ASEE 2022 ANNUAL CONFERENCE
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MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #36994

Using Shaking Table Experiments for Material Characterization and Vibration Analysis (WIP)

Ahmad Fayed (Dr.)

Assistant Professor of Engineering Technology, Southeastern Louisiana University. Ph.D. in Mechanical Engineering

Genesis Alegria Aguilar

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Abstract

In a multidisciplinary Engineering Technology (ET) program with 5 different concentrations, it is not possible to cover the detailed theory and applications of all high-level classes. For this reason, many educational projects are aimed to give students the opportunity to acquire this high-level knowledge through a hands-on practice. At the end of these projects, students conclude their experience and prepare a student manual that, later on, guides other groups in getting the same knowledge through hands-on experience. This initiative is applied through some senior design projects within the Engineering Technology program. In this paper, a shaking table is used to learn the concepts of (1) vibration analysis, (2) vibration absorber design (that is usually covered in Mechanical Vibration class which is not currently offered at our ET program), and (3) elastic material property evaluation of metals and non-metals (including 3D printed parts) through experiments. A Shake Table II, made by QUANSER, a MakerBot Replicator+ 3D printer, two 352C33 accelerometers, and a 2-channel ICP signal conditioner, are used in these experiments. Structures made from different metals and 3D printed materials are designed and built to simulate Single Degree of Freedom (SDOF) parameters and dynamic behavior. Vibration absorber are designed and tested through experimentations. Elastic properties such as Young's Modulus, equivalent spring stiffness, and natural frequencies are evaluated through different experiments. The wok is documented and experiment manuals are generated. This is a leading effort in creating learning modules for subsequent students to learn by experiments which can be added as a lab module in upper level classes.

Objectives

The main objective was to educate the Engineering Technology (ET) undergraduate students about Vibration Analysis and perform relevant research. Shaking Table II, two accelerometers, and data acquisition kit were used to serve this purpose. Figure 1 and Figure 2 show the details of the equipment and data acquisition kit. The used accelerometer allows the analysis of several vibration conditions with measurement of RMS or Peak Vibration Readings over wide range of frequencies, measurement of acceleration up to 490 m/sec^2, with sensitivity of 10.2 mV/(m/s^2).

Methodology

A team of three undergraduate students enrolled in ET494 (the Senior Design II) was assigned to this project. The team use performed three major types of experiments for different settings and materials. The experiments ranged from simulation of a simple system to analyzing the output of the system under different conditions including the addition of a vibration absorber.

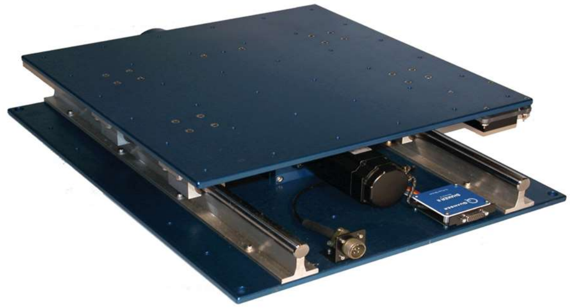


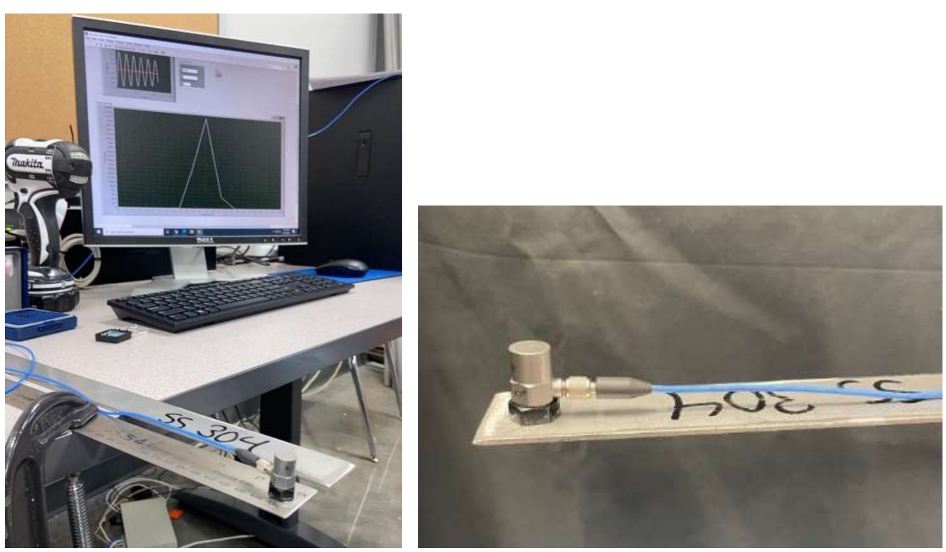
Figure 1 Quanser Shake Table II

(a) (b) (c)

