPECTIME, is designed to iteratively compute a time history that conforms to the RRS using a set of random, windowed, and band passed starter seed arrays. The algorithm used is similar to that developed by Gasparini and VanMark (MIT 1964). To conform to certain test standards, such as AC156, the time history that SPECTIME produces is trapezoidal shaped with about 20 seconds of strong motions. During the iterations, the amplitudes are to make the Computed Response Spectrum (CRS) of the time history closely fit that of the desired Required Response Spectrum (RRS). The RRS can be specified by the user. The fit typically has an error of less than 10%.
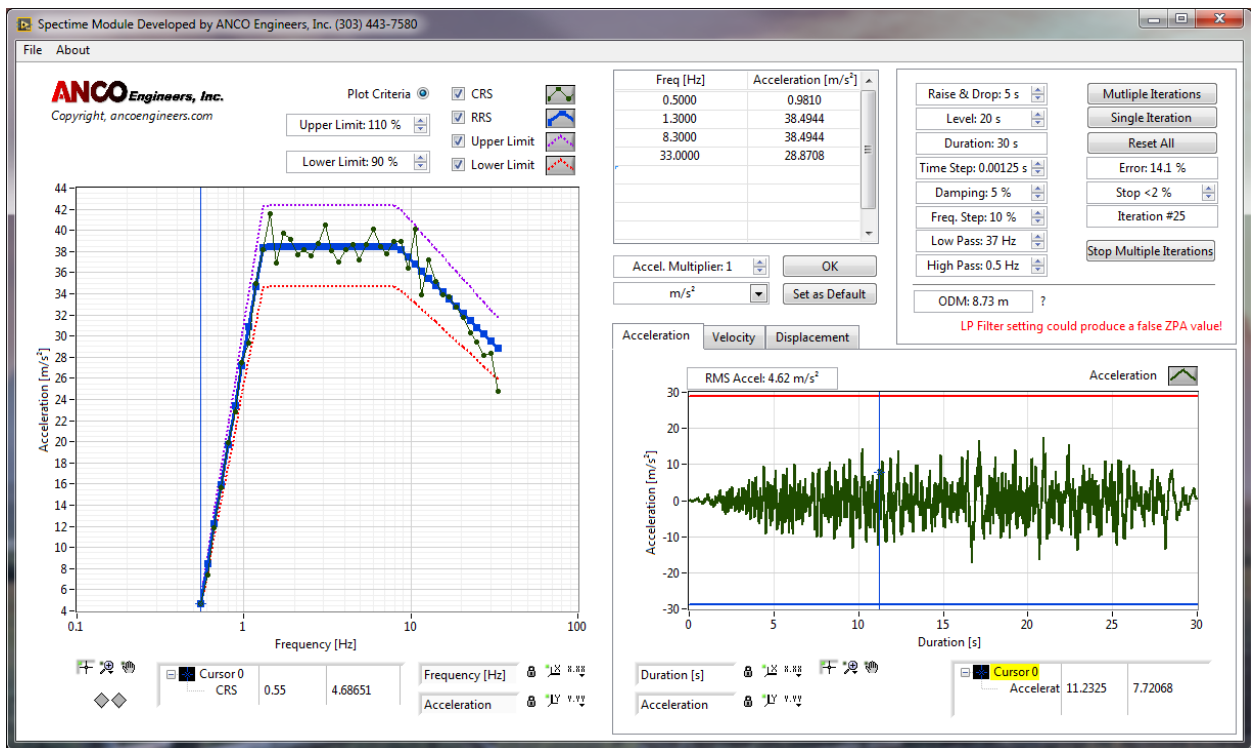

Note: There are certain mathematically unrealizable spectra. For example A_{rigit} for the theoretical time history of a typical AC156 spectra for both horizontal planar motion cannot be mathematically achieved. Difficulties arise when RRS's with peak energy ratios to that at the ZPA levels are low (1.33). Although the mathematical fit may be excellent, the resultant computed time history may not be in compliance. Despite this deficiency, a well equalized shake table can return an AC156 Section 6.5.3.2.3 (per ASCE 7) qualified time history.

2   SPECTIME WINDOW FUNCTION DESCRIPTIONS

2.1 Main Editor

Many functions of Spectime can be accessed via the standard Windows toolbar 'File' menu:
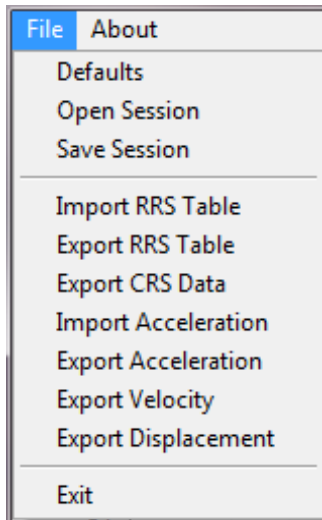
Defaults: Resets the RRS to a previously stored 'Default' value, reset any iteration to '0', and generates a random time history with a predefined shape.
Open Session: Opens a previously saved session with all associated variables and parameters.
Save Session: Saves the current session and all associated variables.

Import RRS Table: Imports a previously stored RRS table. Only the RRS table is loaded, no other variables are being modified.
Export RRS Table: Exports data stored in the RRS table. No other variables are being saved. Data are written as a text file but with a 'rrs' extension and can be opened in a text editor.
Export CRS Data: Exports the CRS data as a text file but with a 'crs' extension. This file can be opened in a text editor.
Import Acceleration: Allows importing a text based vertical column delimited acceleration time history and derives its CRS.
Export Acceleration: Exports a text based vertical column delimited acceleration time history that was derived from the CRS.
Export Velocity: Exports a text based vertical column delimited velocity time history that was derived from the acceleration time history.
Export Displacement: Exports a text based vertical column delimited displacement time history that was derived from the acceleration time history.

