Project # 6: Modern Aseismic Design Strategies for Buildings

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Project Summary:

On 1/26/01 an earthquake of magnitude 7.9 on the Richter scale, centered in India left tens of thousands of people killed or injured whereas on 1/28/01 the Nisqually Earthquake near Olympia, Washington had a comparable magnitude of 6.8 but resulted in only one death, and a few hundred minor injuries. The difference in outcomes from these earthquakes is attributed to the use of aseismic design techniques, the main strategy in which is to employ various energy-absorbing and base isolation devices. In this project the teachers will explore such technology, and learn how it can be geared toward educating and exciting physics and math students.

To understand the behavior of structural systems with aseismic devices, one needs to perform physical testing of complete structures subjected to earthquake motions. Because of the size limitations and expense of seismic simulators (shake tables) available and the need to test complete building structures, small-scale models are often the only choice for testing. It is generally agreed that testing of larger scale models (1/3 size) gives better information about localized behavior such as member cracking, however much of the same global behavior can be obtained at a much lower expense by testing much smaller models (1/12 to 1/24 size). The expense reduction due to the use of small-scale models is due to lower specimen production and instrumentation costs and drastically lower simulator (shake table) costs.

The objective of this project is to test, evaluate, and compare results from small-scale (1/24) models of steel frame building structures fitted with various types of base isolators and subjected to base motions. Base isolation systems are a means of allowing the ground to move horizontally underneath a building due to an earthquake while the building remains relatively steady. To accomplish this, base isolation systems must have very low horizontal stiffness between the building being isolated and the supporting ground. Also, the isolation system must have a relatively large vertical stiffness to support the weight of the building and prevent the building from overturning. These systems are gaining popularity as more economical and effective isolators have been developed. It is desirable to create accurate small-scale models of these new systems so that the overall performance of scaled structures supported by them can be studied on seismic simulators. One of the more common designs of base isolators is a stack of rubber layers laminated with a series of horizontal very thin steel plates. The steel plates distributed among the rubber layers retain the lateral bulging of the rubber, thus increasing the vertical stiffness and strength. At the same time, the steel plates interfere very little with shear deformation of the rubber layers, giving relatively low shear (horizontal) stiffness.

Since the RET participants may not have a background in Structural Dynamics, an understanding of basic vibration principles and use of electronic sensors (displacement and velocity transducers and accelerometers) and computerized data acquisition systems (DAS) to measure dynamic response parameters of interest will be taught in a special lab developed for testing small-scale structural models. The project will begin with learning of basic vibration principles through experiments on 1/24-scale one-story small-scale building models to explore their use to: experimentally determine their frequencies, mode shapes and damping characteristics. The building model structures used will consist of four spring steel columns for each floor, which have fixed connections at the base, and a large steel block mass for each floor. The first set of experiments will deal with free vibration motion characteristics of one-story models mounted on the laboratory table, deformed, and released to freely vibrate, as shown in Figure 1. The displacement, velocity, and acceleration response will be recorded. For all these experiments, prefabricated parts of the model structures and other needed devices will be utilized. The teachers will be required to assemble the components, install the necessary instrumentation (displacement, velocity, and acceleration transducers), and acquire and process the data using the computer software *LabVIEW*. These models will not be tested to failure and will be reusable.

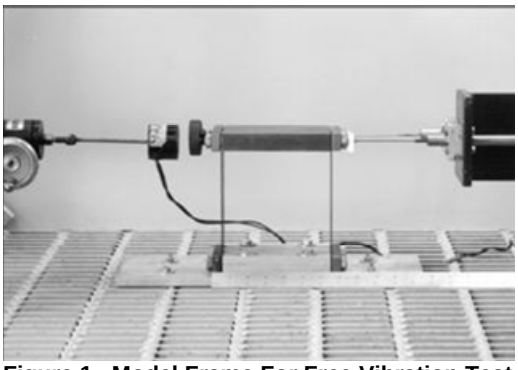

Figure 1. Model Frame For Free Vibration Test

In the next set of experiments the one-story model will be mounted with and without base isolators on a small unidirectional shake table that has a 6.25” stroke, 30 lb force, 50 lb maximum payload capacity, and a 9” x 12” horizontal table matched with the shaker, as shown in Figure 2. For these tests, using the knowledge gained from the first series of free vibration tests, teachers will design the models with a known fundamental natural frequency. Each test will be repeated for three different base (i.e., shake table) motion frequencies--lower, about equal and greater than the model fundamental frequency.

