



Help Page for the Java-Powered Simulation for Experimental Structural Dynamics



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Document created by Sung-Han Sim

Introduction

Welcome to the help page of the Java-Powered Simulation for Experimental Structural Dynamics.

Many principles in structural dynamics are best illustrated in the laboratory, collecting and processing data to extract the basic features of the structure. The purpose of this tool is to simulate the laboratory environment providing a Virtual Laboratory (VL). This VL utilizes a multi-story shear building model as the test bed and provides essential features of the experiment such as sensors, noise, anti-aliasing filter, finite time windows, etc. With the user-defined parameters for the virtual experiment, the VL calculates the structures responses through the linear/nonlinear dynamics analysis. Results from these analyses give users unique insight into the dynamic behavior of the structure from the response measurement point of view.

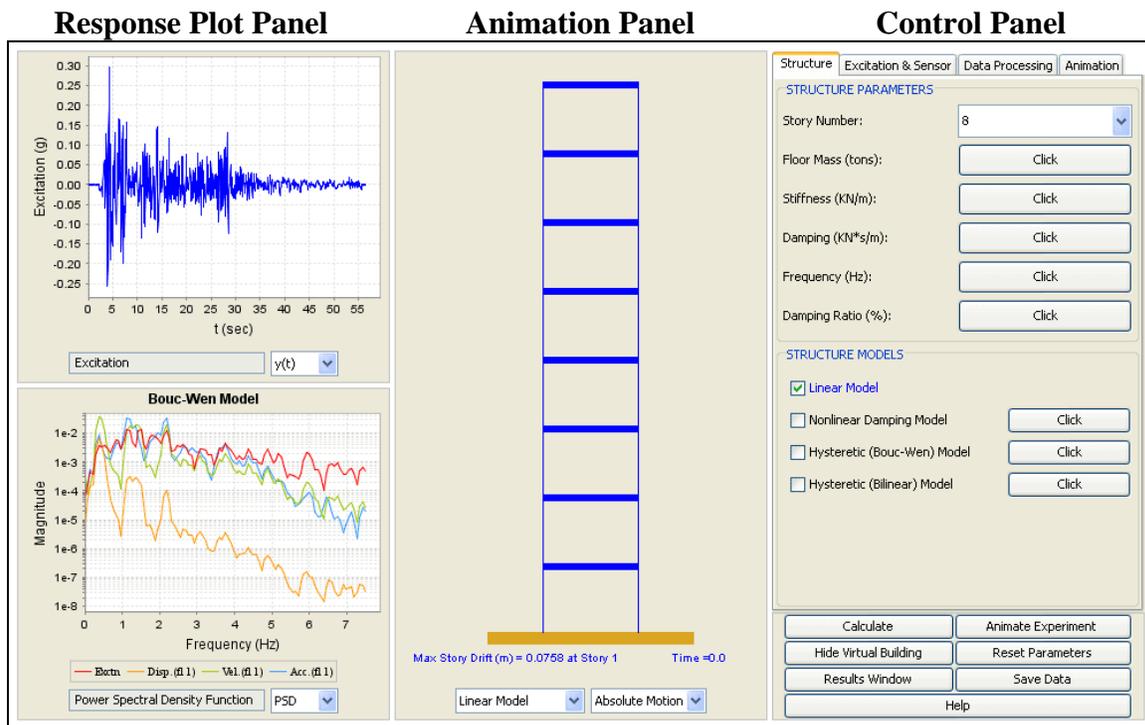
The VL supports two types of parameters which are allowed for users to set up. The parameters for structure includes story number, mass, stiffness, damping, yield displacement, and post-yield stiffness. These parameters are located at the top of the control panel as shown in Figure 1. The other parameters for the experiment are found in the middle of the control panel. A total 8 kinds of excitation is provided and noise level of the excitation is adjustable from 0% to 5%. The sensor location and type can be determined by the user. There are 6 types of sensors available which are displacement, velocity, acceleration, spring force, shear force and damping force sensors. The anti-aliasing (AA) filter is also available and the cutoff

frequency of the AA filter is changeable by the user. There are other parameters related to the FFT calculation such as the number off FFT and average, overlap and windowing.