Exit: Exits the program. Pressing the 'x' to the top right of the program has the same function.

2.2 **Spectime Activation**

Spectime ships in 'Demo' mode and with limited functionality. A license file can be purchased from ANCO Engineers, Inc. at www.ancoengineers.com to unlock the added functionality.

In order to obtain a valid license file a license code needs to be generated that is unique to the PC the software is installed on. Go to the 'About' menu and navigate to the License tab. Press the 'License code to clipboard' button and email the content of the clipboard by pressing CTRL-V in the text message to ANCO.

ANCO will then generate a unique license file (Spectime….ALF) and email it back to you. Store that file on a known location on your PC and then press the 'Import ANCO License File' button. Navigate to the previously stored license file on your PC and once it is successfully loaded into the program the 'License' tab will disappear and all features of Spectime will be unlocked.
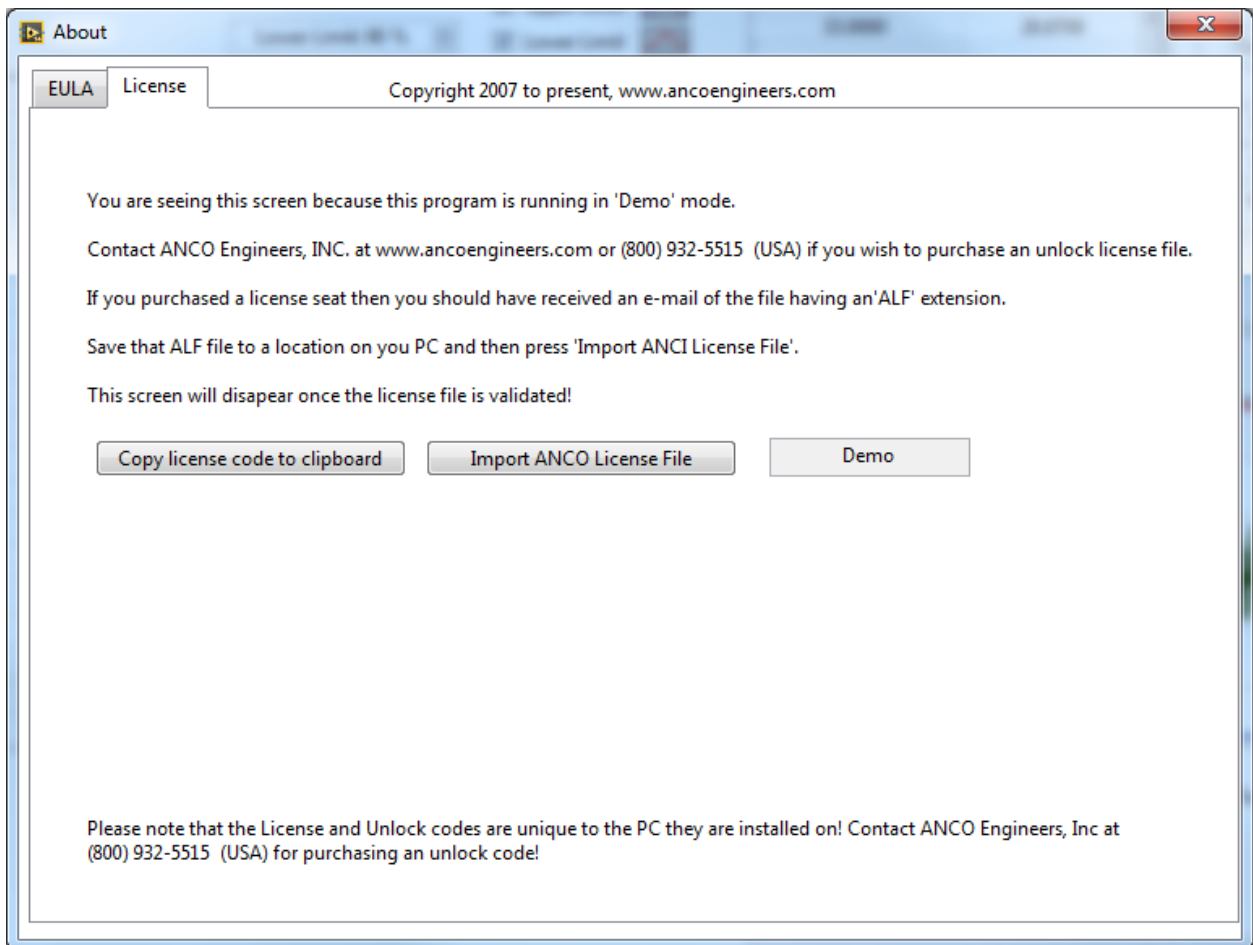
2.3 Importing an Acceleration Time History

This feature is accessible through the File Toolbar menu and allows importing multicolumn vertical acceleration text files.

Using the 'Import text File' button a multicolumn vertical text file can be imported and then scaled in amplitude and time. Exiting this import menu will instruct Spectime to derive the imported time histories CRS.

2.4 Generation of compliant Time Histories

Populate the **RRS table** using pairs of frequencies and acceleration data. Note the correct units of your entered data pairs. The CRS graph to the left will automatically plot the results of the RRS table. Using the **Acceleration Multiplier** field followed by pressing the '**OK**' button will modify the RRS acceleration column. Data in the RRS table are automatically sorted by frequency. Only positive values of data pairs are allowed. Negative entries are set to absolute and may interfere with the automatic sorting function.