Figure 2 Accelerometer and data acquisition kit (a) Signal Conditioner, (b) accelerometer, (c) Coaxial cable

1. First set of Experiments

The first set of experiments were to estimate the elastic properties of three different materials, namely Steel, Aluminum, and 3D printed Polylactic acid (PLA). This was done by giving a cantilever bar made of each material an initial displacement and measuring the frequency of the resulting oscillation using an accelerometer, Figure 3. A custom LabVIEW Virtual Instrument (VI) was built to acquire the accelerometer reading through the data acquisition system. The frequency read by accelerometer could be identified by passing its signal through an FFT VI as seen in Figure 4.



(a) (b)

Figure 3 First Experiment (a) Steel bar, (b) Aluminum bar.

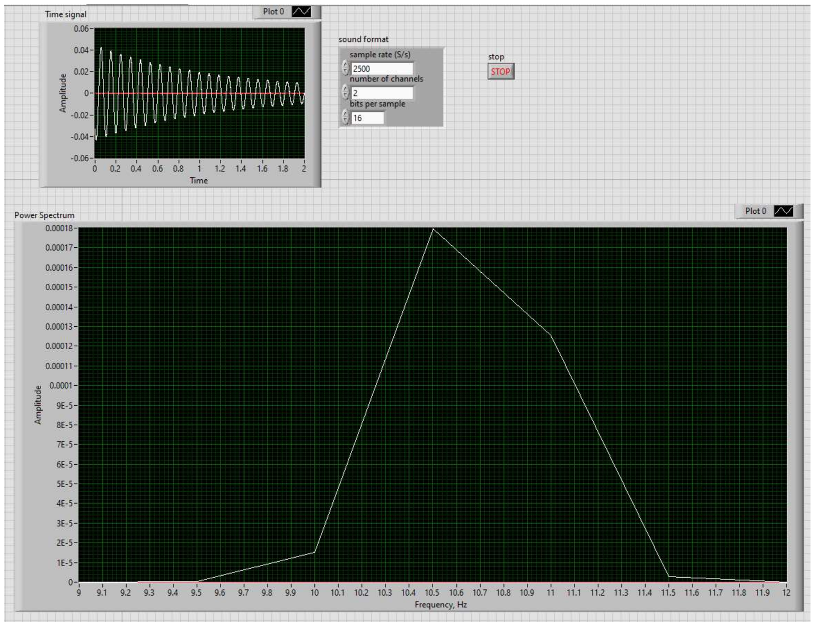


Figure 4 Sample Front Panel of a LabVIEW VI to read the natural frequency.

The accelerometer then reads the acceleration and frequency and sends them to LabVIEW software, Figure 4, through the signal conditioner/Data acquisition modules and the BNC coaxial cable. Assuming that the three bars oscillate in completely elastic mode with no damping, the measured frequencies are corresponding to the natural frequency of each of the bars. The equivalent lumped mass of each bar was calculated and used in the natural frequency formula along with the measured natural frequency to find the equivalent spring stiffness, k, of each bar. The deflection formula for a cantilever bar along with Hook’s law were then solved together to find the modulus of elasticity, E, of each material.

2. Second set of Experiments

The second sets of experiments were to use the accelerometer, data acquisition kit with Shake Table II to study the vibration effects and design a vibration absorber for three Single Degree of Freedom (SDOF) structures, Figure 5. The structures were made with elastic bars (acting as springs) made from the three aforementioned materials, Figure 6 and Figure 7, and were subjected to two different inputs. The first input was in a form of initial displacement/excitation and the second input was a sinusoidal sweep input, ranging from 0 to 20 Hz, generated by the Shake Table through the control VI, Figure 8. The frequency of the oscillations (output) resulting from the first input, which corresponds to the natural frequency of the SDOF, was measured through an accelerometer and displayed on LabVIEW through the resulting Waveform and its corresponding Fast Fourier Transform (FFT) spectrum. The frequency of the oscillations resulting from the second input was measured and both the output time signal and its FFT spectrum were produced through LabVIEW. The FFT plot clearly showed the peak corresponding to the natural frequency of each structure. The natural frequency of each of the three SDOF structures were noted and three vibration absorbers having the same natural frequency were designed to suppress the oscillation at the natural frequency (resonance frequency).