The VL provides useful buttons which can be found at the bottom of the control panel. The VL displays an animation based on the building response, which gives users a better understanding of dynamic analysis. In addition, the user can save all data by clicking the Save Data button.

To portray the structure, four models are used, which include (a) linear stiffness and linear viscous damping; (b) linear stiffness and nonlinear power-law damping; (c) hysteretic stiffness using the Bouc-Wen model and linear viscous damping; and (d) hysteretic bilinear stiffness and linear viscous damping.

This document offers a description of how to operate and use the Java-Powered Simulation for Experimental Structural Dynamics as well some technical background. A number of "homework" problems (or exercises) are also suggested and references are provided.



Response Plot Panel

Figure 1. Java-Powered Simulation Applet

How to Use the Virtual Laboratory

The user interface of the VL is shown in Figure 1. The program interface consists of (1) control panel, (2) animation panel, and (3) four response plot panels. Note that users can toggle between two response plot panels and the animation panel by clicking Hide Virtual Building or Show Virtual Building button of the control panel.

Control Panel

Located on the right of the simulator, this panel is used to specify various parameters for the structure, ground excitations and data processing. This panel also contains buttons to conduct computation and animation.

Structural Parameters

- Story Number: total number of stories. (The default value is 8.)
- Floor Mass: The mass of each floor. Clicking the button, a dialogue box will pop up, in which users can specify the mass of each floor. (The default mass of each floor is 8 tons.)
- Stiffness: linear stiffness for each story. (The default value is 2000 kN/m.)
- Damping: viscous damping coefficient for each story. (The default value is 10.0 kN*s/m.)
- Frequency: natural frequencies associated with the structural parameters. These values will be updated automatically if structural parameters are changed.
- Damping Ratio: damping ratio associated with the structural parameters. These values will be updated automatically if structural parameters are changed.

The screenshot shows a software interface with four tabs: Structure, Excitation & Sensor, Data Processing, and Animation. The 'Structure' tab is active, displaying 'STRUCTURE PARAMETERS' and 'STRUCTURE MODELS' sections.

STRUCTURE PARAMETERS

- Story Number: 8 (dropdown menu)
- Floor Mass (tons): Click
- Stiffness (kN/m): Click
- Damping (kN*s/m): Click
- Frequency (Hz): Click
- Damping Ratio (%): Click

STRUCTURE MODELS

- Linear Model
- Nonlinear Damping Model (Click)
- Hysteretic (Bouc-Wen) Model (Click)
- Hysteretic (Bilinear) Model (Click)

At the bottom, there are buttons for: Calculate, Animate Experiment, Hide Virtual Building, Reset Parameters, Results Window, Save Data, and Help.

Figure 2. Control Panel

Structure Models

- Structure Models: checking one or more checkboxes leads to display corresponding responses on the response plot panel.
- Involution Coefficient: parameters associated with the nonlinear damping model. By clicking the button at the right of the Nonlinear Damping Model, a dialogue box will be open allowing users to change these coefficients. The default value is 0.5.
- Yield Displacement and Post-yield Stiffness: these parameters are used in the Bouc-Wen model and bilinear model. The defaults values are 0.02m and 1000KN/m, respectively.

Excitation and Sensors

- Excitation: This drop-down menu allows users to select a ground excitation among band-limited white noise, impulse, sinusoidal, chirp, and 4 historical earthquake excitations. The default excitation is the N-S component of the 1940 El-Centro earthquake.
- Time Step: time step of the ground excitation. This value for the historical earthquake data is 0.02sec. Otherwise the time step is 0.25 times of the sampling time.
- Sensor Type and Location: clicking the button, a dialogue box will pop up, in which users can change sensor type and location. Total number of sensors is limited as it is in real experiments. Furthermore, it also prevents the large number of sensors from causing Out-of-memory problem. The maximum number of sensors is 8.