Freq [Hz]	Acceleration [m/s²]
1	1.0000
1.3	40.0000
8.3	40.0000
33	30.0000

Accel. Multiplier: 1   OK
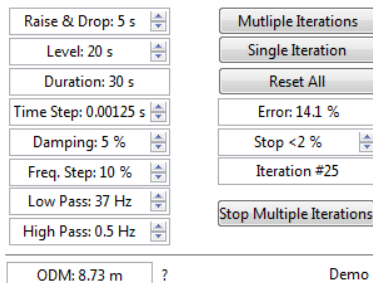m/s²   Set as Default

Reinitialize to Default Value
Cut Data
Copy Data
Paste Data
Description and Tip...
Empty Table
Insert Row Before
Insert Column Before
Delete Row
Delete Column
Show Selection
Export
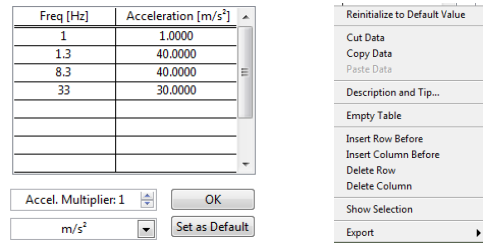
Right clicking the table field allows the user to add/delete rows. Note: Do not delete or add columns! If this happens by accident invoke the 'Defaults' function from the Files tools menu to restore operability.

Units can be in m/s² of G's. When converting data from one unit to another a very small rounding error (<1E-3) may become visible. Pressing the '**Set as Default'** button will generate a 'Default' file. This file will be loaded when Spectime is opened, or the 'Defaults' file menu entry is invoked.

Raise & Drop: 5 s
Level: 20 s
Duration: 30 s
Time Step: 0.00125 s
Damping: 5 %
Freq. Step: 10 %
Low Pass: 37 Hz
High Pass: 0.5 Hz

Mutliple Iterations
Single Iteration
Reset All
Error: 14.1 %
Stop <2 %
Iteration #25

Stop Multiple Iterations

ODM: 8.73 m   ?   Demo

The time history can be 'shaped' by entering the relevant fields for '**Raise/Drop**' and '**Level**' in seconds. The '**Time Step**' is set by default to 800Hz (0.00125s) but can be modified as needed. Please note the finer the step size to longer the CRS computations.

The Damping value is entered in percent prior to iterations. A typical damping value is 5%. The '**Freq. Step**' value of the CRS is entered in percent. All frequency steps of the graphs plotted in the CRS window are interpolated to that parameter.

Low and **High Pass** filters must be entered before iteration is invoked. Modifying the filter settings after iteration is complete will have no effect on the displayed time history.

When invoking the '**Multiple Iterations'** button Spectime will iteratively derive the CRS and display the corresponding time histories. The automatic iteration will stop if the '**Error**' is equal or less than the entered '**Stop**' error. The iteration will also stop if the '**Stop Multiple Iterations' button** -, the ESC key is pressed, or the **Iteration** runs past 100. Pressing the 'Single Iteration' instructs the program to manually iterate.

Pressing '**Reset All'** returns to the started seed array and lets the user start a new set of iterations.

The **ODM** parameter: Oil Displacement Multiplier. This value is the time integral of the absolute value of the velocity time history. It is a measure of the total volume flow required from the hydraulic power supply in a servo hydraulic shake table. Multiplying this ODM by the total shake table actuator piston area will yield the volume of oil required to produce this time history. It does not take into account valve or actuator leakage or pilot valve flow. Pressing the '**?**' will display its definition in a separate popup window.

2.5.   **Saving the Time Histories**

The computed time histories can be exported into a tab delimited text file. Exporting is done by using the 'File' menu tool and as described in section 2.1. Other export formats are available by right clicking the relevant graphs. Images, text files, or Excel files can then be generated for further analysis.
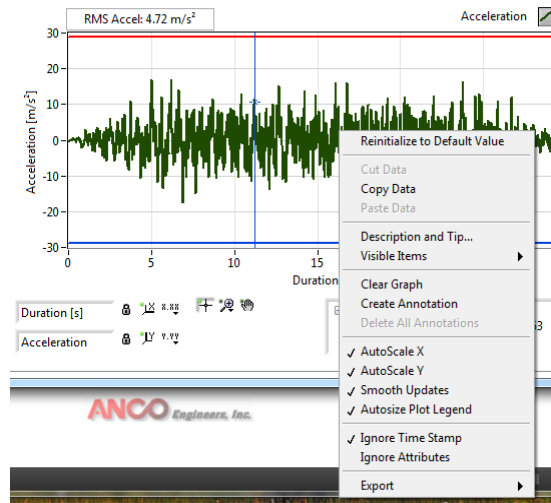

Please note that if the **Plot criteria** field in the CRS graph is checked a set of horizontal lines representing $\pm A_{rigit}$ will also be plotted on the acceleration time history plot. In addition there are RMS values displayed for each time history plot.

Velocity and Displacement data are the result of integrations. Hence an additional **High Pass** filter can be employed to reduce any associated background effects. This high pass filter can be accessed in the Displacement tab. To reduce issues related to over filtering set the '**High Pass**' filter to the lowest possible value.

