## **Project # 6: "Buildings that Resist Earthquakes Better" (Earthquake Project)**

RET Participants: Grant Keys, Winton Woods High School, Cincinnati, Ohio and Rachel Rice, Pre-service teacher, University of Cincinnati, Cincinnati, Ohio.

Faculty Mentors: Dr. Anant Kukreti, Director for Engineering Outreach and Professor of Civil and Environmental Engineering and Dr. Kelly Cohen, Associate Professor, Department of Aerospace Engineering, University of Cincinnati.

Graduate Student Mentor: Mr. Raviteja Chalasani, Ph.D. student, Structural Engineering, Department of Civil and Environmental Engineering, University of Cincinnati.

*Goals and Objectives*

A pre-service science teacher and an in-service high school teacher worked on this project. Looking at their educational interests, the goals of the project for each were as follows:

For Pre-service Teacher:

1. To find connections between biology and other areas of science such as engineering and earthquakes.
2. To gain experience from more seasoned teachers.

For In-service High School Teacher:

1. To work cooperatively with other teachers and mentors to find effective and practical teaching strategies.
2. To bring his curriculum to life through real world applications and community connections.

To achieve the above goals, the objectives of the project were fixed as follows:

1. Study the natural system response when different disturbances (sine waves, chirps, impulses) and random ground motion are introduced to a structural system.
2. Study the system's response when base isolators are introduced.
3. Study the system's response when passive viscous damping is introduced.
4. Study the system's response when active damping is introduced.
5. Compare the damping coefficient, circular frequency, and settling time for the above when the same disturbances are introduced in order to determine if using base isolators, actuators and damping sensors produce significantly better results.

*Research Tasks and Methodologies***:**

The teachers conducted four sets of experiments on 1/24-scale one-story building frame model, including: free vibration test to find its natural response, response when base isolators are mounted under the columns, a passive damping device is installed as a brace, and a computer-controlled active damping device is installed on the top floor mass. The teachers used a Linear Variable Displacement Transducer (LVDT) to measure the system's displacement response without and with base isolators and passive damping brace. A data acquisition system and computer was used to record the response and display the results in real time. Since the LVDT measures change in volts, the teachers first calibrated the LVDT to correlate change in voltage to displacement in inches of the LVDT plunger. All data recorded was stored as an Excel file and graphed with time on the horizontal axis and displacement on the vertical axis. These graphs looked like a sine wave with the peaks of successive sine curves decreasing exponentially till the structure comes back to it original equilibrium state. The teachers fitted an exponential function through the peaks of the sine curve and found the exponential regression equation. This information was used to find the structural damping coefficient of the structure. They also calculated the number of peaks per second to find the period of vibration and multiplied the result by $2\pi$ to find the circular frequency of vibration in radians per seconds. The teachers conducted the tests for four scenarios, free vibration, with base isolators, with passive damper, and with active damper, in order to compare and contrast their findings. **Figures 1 to 4** show the different experimental set-ups used by the teachers.

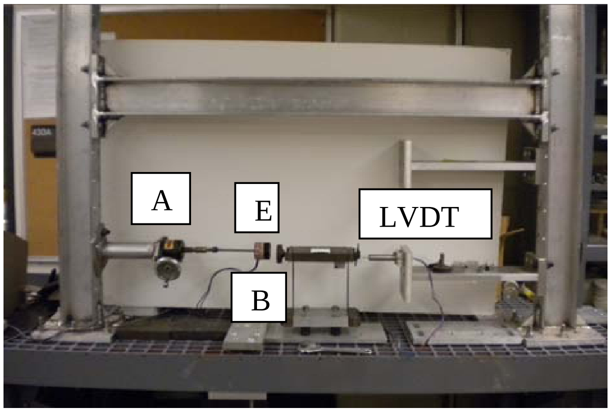


**Figure 1. Experimental Setup with Actuator (A), Electromagnet (E), One-Storey Building Frame Model on Base Isolators (B), & LVDT**

**Figure 2. Teacher Installing Damping Device**

**Figure 3. Teacher Operating the Data Acquisition System**

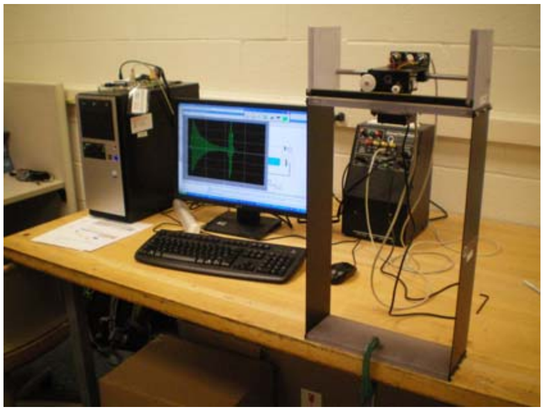

**Figure 4. Active Damping System Setup in Controls Lab**

<u>*Equipment Training*</u>:

