Vibration Course Enhancement through a Dynamic MATLAB® Graphic User Interface

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Abstract – From the string of a guitar to the radio wave, vibration occurs all the time and everywhere. Although vibration is an everyday phenomenon, related topics tend to be difficult for both undergraduate and graduate students. The ability to visualize motion through differential equation analysis is essential for subject comprehension. In order to help students have deeper understanding of vibration as well as inspire the interest of high school students, a MATLAB® Graphic User Interface (GUI) program has been formulated at the University of Mississippi. The GUI described herein includes the analysis of four different types of systems: single-degree-of-freedom (SDOF), multi-degree-of-freedom (MDOF), axial rod, and transverse beam. This is the only program that combines four modes of motion with interactive controls. This classroom technology has received positive feedback from students both familiar and unfamiliar with vibrations.

Keywords: GUI, SDOF, MDOF, Rod, Beam

INTRODUCTION

Prior demonstrations have been programmed to assist comprehension of different vibration cases. A Java applet for free vibration animation of a single-degree-of-freedom (SDOF) spring-mass system has been developed at the Virginia Polytechnic Institute and State University. As provided in Dr. Jing Li's website, the closed form solution is used to plot the motion of the mass. The advantage of this system is that it can be included in HTML page, but a disadvantage is that the animation shows outside frame when a relatively large initial displacement or velocity is given to the program [5]. At the University of Illinois at Urbana-Champaign a Virtual Laboratory for Earthquake Engineering project has been constructed by the Smart Structure Technology Laboratory. Six different virtual experiments are available on the website; Options are offered in these programs for performing diverse cases study, but its main shortcoming is that the program strictly covers a two-degree of freedom system [4]. Another educational website is the Live Shake Table Experiment, or 'Webshaker', provided by the Network for Earthquake Engineering Simulation Cyberinfrastructure Center (NEESit). This program allows users to set up their own experiments online and watch the resultant deflection via live video. The site is designed for demonstration only as the experiment types are quite limited [1, 3]. At the University of Seville in Spain a MATLAB® Graphic User Interface (GUI) has been developed for the demonstration of lateral vehicle dynamics. The bicycle model with two degrees of freedom can test different vehicles but lacks animation of the motion [2].

Although vibration is an everyday phenomenon, related topics tend to be difficult for both undergraduate and graduate students. The ability to visualize motion through differential equation analysis is essential for subject comprehension. In order to help students have deeper understanding of vibration, a MATLAB® GUI program has been formulated at the University of Mississippi. This is the only program that combines four modes of motion with interactive controls. As MathWorks MATLAB® is commonly used in the engineering field, any exercise that has students using this program is helpful for their professional education. A GUI provides high-technology interactive demonstration tools that can aid learning. Setup requirements include appropriate software packages and knowledgeable programmers, but novice users can operate the GUI. Named GUIde, the MATLAB® package also provides the display framework for GUI construction [6].

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INTERFACE AND EXAMPLE PROBLEMS