Data Processing

- AA Filter: users can choose to turn on or turn off the anti-aliasing filter. Changing this value will immediately affect the response plot panels. By turning off the AA filter, the unfiltered excitation or responses will be used to plot within the range between 0 Hz to the Nyquist frequency (half of the sampling frequency).
- Cutoff Frequency: cutoff frequency of the AA filter. Since the sampling time is related to the cutoff frequency, users may want to change the cutoff frequency to select other values of sampling time. (The default value is 7.5Hz.)
- Sampling Time: Time step of sampling. This value is 2.56 times of the cutoff frequency and will be automatically updated if cutoff frequency of the AA filter changes. Even though the AA filter is turned off, the sampling time is determined by the cutoff frequency of the AA filter.
- # of FFT: number of data points in the FFT calculation. (The default value is 256.)
- # of Averages: number of average of each data defined by the number of FFT. The total simulation times for non-earthquake excitations are determined by overlap, the number of FFT and Average. Thus, this option is not available for earthquake data since durations of them are already decided. Large number of FFT or average results in long simulation time. (The default value is 5.)

- **Overlap:** portion of overlap used in the calculation of the auto and cross spectral density functions. Since windowing discards the relevant information at the beginning and end of the data, overlapping is introduced to reduce the variance of the resulting spectral estimates. (The default value is 50%.)
- **Windowing:** windows used in the FFT calculation. To minimize the spectral leakage, it is common to use a time window that eliminates the discontinuities at the beginning and end of a time history. Three windows are provided; Hanning, Hamming, and Boxcar.
- **Response Window:** width of the response frames (in seconds) during the animation. (The default is 6.0 seconds.)

Action Buttons

- **Calculate:** conduct calculation.
- **Reset Parameters:** reset all the parameters to their default values.
- **Animate:** start/stop animation in the response plot panels as well as the animation panel.
- **Results Window:** clicking this button, a results window will pop up and display important analysis results after each computation.
- **Show Virtual Model:** by clicking this button, the response plot panels and animation panel are interchanged with each other.
- **Save Data:** open a dialog in which users can save all data computed during the simulation.
- **Help:** open the Help Page, which is the page you are looking at.

Animation Panel

Located in the middle of the simulator, the animation panel shows a simulation of the structural system undergoing the excitation. One of the 4 models, linear model, nonlinear damping model, Bouc-Wen model, and bilinear model, may be selected by users to define the property of the building, thus its dynamic behavior. Users are also able to choose to animate absolute or relative motion of the structure:

- **Absolute Motion** displays the response of the structure from an inertial reference frame. Thus, the ground is seen moving.
- **Relative Motion** displays the response of the structure from a reference frame attached to the ground.

Response Plot Panel

There are four response plot panels, two of which are located on the right of the simulator and the other two are hidden under the animation panel. These two hidden panels and the animation panel are interchangeable by clicking Hide Virtual Building or Show Virtual Building button of the control panel.

Measured responses and various functions related to spectral analysis are shown on these panels. Users can choose what they want to see by using the drop-down menu under each response plot panel, which will open response selection window . Functions which users can choose on the drop-down menu are as follows.

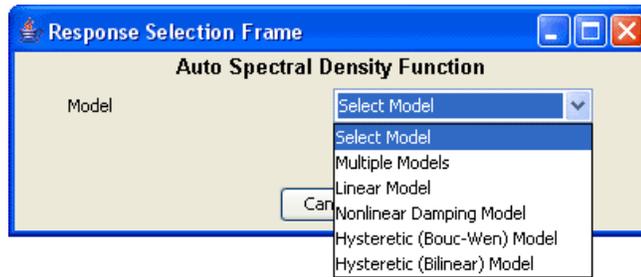
- $y(t)$: time history of the ground excitation and the corresponding measured responses
- x-y: response vs. response plot
- FFT: fast Fourier transform of the ground excitation or the measured responses
- PSD: power spectrum density function of the ground excitation or the measured responses
- CSD: cross spectral density function between the ground excitation and one measured response or between two measured responses
- Xfer: transfer function between the ground excitation and one of the measured responses or between any two of the measured responses
- ACorr: auto correlation function of the ground excitation or the measured responses
- Ccorr: cross correlation function between the ground excitation and one measured response or between two measured responses
- Cohere: coherence function between the ground excitation and the measured responses
- Impulse: impulse response of the structure at sensor locations