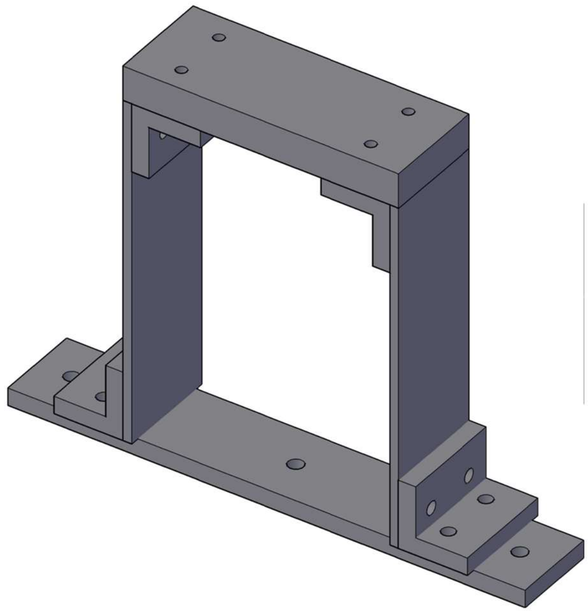


Figure 5 SolidWorks Model for the SDOF structure with elastic side elements

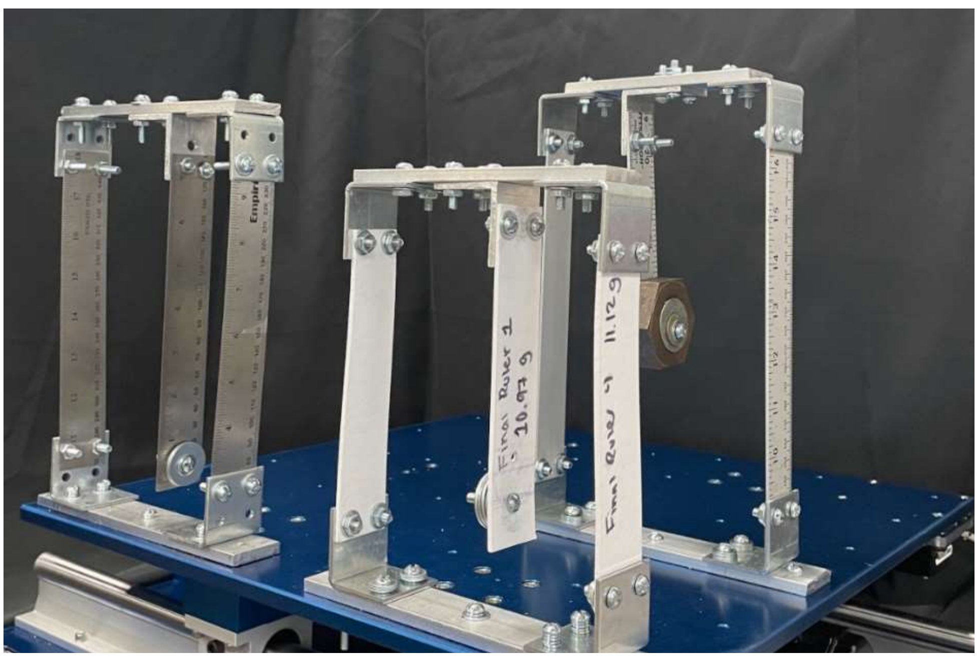


Figure 6 Three SDOF structures with elastic side elements (a) Steel (left), (b) PLA (middle), (c) Aluminum (right).