2.6 The CRS Plots

All spectral plots are located to the left of Spectime.
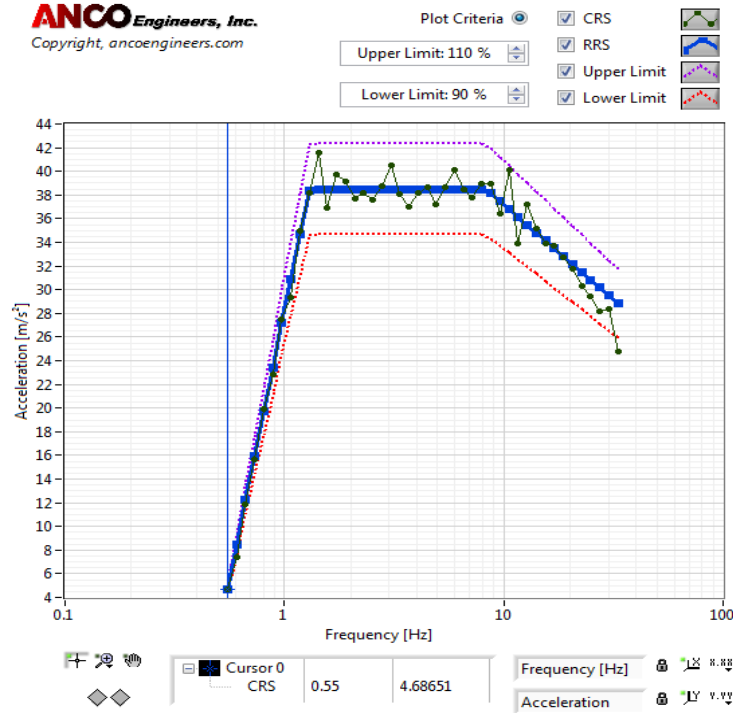
The CRS graph displays RRS, CRS, and user definable upper/lower criteria. AC156 for example require that the CRS should be within an envelope of 130% and 90%.

Right clicking the graph gives the user the same export features as described in section 2.5 Saving Time Histories.

Checking the CRS/RRS/Upper/Lower Limit check marks next to the plot will make the selected plot visible/unvisible.

Note: Pressing ALT-Print Screen will take a screenshot of the active Window. This is a useful feature for displaying data in reports.

Each plot in Spectime includes an extended legend. There added features are available related to plotting (log/linear), scaling (auto/manual) and axis labeling. A freely movable cursor can be used to pick out specific data points as x/y coordinates in the graph.

3.   **Derivation of Response Spectra using MATLAB and Use to Cross Check ANCO DANCE (Spectime)**

This document outlines a program written in MATLAB (Version R2010a) used to validate the response spectrum results obtained using the ANCO Dance (Ver 6.11) program. The program uses the recurrence method to compute spectral response given an acceleration time history of a sine wave or earthquake. The following assumptions are embedded in the recurrence method:

1.   This program is used for a single degree-of-freedom system.
2.   Excitation (ground motion) is linearly interpolated at each time segment, hence using smaller time steps will produce more accurate results.
3.   Assumes linear-elastic behavior.

The recurrence method is a numerical method. It uses constants derived from the solution that are functions of the dynamic characteristics of the system and time step size, and are constant throughout the analysis if Δt (ground motion time step) remains constant.

Inputs required include:

- Ground motion time history (must be in a single column)
- Time step at which the time history was recorded (sampling period)
- Fraction of Critical Damping
- Frequency step size for evaluated Response Spectrum (RS)
- Initial and final frequency values

The program runs through three loops as explained below:

1. Two small iterative loops define the frequency vector
2. An inner loop runs through time history response.
3. The outer loop steps through each position in the frequency vector and creates an equal length vector for the spectral response, recording the maximum value from the time history at each frequency. This creates a spectral response for displacement, velocity, and acceleration.

To test the accuracy of the ANCO DANCE program against an independently created program, 1, 3, 10, and 30 Hz sine wave time histories were created to use as input into both programs. Each sine wave has an amplitude of 9.81 m/s^2 (1g) and tapered at the beginning and end using a Hanning raise envelope function. This envelope was applied as a caution in an effort to reduce anomalous calculations resulting from startup transients in a typical sine wave acceleration time history starting from zero acceleration amplitude with an instantaneous non-zero velocity. These time histories are saved as a TH (*.txt) file in various project folders under QA Program Checking. An earthquake ground motion time history was also created and saved in this folder. Both the sine waves and the earthquake generated have a time step of 0.00125 seconds and last for 30 seconds.

ANCO Dance Spectime Ver6.11 was run on an HP Pavilion g6 Notebook PC model number: A6Y41UA#ABA. The MATLAB spectral response program was run on an HP

G62 Notebook PC with model number: WQ765UA#ABA. Spectral response is calculated at a fractional frequency step of 0.01, with the damping ratio set at 5% (0.05) or 2% (0.02). In each program, the same time histories were run and the results compared. See Figures 1-10 for resulting response spectra from DANCE and MATLAB. Full data are contained in attached Microsoft Excel file (filename: VV Dance Cal Results.xlsx).

Note that the correct RS for a long sine wave is well known from analytical analysis. The asymptotic value of the RS has to be exactly the peak value of the time history. In addition the amplification of the resonant peak is very close to 1/2B above the ZPA where B is the fraction of critical damping. This relation is accurate to better than 2% for values of B less than or equal to 0.10. Lastly, within the same accuracy the peak should occur at the frequency of the applied sine wave. These relationships, when checked at several frequencies, provide strong support for the correct operation of the software.