The GUI program simulates four different types of systems: SDOF, multi-degree-of-freedom (MDOF), axial rod, and transverse beam. Each vibratory system will be detailed in the next four subsections.
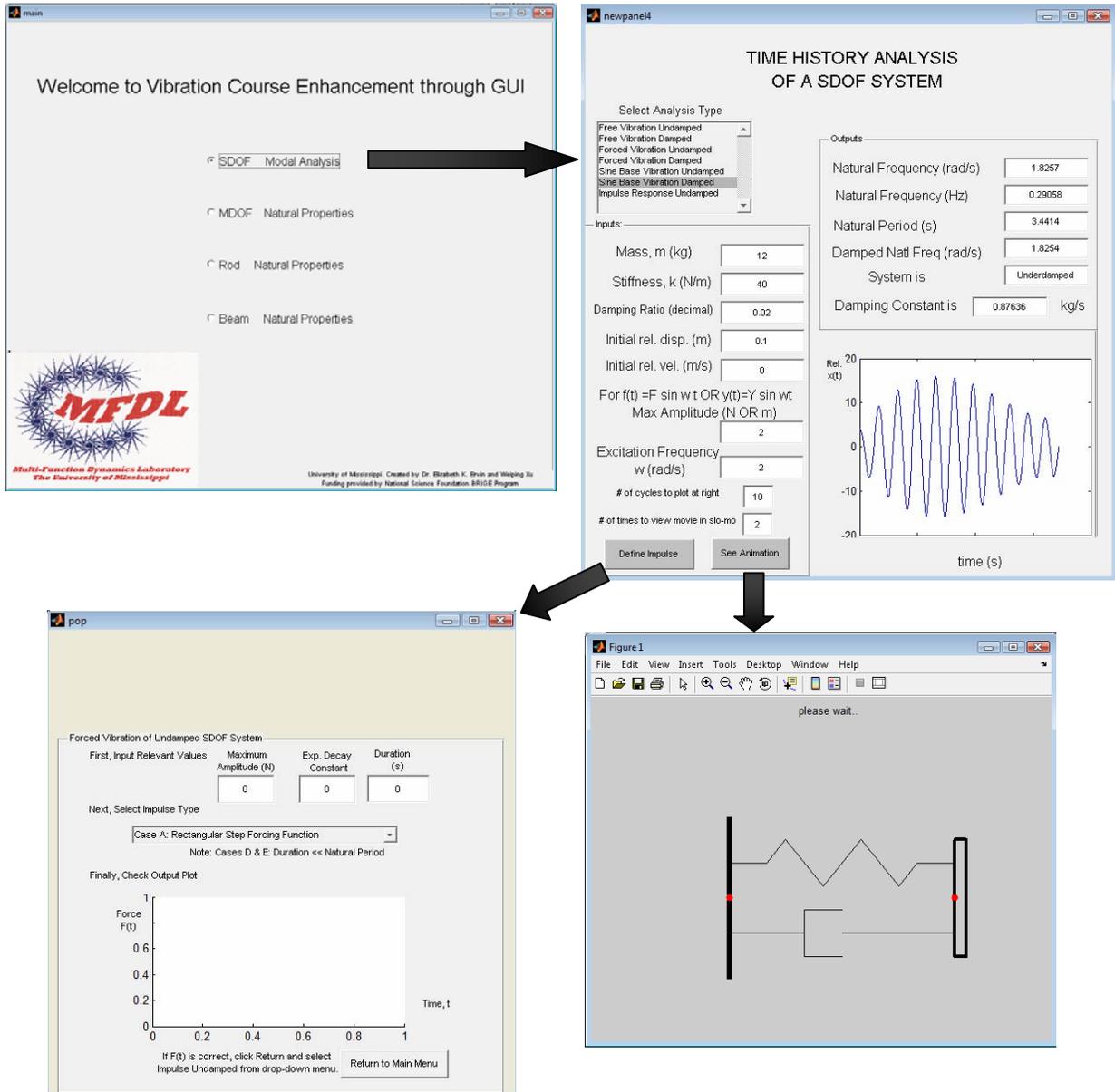

Figure 1. Interface flowchart for SDOF simulation and Example 1.

SDOF Modal Analysis

Seven different single-degree-of-freedom cases can be analyzed using the GUI. The seven cases are undamped and damped free vibration; undamped and damped forced vibration; undamped and damped sinusoidal base vibration; and undamped impulse response.

The required inputs are the mass, stiffness, and damping ratio of the system. All quantities in the GUI are in the International System of Units. Initial relative displacement and initial relative velocity can also be user-defined. For harmonic excitation, a sinusoidal base excitation with changeable maximum amplitude and frequency can be characterized. The number of cycles shown in the on-screen plot and the number of times to view the movie can also be set by the user. A variety of impulses can be defined from another popup window. The impulse options include rectangular step forcing function, linear forcing function, exponential decaying forcing function, short rectangular impulse, and short half-sine pulse. After providing a maximum amplitude, decay constant, and time duration, the impulse is plotted on-screen.

The calculated outputs are the natural frequency (in both radians per second and Hertz), natural period, damped natural frequency, and damping constant. The system is classified as over-damped, under-damped, and critically-damped, and the time history of the relative response is automatically plotted to the screen with any parameter change. The most inventive feature is a button-activated animation which shows the actual spring-mass-dashpot system in motion.

Example 1: Damped sinusoidal base vibration.