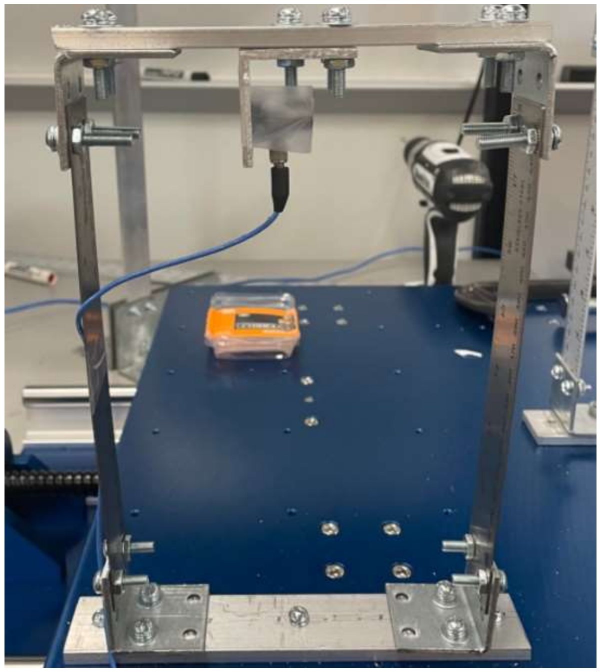


Figure 7 Second Experiment: SDOF structure with steel side bars and accelerometer attached.

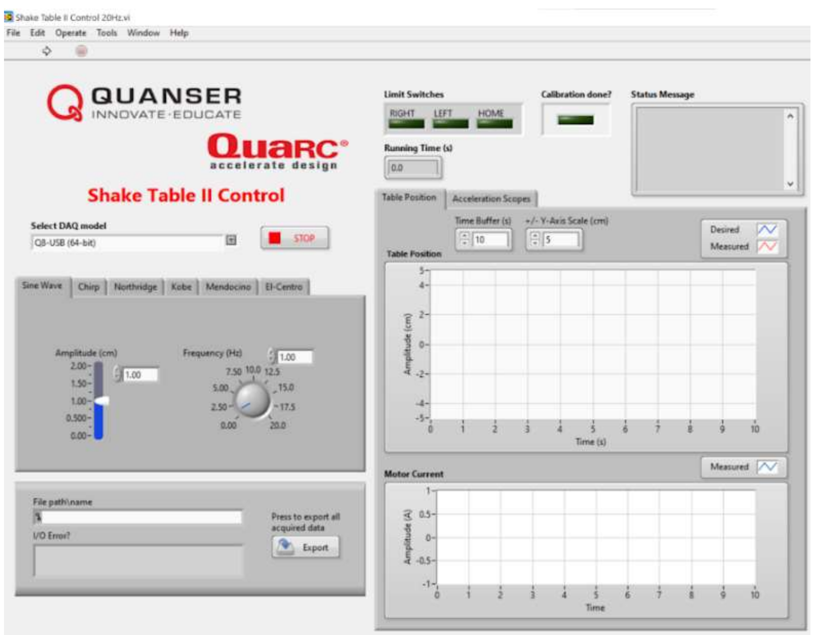
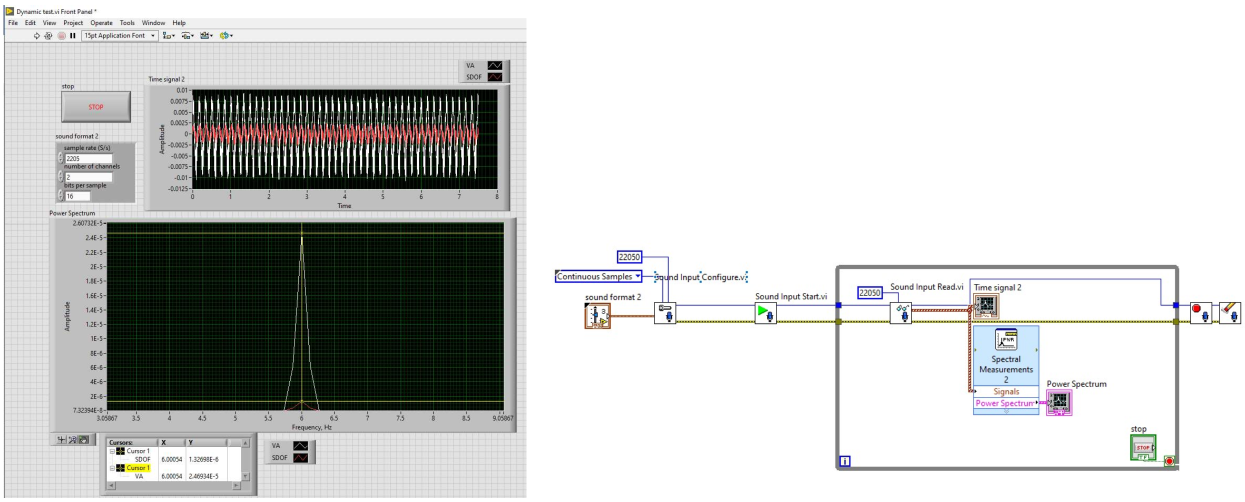