Figure 1 –Acceleration Response Spectrum for a 1Hz, 1G, 30s Sine Wave at 5% Damping in (a) ANCO DANCE and (b) MATLAB
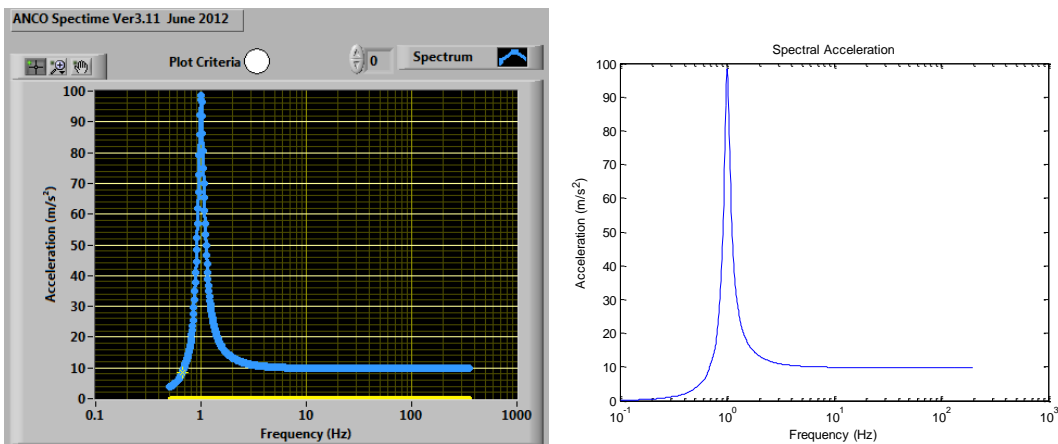

Figure 2 - Acceleration Response Spectrum for a 1Hz, 1G, 30s Sine Wave at 2% Damping in (a) ANCO DANCE and (b) MATLAB
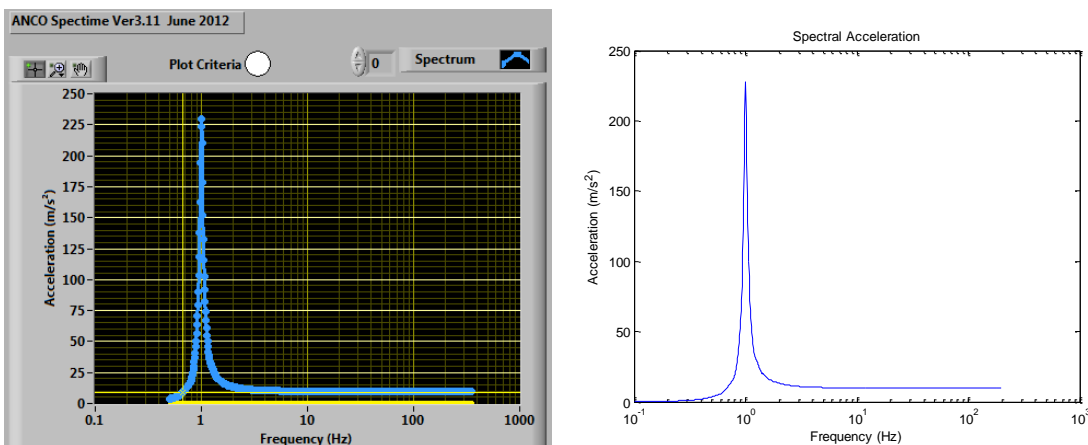
Figure 3 - Acceleration Response Spectrum for a 3Hz, 1G, 30s Sine Wave at 5% Damping in (a) ANCO DANCE and (b) MATLAB
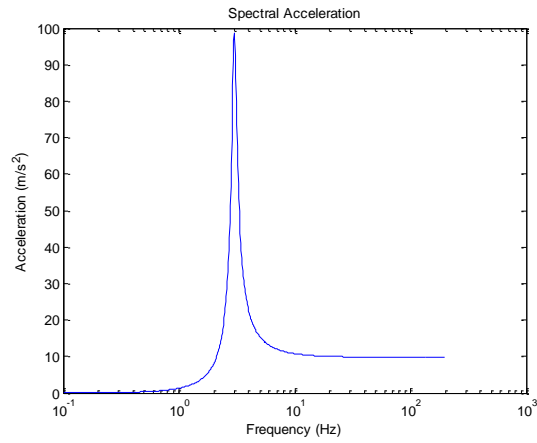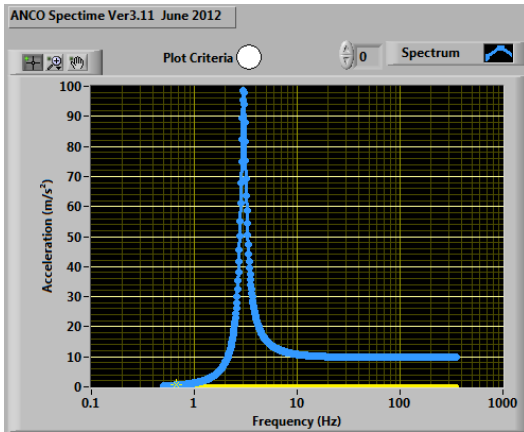

Figure 4 - Acceleration Response Spectrum for a 3Hz, 1G, 30s Sine Wave at 2% Damping in (a) ANCO DANCE and (b) MATLAB
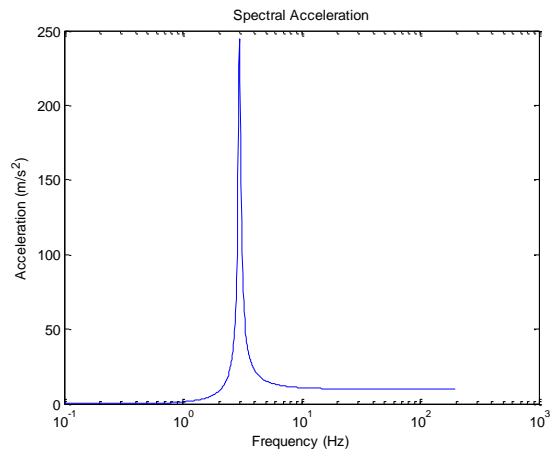
Figure 5 - Acceleration Response Spectrum for a 10Hz, 1G, 30s Sine Wave at 5% Damping in (a) ANCO DANCE and (b) MATLAB