Input parameters include a mass of 12 kilograms, a stiffness of 40 Newtons per meter, a damping ratio of 2%, an initial displacement of 0.1 meter, and no initial velocity. The maximum amplitude of the base excitation is 2 meters and the frequency is 2 radians per second, so that $y(t) = 2 \sin (2t)$. Using ten cycles, the resulting relative response will be shown automatically. By clicking the "See Animation" button, the movie will show in a pop-up window as in Figure 1. As this system has motion of both the base and the mass, each red point will move. The spring and damper will expand and contract during motion.

MDOF Natural Properties

As shown in Figure 2, the degrees of freedom are set by the user. Two input vectors are needed for the system: the stiffness vector and the mass vector.

The first three natural frequencies are calculated, and the user may input the number of the mode which he/she wishes to animate.

Example 2: A four-degree-of-freedom system.

Input parameters contain a stiffness vector of 123, 145, 156, and 145 Newtons per meter, and a mass vector of 12, 12, 12, and 12 kilograms. By clicking the "Get Frequencies" button, the first three frequencies are calculated as in Figure 2. In the animation, four red dots are used to represent the four masses in this system. The springs will again expand and contract based the simulated mode during motion.
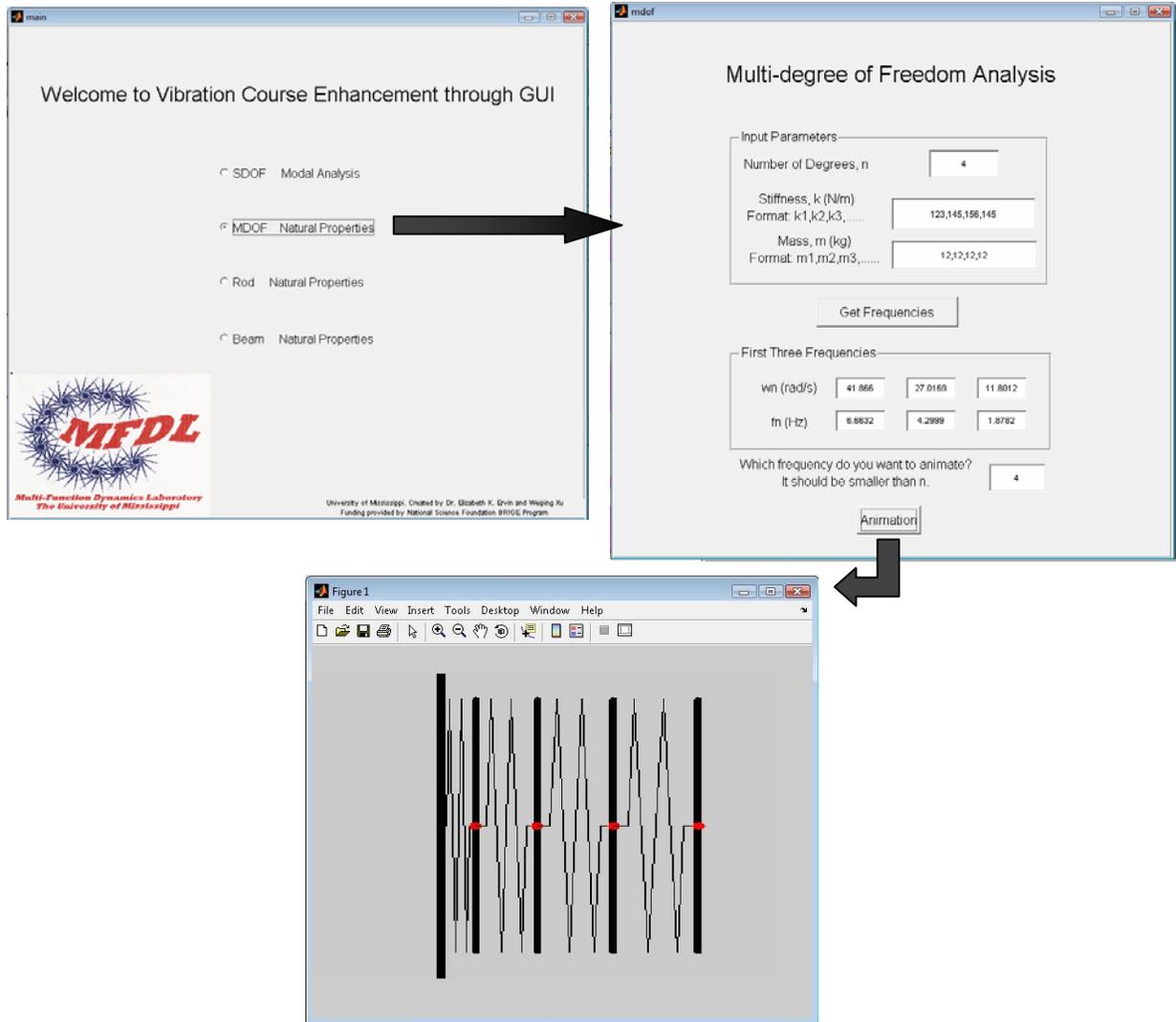
Figure 2. Interface flowchart for MDOF simulation and Example 2.