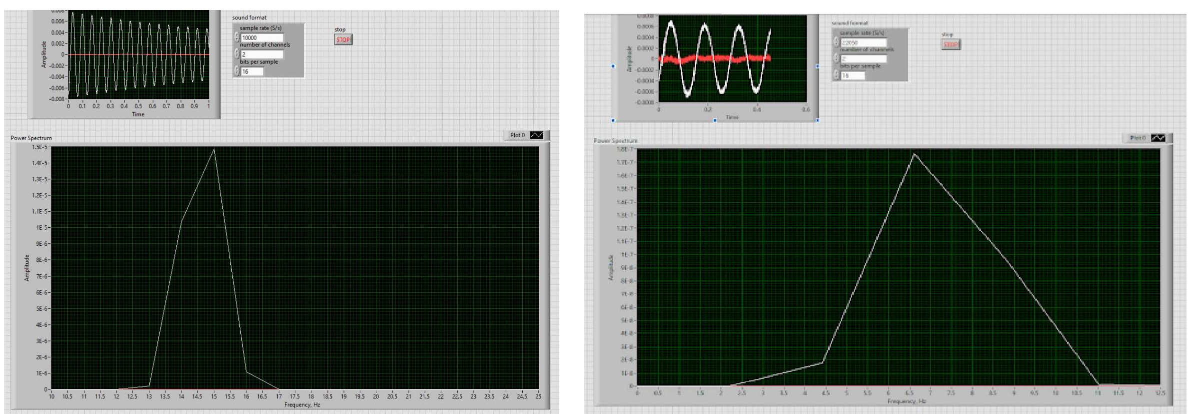
Figure 8 LabVIEW interface for controlling Shake Table II.

The LabVIEW code (Block Diagram) and results (Front Panel) for the case of SDOF structure with PLA and aluminum side bars are displayed in Figure 9, and Figure 10.



(a) (b)

Figure 9 LabVIEW results for the second experiment of SDOF structure with PLA bars (a) Front Panel, (b) Block Diagram.



(a) (b)

Figure 10 Resonance frequency of the SDOF structures without vibration absorber (a) Aluminum, and (b) PLA.

3. Third Set of Experiments

The third set of experiments were to build and install the vibration absorbers and adding them to the SDOF structures then test the structure through (a) manual excitation (initial displacement), and (b) sine sweep (generated by the Shake Table similar to the second experiment.)

The resulting FFT showed clearly that the amplitude of the oscillations was eliminated at the resonance frequency and significantly suppressed around it, Figure 11 and Figure 12.