Figure 6 - Acceleration Response Spectrum for a 10Hz, 1G, 30s Sine Wave at 2% Damping in (a) ANCO DANCE and (b) MATLAB
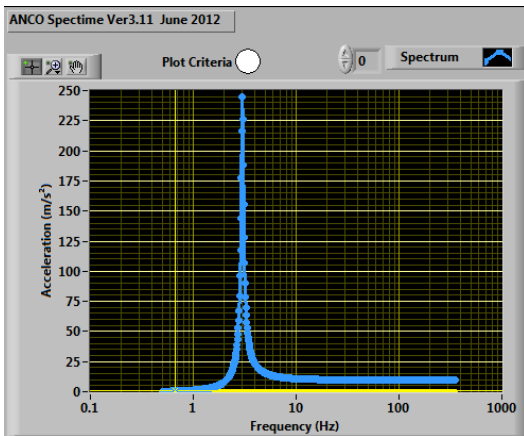
Figure 7 - Acceleration Response Spectrum for a 30Hz, 1G, 30s Sine Wave at 5% Damping in (a) ANCO DANCE and (b) MATLAB
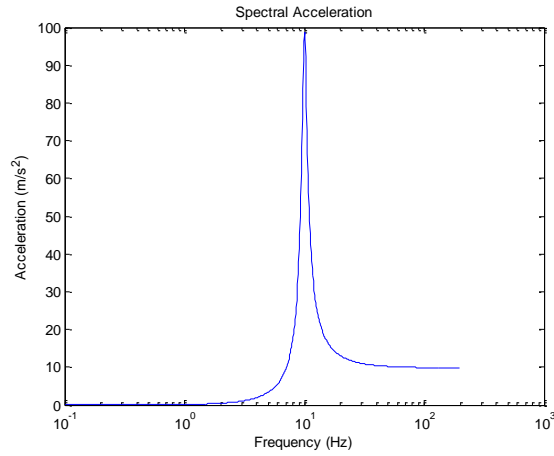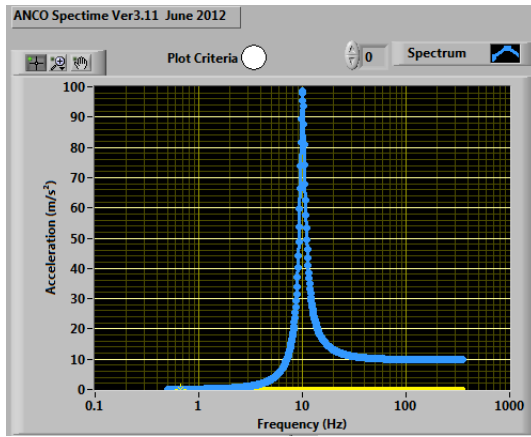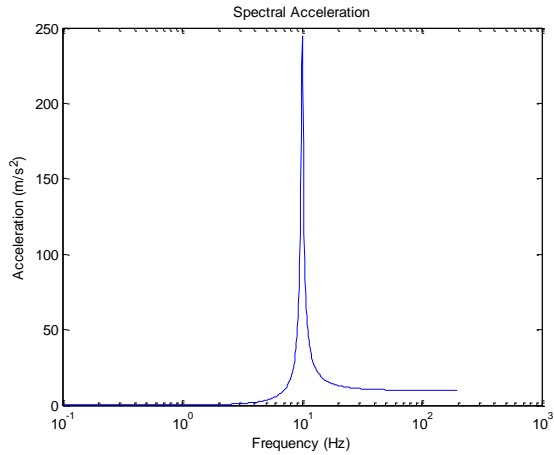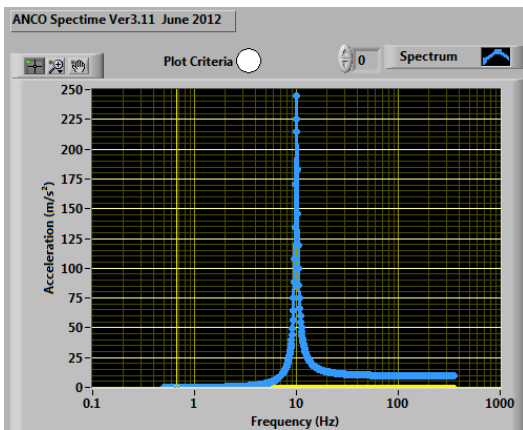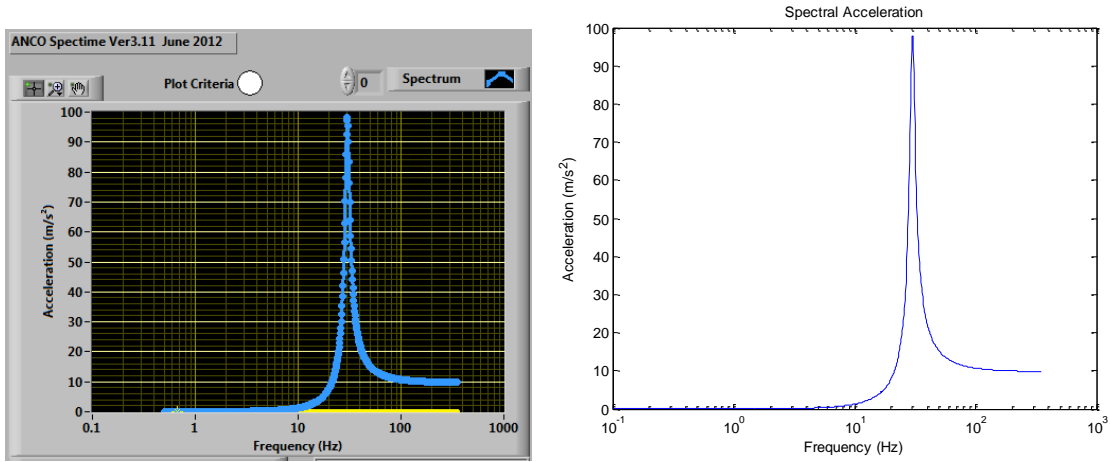