Rod Natural Properties

For the second-order rod simulation, the three different boundary conditions are Free-Free, Fixed-Fixed and Fixed-Free. The five input parameters for this analysis are the length, width, height, elastic modulus, and density of the specimen.

Again, the first three natural frequencies are calculated, and the user can select the mode to animate as well.

Example 3: A rod with Free-Free boundary conditions.

Input parameters include a elastic modulus of 200 GigaPascals, a density of 7900 kilograms per cubic meter, a width of 0.02 meter, a height of 0.01 meter, and a length of 0.5 meter. The first three natural frequencies are obtained by clicking the "Get Frequencies" button. In the animation, eight different colored points are employed to visualize the axial motion of this system.
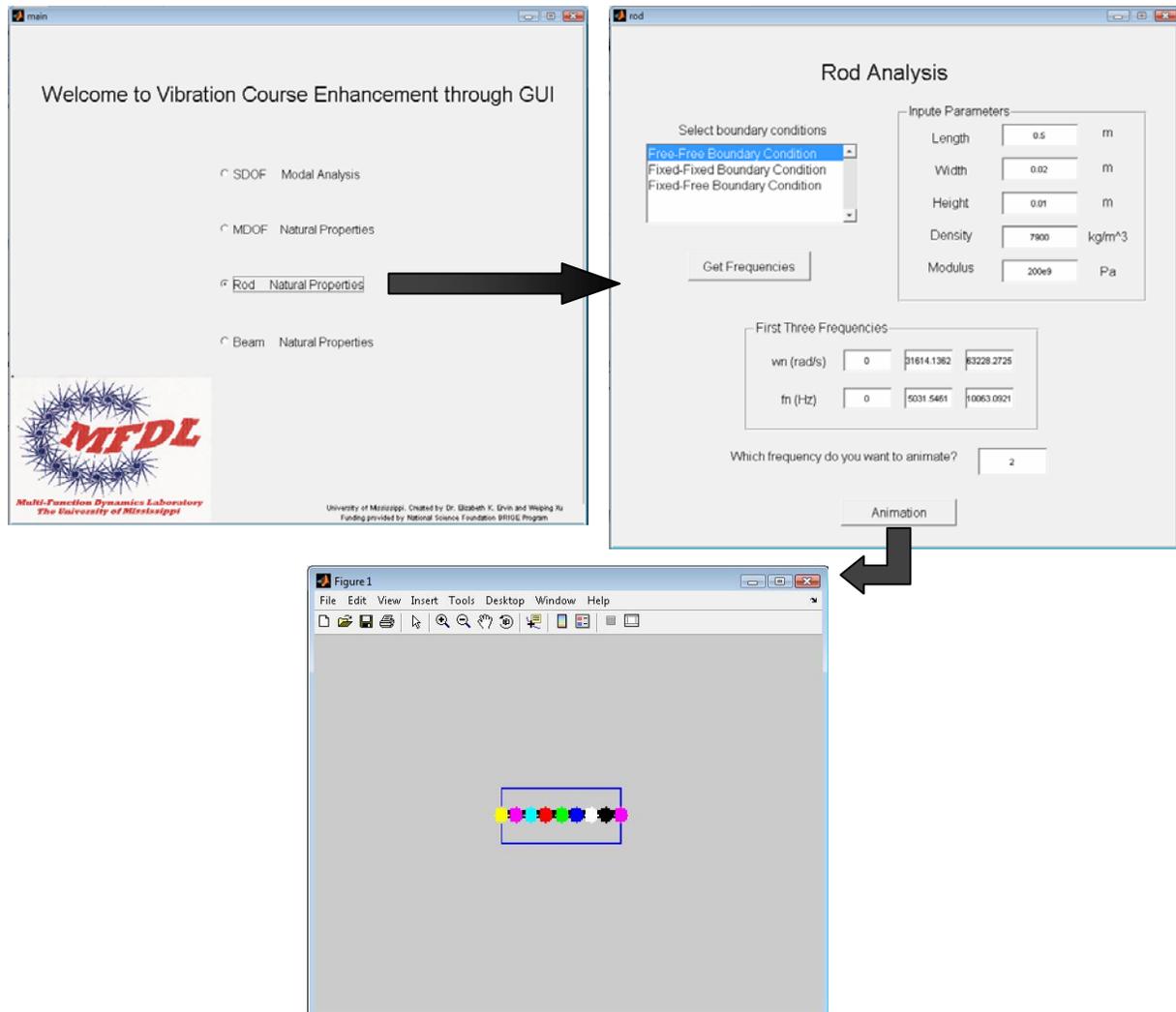
Figure 3. Interface flowchart for Rod system and Example 3.