The teachers were trained by the Faculty and Graduate Student Mentors to use:

1. Linear Variable Displacement Transducer (LVDT) to measure the displacement response of a structure when a disturbance is introduced.

2. Virtual Bench Logger Software and Data Acquisition System used to record the displacement every thousandth of a second.
3. Microsoft Excel used to tabulate and graph the data, find maximum values, and to do exponential regression analysis.
4. Quanser shake table.
5. Remote access through web cam to the Controls Lab:

*Highlights of the Research Findings*

In general, as the damping coefficient increases the circular frequency and the settling time decrease. The results obtained by the teachers are summarized in the **Table 1**. As can be seen, all asiesmic devices, base isolators and active and passive damping devices, shifted the natural frequency of the structure sufficiently away from the expected ground motion frequency, thus making them affective in reducing damage during an earthquake. But, the active damping system produced highest damping and also sufficiently shifted the natural frequency of the structural system. Also, it had the significantly least setting time.

**Table 1. Dynamic Response Test Results**

| TESTING SCENRIO | DAMPING COEFFICIENT | CIRCULAR FREQUENCY | SETTLING TIME (Seconds) |
|---|---|---|---|
| NO DAMPING | 0.4% | 66.84 | 9.58 |
| PASSIVE DAMPING (OIL) | 0.8% | 67.35 | 4.84 |
| PASSIVE DAMPING (SOAP) | 0.9% | 66.65 | 4.08 |
| PASSIVE BASE ISOLATION | 3.7% | 44.01 | 1.94 |
| ACTIVE DAMPING (NO) | 2.8% | 15 | 6.03 |
| ACTIVE DAMPING (YES) | 13% | 14.78 | 0.52 |

*Plans for Classroom Implementation*

For Pre-service Teacher: This lesson is created for a $10^{th}$ grade Biology class. It was a challenge to find a solid connection between the work the teacher did in the lab and the content material the teacher was planning for the coming year. She decided to focus on the ability of animals to detect earthquakes. To preface this lesson, the engaging activity was designed to involve students making observations as a number of different objects are stretched, bent or broken. This will get them in the mindset of thinking about forces created and how they may relate to how structures behave under earthquakes and how they are likely to fail. They will then learn about early warning signs of earthquakes. The teacher will then talk briefly about the physical causes of earthquakes: fault boundaries, plate tectonics, and types of waves created during ground motion. The teacher will demonstrate the various scientific devices used to detect and measure earthquakes and relate these to the sensory system of animals that detect similar responses. Various theories and incidents available in the literature about earthquake prediction by animals - evolution and sensory perception will be presented and discussed.

For High School Teacher: This lesson is structured for freshmen Algebra 1 students. The teacher studied circular frequency in doing their research. Circular frequency for a one-story lumped mass system representing a one-story structure can be calculated by taking the square root of the quantity representing the stiffness of the columns divided by the floor mass they support. Stiffness is the force required to produce one unit of displacement of the column top and is a constant for given geometry of the column cross-section, height, and material used. The teacher will first ask the students to conduct a test to find the stiffness of a spring. They can do this by making a table of incrementally increasing weights (10 grams, 20 grams, etc.) and recording the corresponding elongation (or displacements) of the spring in inches. The graph of the table should be linear, and the slope is the stiffness. This experiment should prompt a discussion of slope, the-intercept, and linear equations. Next the teacher will ask the students to calculate the stiffness for different common objects like a rubber band, metal wire, shoe lace, and a cantilevered metal rod, etc. The goal of the unit is for students to have a broad knowledge of linear equations and be able to translate freely between table, graph, and equation forms. As an extension the teacher will ask the students to experimentally determine the circular frequency of a K'NEX building frame structure. The structure will then be mounted on a K'NEX robot to shake the structure at increasing frequencies in order to explore the idea of resonance. Resonance occurs when the frequency of the disturbance matches the frequency of the building and cause the structure to be unstable and vibrate wildly. The students will then explore strategies to avoid resonance.