Figure 8- Acceleration Response Spectrum for a 30Hz, 1G, 30s Sine Wave at 2% Damping in (a) ANCO DANCE and (b) MATLAB
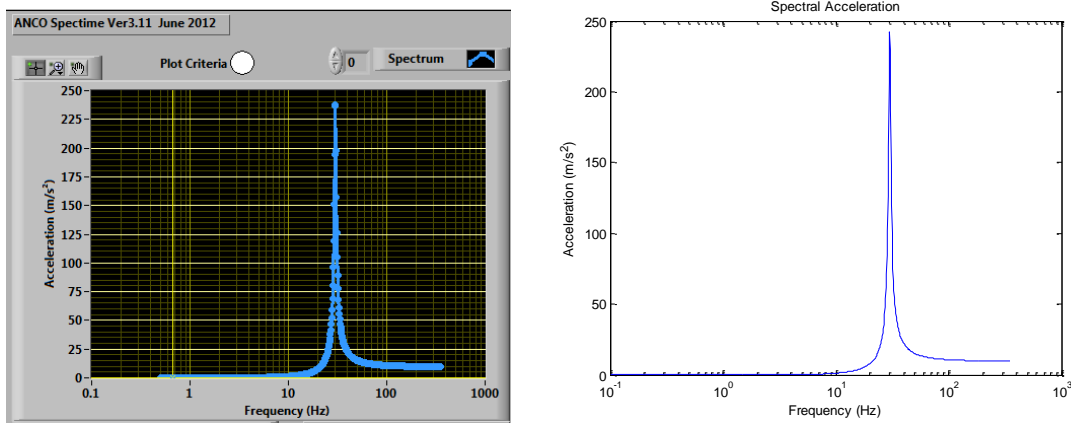
Figure 9- Acceleration Response Spectrum for a Reference Earthquake at 5% Damping in (a) ANCO DANCE and (b) MATLAB
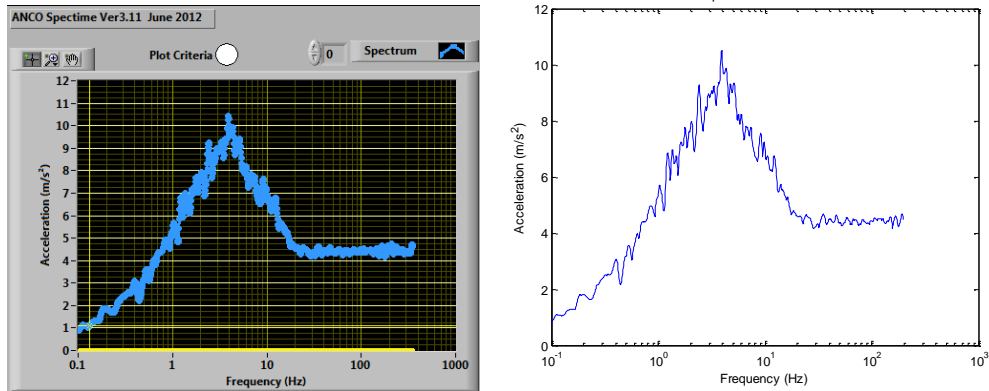
Figure 10 - Acceleration Response Spectrum for a Reference Earthquake at 2% Damping in (a) ANCO DANCE and (b) MATLAB
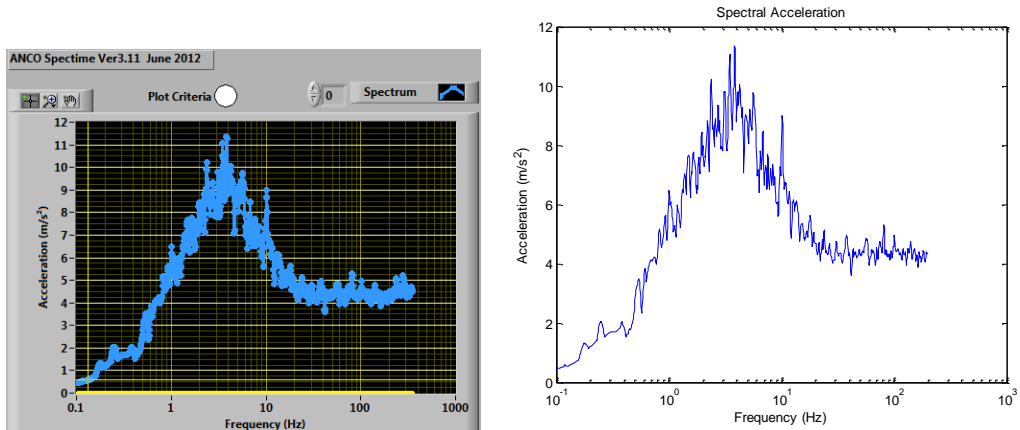
For a sine wave response spectrum there are several general checks that can be done to show that the critical values are correct.

1. The ZPA should be the same as the amplitude of the sine wave input.
2. The amplitude of the peak of the response spectrum should be equal to ZPA*1/(2β).
3. The peak response in the response spectrum should occur at the natural frequency of the input time history.