Beam Natural Properties

For the fourth-order beam simulation, six boundary conditions can be formed: Pinned-Pinned, Free-Free, Fixed-Fixed, Fixed-Free, Fixed-Pinned, and Pinned-Free. Input parameters include the beam's length, width, height, density, and elastic modulus.

The first four natural frequencies are calculated, and the mode shape for each is shown in different colors. The animations for these four modes are available by clicking separate buttons. No higher modes are included due to computational limitations.

Example 4: A Fixed-Free beam.

Input parameters incorporate a length of 0.5 meter, a width of 0.01 meter, a height of 0.02 meter, a density of 7900 kilograms per cubic meter, and an elastic modulus of 200 GigaPascals. The first four natural frequencies are calculated by clicking the "Get Results" button, and the four associated mode shapes are shown in different colors. The animation for each mode can also be viewed by clicking the appropriate button.
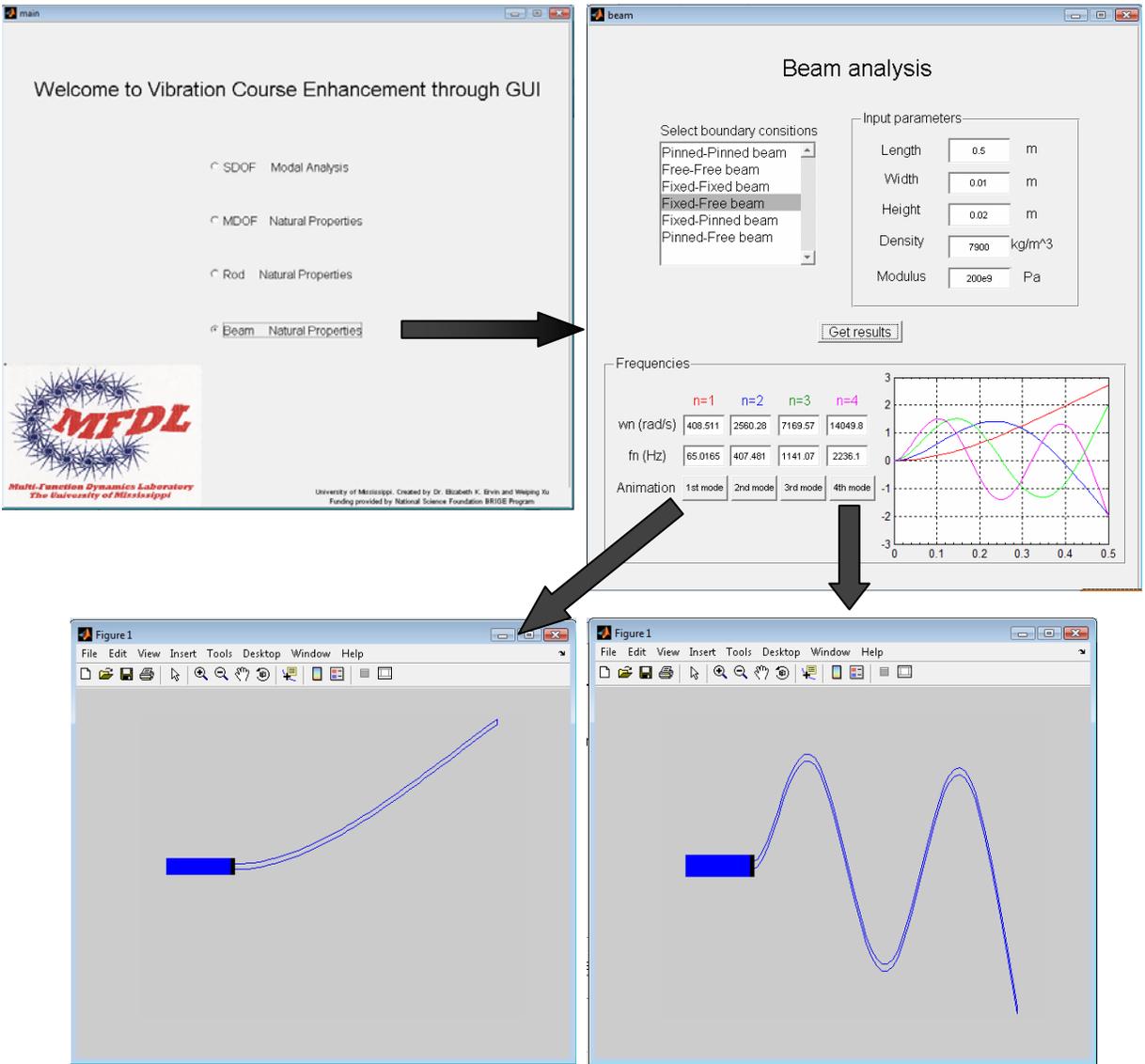
Figure 4. Interface flowchart for Beam system and Example 4.