Response Selection Window

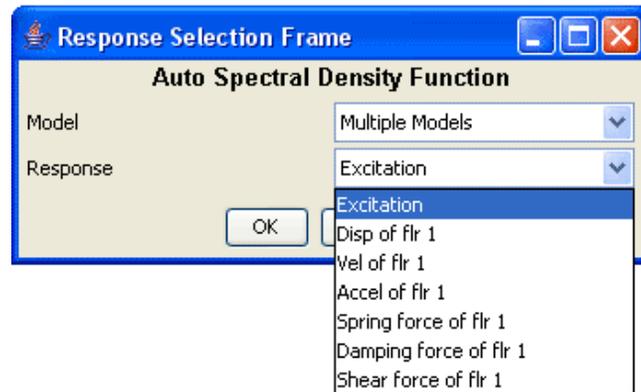
Response selection window allows users to select responses to be shown on the response plot panel. It is straightforward to plot $y(t)$, x-y, correlation functions and impulse response functions. When users select FFT, PSD, CSD, Xfer, or Cohere, a window as shown in Figure 3-(a) will pop up and change to Figure 3-(b) or (c) according to selected model.

Save Figures and Data

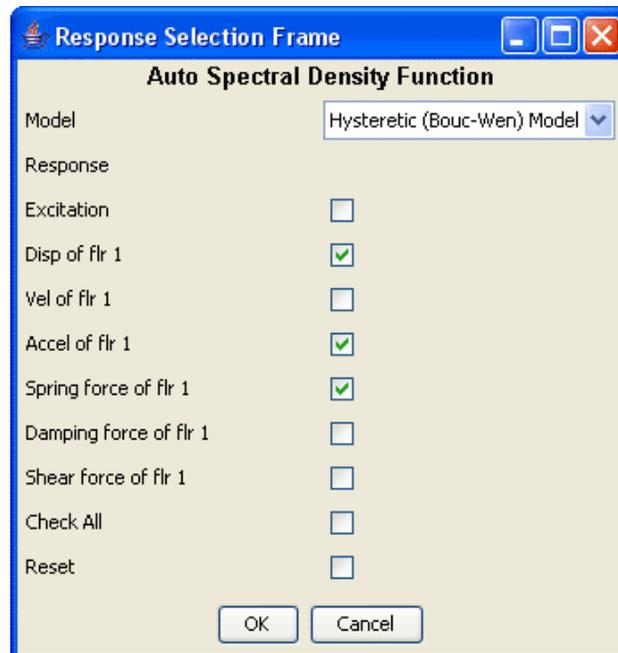
The VL supports two saving options, one for figures and the other for data. Figures shown on the response plot panels can be saved by clicking any figure except the virtual building. Figures are saved as PNG format. Users are also able to save all data by clicking the "Save Data" button on the bottom of the control panel.



(a) Model selection



(b) Multiple models



(c) A selected model

Figure 3. Response Selection Window

Technical Backgrounds

Mathematical Model

The mathematical models used in this simulator are the same as those of Java-Powered Simulation for Nonlinear Multi-Story Buildings by Yong Gao. The technical background for mathematical models is found at <http://sstl.cee.uiuc.edu/java/mdof/help/mdofstoryhelp.htm>

Definition of parameters

- N : Number of FFT
- n_d : Number of averages
- Δt : Time step

Spectral Analysis

- Fast Fourier Transform (FFT)

$$X_k = \sum_{n=0}^{N-1} x_n e^{-i \frac{2\pi kn}{N}} \quad k = 0, 1, 2, \dots, N-1$$

- Auto Spectral Density

Let the record be divided into n_d segments, each of length T . x_{in} is the i -th data value of the n -th segment.

$$X_i(f_k) = \Delta t \sum_{n=0}^{N-1} x_{in} e^{-i \frac{2\pi kn}{N}} \quad k = 0, 1, 2, \dots, N-1$$

$$S_{xx}(f_k) = \frac{1}{n_d N \Delta t} \sum_{i=1}^{n_d} |X_i(f_k)|^2 \quad k = 0, 1, 2, \dots, N-1$$