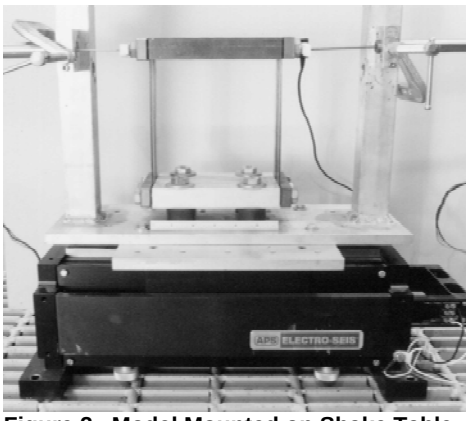

Figure 2. Model Mounted on Shake Table

Cylindrical rubber mounts are commonly used as supports in mechanical machinery, and their use as base isolators for aseismic design will be first investigated. This project will also evaluate the use of in-house fabricated elastomeric base isolators (EBI) laminated with steel plates and with and without lead plugs. The small-size (1” x 1” in plan with varying height since the number of steel plate layers are changed, but rubber height between layers kept constant) EBI, as shown in Figure 3, requires skill and precision to cast them. Hence, most of the EBI will be pre-fabricated and made available to the teachers; however they will fabricate one set of 4. This will also save valuable time. The teachers will conduct two series of tests. In the first series, the response of the one-story bare frame model will be measured, in the second series the cylindrical rubber mounts or EBI will be installed under each column of the model frame so that the model is de-coupled from the shake table over which it is mounted. The test will be repeated for each type of cylindrical rubber mounts or EBI manufactured, and the response for each will be recorded and compared to that obtained for the bare model. In addition, teachers will shown how to conduct tests to determine the shear (horizontal) and vertical stiffness of an EBI. Using these test results, teachers will investigate and quantify the effect of the different type of base isolators in decreasing the amplitude of the displacements and accelerations.

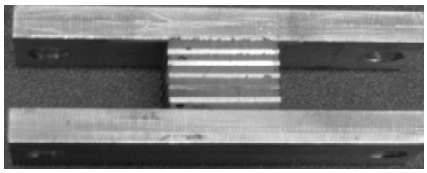

Figure 3. EBI laminate with Steel Plates

Possible Ideas for Classroom Implementation

The teachers may design and construct three distinct demonstrations, including a lumped mass model, a Plexiglas® fluid tank model, and a light weight portable shake table (see Figure 4). The lumped mass model will basically consist of a steel cylindrical solid mass piece screwed to one end of a rod, and the other end of the rod will be rigidly connected to the shake table top. By filling the tank model with colored fluid and mounting it on the shake table, one can demonstrate how the ground motion profile changes over a range of frequencies. Even at the high school level, concepts in dynamics such as natural frequencies and mode shapes can clearly be portrayed during such experiments. The teachers may develop a lesson plan on "Earthquakes: Causes, Effects, and Damage Control," in which the use of these hands-on demonstrations can be integrated. In addition, a student competition could be designed with the theme to design a *Model Lego Building to Withstand Earthquakes*, which can be tested using the University of Cincinnati's shake table.

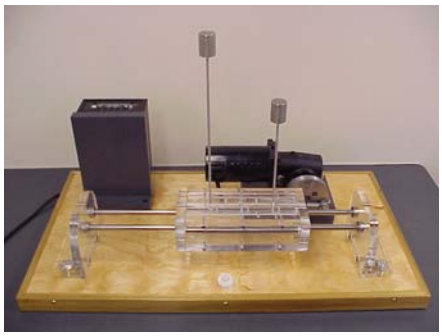

Figure 4. Classroom Demonstration Shake Table