ASSESSMENT

In spring 2008, the SDOF portion of the MATLAB® GUI was written to aid University of Mississippi students in understanding fundamental structural dynamics issues through the technical elective of Civil Engineering Structural Analysis II (CE 511). Held jointly with Special Topics in Engineering Science (ENGR 699-21), this course focused on structural dynamics, including SDOF systems, MDOF systems, and introductory continuous systems. The total student population was 3 civil engineering undergraduate seniors, 4 mechanical engineering graduate students, and 3 mechanical engineering graduate students. Program demonstrations were shown in class, and homework activities required each student to open MATLAB® and run the GUI.

Indirect survey assessments were used to evaluate the educational effectiveness of the computer simulation. A diagnostic survey showed that less than 50% students were familiar with either MATLAB® or SDOF vibratory systems. As no undergraduate vibrations course is required at the University of Mississippi, unfamiliarity with simple vibrations is expected. However, MathWorks MATLAB® is a widely used programming tool for engineers, and some introduction to this program was expected. Among the graduate students, the average rating was 4.35 on a

scale of 0 to 10 where 0 represents "I have no idea what you are talking about" and 10 represents "I am a confident user."

A survey at the course's conclusion showed that 90% of the students agreed or strongly agreed that they better understand structures as a result of this course. 90% of the students also agreed or strongly agreed that they better understand SDOF systems as a result of the MATLAB® GUI. On a scale of 0 to 4, the response average was 3.5, where 3 is "Agree" and 4 is "Strongly Agree." The single student that was unable to agree admitted that he did not even open the program. Furthermore, 40% of the students agreed or strongly agreed that they better understand MDOF and continuous systems as a result of the MATLAB® GUI. This result was a pleasant surprise as the program only included SDOF systems at this time and thus was not directly applicable to higher order systems. Using the lecture with the program's understanding, the students were fairly successful at making the advanced concept connection. 80% of the students stated that they are now more familiar with modern calculation programs, including MATLAB®. Student comments ranged from "The GUI is good as it is." and "It helped me a lot to understand dynamic motion." to "It would be neat for you to click an icon and open it up [rather than loading MATLAB]."

CONCLUDING REMARKS

Preliminary assessment thus far shows that the program aids dynamics comprehension for both inexperienced and experienced users. For those with little or no understanding of vibrations, the GUI can provide informative animations with interactive options. Although controlled by differential equations of motion, the visible system can be understood without mathematics. For students with some vibration knowledge, the GUI can visualize derived equations to provide deeper command of the material. The relationship between SDOF systems and continuous systems can also be illuminated for both undergraduate and graduate students.

Future plans include larger distribution of the GUI; to post online, conversion to a programming language is required. Despite a few remaining glitches, the program will be expanded to include further modal analysis.

ACKNOWLEDGEMENT

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AUTHOR BIOGRAPHIES

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