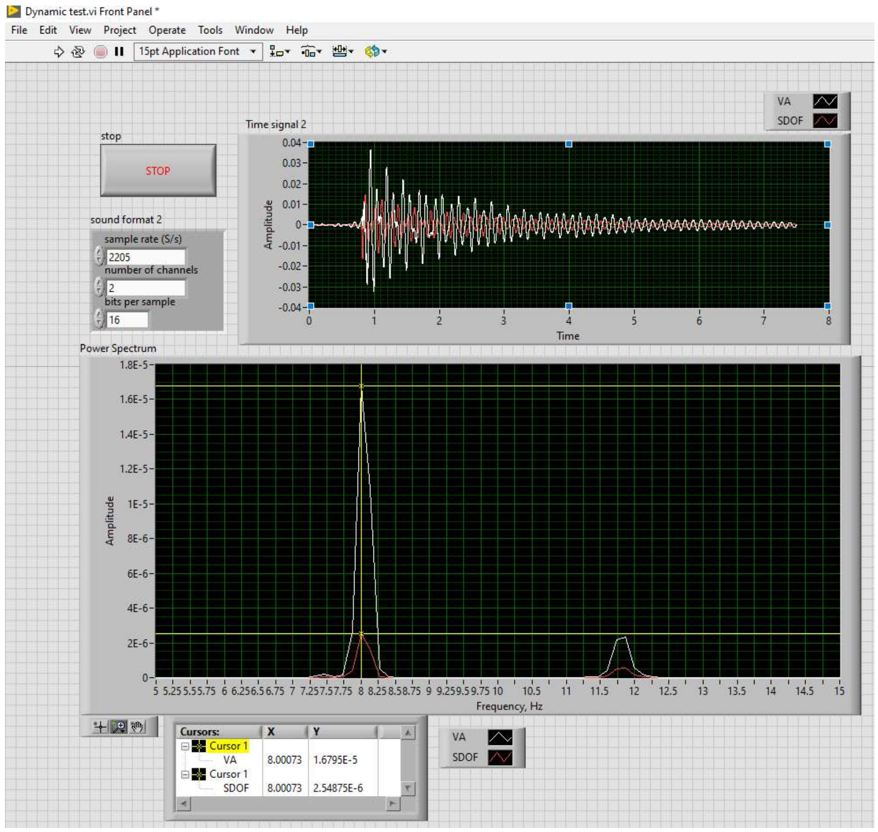
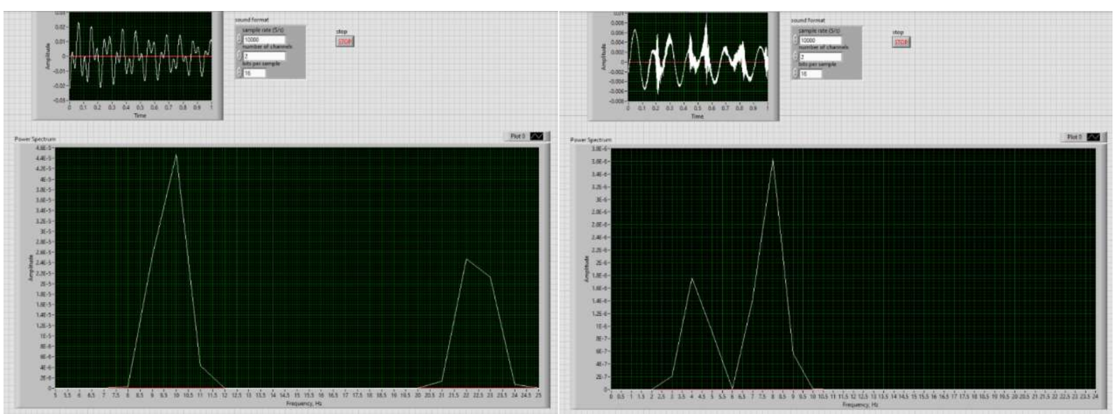


Figure 11 Vibration Absorption Test Results for Steel with manual excitation (initial displacement).



(a) (b)

Figure 12 Sine sweep response of the SDOF structures with vibration absorber (a) Aluminum, and (b) PLA.

These experiments were great demos that experimentally introduced multiple concepts about the analysis of mechanical vibrations which is normally covered in a Mechanical Vibration class that is not covered in the ET curriculum and sometimes taught as a graduate level class.

Achievements

As seen from the experiment details above, the goals set for this project were achieved as a group of ET graduating seniors were introduced to the concepts of vibration and simple research was conducted. The team developed good understanding of the concept of the theoretical vibration concepts through experiments and calculations were made to verify the compliance with the theory. The student team learned how to run the Shake Table using Simulink through the QUARC interface as well as using LabVIEW. That was another learning experience that they do not usually get in other classes, especially as they went through a quick certification program to learn coding with LabVIEW and built their own customized LabVIEW VI's. The student team made a virtual poster presentation at a local conference. Using the Shake Table II, the team was able to study Young's Modulus, find resonance frequency for structures with side walls, acting as springs, made of different materials. Different configurations could be created with the specimen structures constructed out of three different materials: aluminum, steel, and PLA. All structures that were built were a single degree of freedom (SDOF), and were subjected to vibrations from the shaker table. Experiments had been set up incorporating shock absorption masses. This allowed the team to understand how vibration absorption works and how they can reduce or eliminate displacement when vibrations are applied to a system that create hazards to that structure. The team has gotten a much better understanding of the mathematical concepts of vibration theory, which allowed the importance of a spring mass in structures to be determined. The research will advance with addition of extra equipment and more students will benefit from the setup.

Acknowledgement

This project is partially funded by the department of Industrial and Engineering Technology (IET), and the Center for Faculty Excellence (CFE) of Southeastern Louisiana University.

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