- Cross Spectral Density

$$S_{xy}(f_k) = \frac{1}{n_d N \Delta t} \sum_{i=1}^{n_d} |X_i(f_k) Y_i(f_k)|^2 \quad k = 0, 1, 2, \dots, N-1$$

- Transfer Function

$$H(f_k) = \frac{S_{xy}(f_k)}{S_{xx}(f_k)} \quad k = 0, 1, 2, \dots, N-1$$

- Auto Correlation Function

Let $\bar{S}_{xx}(f_k)$ be the two sided power spectral density.

$$R_{xx}(r\Delta t) = \frac{1}{N} \sum_{k=0}^{N-1} \bar{S}_{xx}(f_k) e^{i \frac{2\pi k r}{N}} \quad r = 0, 1, 2, \dots, N-1$$

- Cross Correlation Function

$$R_{xy}(r\Delta t) = \frac{1}{N} \sum_{k=0}^{N-1} \bar{S}_{xy}(f_k) e^{i \frac{2\pi k r}{N}} \quad r = 0, 1, 2, \dots, N-1$$

- Coherence

$$\gamma_{xy}^2(f_k) = \frac{|S_{xy}(f_k)|^2}{S_{xx}(f_k) S_{yy}(f_k)} \quad k = 0, 1, 2, \dots, N-1$$

- Impulse Response Function

$$h(r\Delta t) = \frac{1}{N} \sum_{k=0}^{N-1} H(f_k) e^{i \frac{2\pi k r}{N}} \quad r = 0, 1, 2, \dots, N-1$$

Other Definitions

- Spring Force: force related to stiffness only.
- Damping Force: force related to damping only.
- Shear Force: summation of the shear and damping force.

Homework

- For band-limited white noise of 1g, verify that the locations of peaks of the transfer functions change for the various types of nonlinear models. Explain why.
- Consider a 4-story building model with a stiffness of 20,000 kN/m for the first two floors and 15,000 kN/m for the top two floors and the VL's default mass and damping coefficients. Use a band-limited white noise excitation with a bandwidth of 15 Hz. Set the anti-aliasing (AA) filters at 5Hz. Compare the transfer functions of accelerations with the AA filter on and off.
- Conduct the following virtual experiment. Assume the ground excitation of band-limited white noise is applied to 3-story building. Use the default mass, damping and stiffness.
 - (a) For the nonlinear damping model, plot and compare the transfer functions from the input ground acceleration to the acceleration on the 3rd floor for $\alpha = 0.2, 0.5, 1.0, 1.5$. Use the default amplitude of the random excitation. (Note that α is the involution coefficient of nonlinear damping model.) What conclusions can be drawn?
 - (b) Recalculate the results for part for the case in which the amplitude of the excitation is increased by 25%. Compare these results with those in part (a). What conclusions can be drawn?
 - (c) For the linear and bilinear models, plot and compare transfer functions from the input ground acceleration to the displacement of the 1st floor for $K_p = 500, 1000, 1800$ kN/m. Use the default amplitude of the random excitation. (Note that K_p is the post-yield stiffness for the hysteretic models.) What conclusions can be drawn?
 - (d) For the linear and Bouc-Wen models, plot and compare the transfer functions from the input ground acceleration to the velocity on the second floor for random excitation of amplitude 0.1, 0.3, and 1.0. Use the default Bouc-Wen model parameters. What conclusions can be drawn?

References

- Newman A (1996): Special Edition Using Java. Que Cooperation, Indianapolis, IN.
- Bruce Eckel (2003): *Thinking in Java*. Prentice Hall.
- Julius S. Bendat, Allan G. Piersol (1991): *Random Data*. John Wiley & Sons.
- Robert Sedgewick and Kevin Wayne: *FFT.java, Complex.java*

- Tedesco JW, McDougal WG, Ross CA (1998): Structural Dynamics: Theory and Applications. Addison-Wesley.
- Belytschko T, Hughes TJ (1983): Computational Methods for Transient Analysis. North-Holland.
- Berg GV (1989): Elements of Structural Dynamics. Prentice Hall.
- Press WH, Flannery BP, Teukolsky SA, Vetterling WT (1987): Numerical Recipes: The Art of Scientific Computing. Cambridge University Press.

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