The results of these tests done in both ANCO DANCE & MATLAB are shown in Table 1.

Table 1 – Check of Critical Values

SINE WAVE	5% DAMPING				2% DAMPING			
	Peak Spectral Acceleration (m/s²)	ZPA (m/s²)	Theoretical Peak Spectral Acceleration (m/s²)	Pk Location Correct?	Peak Spectral Acceleration (m/s²)	ZPA (m/s²)	Theoretical Peak Spectral Acceleration (m/s2)	Pk Location Correct
1 Hz-MATLAB	98.4105	9.81020	98.1020	x	227.794	9.81020	245.255	x
1 Hz-DANCE	98.4105	9.81020	98.1020	x	227.794	9.81020	245.255	x
3 Hz-MATLAB	98.6968	9.81177	98.1177	x	244.823	9.81177	245.294	x
3 Hz-DANCE	98.6968	9.81177	98.1177	x	244.823	9.81177	245.294	x
10 Hz-MATLAB	98.6297	9.82976	98.2976	x	244.662	9.82978	245.745	x
10 Hz-DANCE	98.6297	9.82976	98.2976	x	244.662	9.82978	245.745	x
30 Hz-MATLAB	97.7910	9.83022	98.3022	x	242.242	9.83019	245.755	x
30 Hz-DANCE	97.7910	9.83022	98.3022	x	242.242	9.83019	245.755	x
EQ MATLAB	10.4944	4.46048			11.351	4.37986		
EQ Dance	10.4504	4.43372			11.348	4.38272		

These checks show that the critical values are correctly calculated by both programs. Different methods of response spectrum analysis may result in different values in between these critical values. Factors affecting these differences are the assumptions made about interpolation between the time steps. Therefore, smaller time steps will result in more similar results. To show how close the results are between the two programs throughout the response spectra, the spectral accelerations are shown at 1, 3, 10, and 30 Hz (see Table 2), chosen to encapsulate the shape of the required response spectra.

Table 2 – Spectral Acceleration at Specified Frequencies from Each Program

SINE WAVE	Sa(m/s^2) RESULTS AT SPECIFIED f [Hz] (5% DAMPING)				Sa(m/s^2) RESULTS AT SPECIFIED f [Hz] (2% DAMPING)			
	1 Hz	3 Hz	10 Hz	30 Hz	1 Hz	3 Hz	10 Hz	30 Hz
1 Hz-MATLAB	98.4105	11.0349	9.91155	9.82098	227.216	11.0350	9.91329	9.82118
1 Hz-DANCE	98.4105	11.0349	9.91155	9.82098	227.216	11.035	9.91329	9.82118
3 Hz-MATLAB	1.31586	98.6968	10.7769	9.90974	1.26511	244.82273	10.7844	9.91032
3 Hz-DANCE	1.31586	98.6968	10.7769	9.90974	1.26512	244.82273	10.7844	9.91032
10 Hz-MATLAB	0.141862	1.03087	98.6297	11.0352	0.108280	0.987535	244.662	11.0367
10 Hz-DANCE	0.141862	1.03087	98.6297	11.0352	0.108280	0.987535	244.662	11.0367
30 Hz-MATLAB	0.034646	0.140167	1.27874	97.7910	0.017189	0.106836	1.23688	242.242
30 Hz-DANCE	0.034646	0.140167	1.27874	97.7910	0.017189	0.106836	1.23688	242.242
EQ MATLAB	5.39967	8.90509	6.93887	4.25539	6.47436	7.80123	8.63348	4.35619
EQ Dance	5.35560	8.94910	6.91274	4.25393	6.47156	7.80409	8.63062	4.35905

Table 3 shows the percent difference between the results from the two programs at the same time step for each sign wave and the earthquake and at 5% and 2% damping.

	% DIFFERENCE AT SPECIFIED f [Hz] (5% DAMPING)				% DIFFERENCE AT SPECIFIED f [Hz] (2% DAMPING)			
	1 Hz	3 Hz	10 Hz	30 Hz	1 Hz	3 Hz	10 Hz	30 Hz
1 Hz	0.000000	-0.000004	0.000002	-0.000004	0.000000	0.000002	0.000004	-0.000004
3 Hz	0.000006	0.000000	-0.000001	0.000000	-0.000030	0.000000	-0.000004	0.000003
10 Hz	-0.000263	0.000046	0.000000	0.000002	-0.000098	0.000036	0.000000	0.000003
30 Hz	0.000776	-0.000235	-0.000022	0.000000	0.002806	-0.000312	-0.000025	0.000000
EQ	0.819555	-0.492986	0.377355	0.034260	0.043314	-0.036645	0.033146	-0.065671

Table 3 – Percent Difference between Spectral Accelerations from Each Program Under Same Initial Conditions

The percent difference shows very close agreement between ANCO DANCE Spectime and the MATLAB program. At the frequencies chosen the percent difference ranges from 0.00% to 0.8196% with the percent's calculated out to 6 decimal places. Less than 1% difference shows that the programs are precise and comparison to the theoretical mathematical values shows they are both accurate. Since the earthquake time step is very small, most methods will result in very precise results unless the assumptions greatly differ.

Software Note: The purpose of this study is to VV the ability of DANCE to correctly compute RS. DANCE is a collection of programs which include a module called DANCE and a module called SPECTIME. Both DANCE and SPECTIME use the same ANCO generated sub-module to compute the RS. For ease of computation this study used the SPECTIME module to compute the RS and provide the plots presented. This is why the graphs are labeled as coming from SPECTIME. But the exact same sub-module is used for both SECTIME and DANCE and so the results will be identical.