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The George E Brown, Jr. Network for Earthquake Engineering Simulation

CU-NEES
Instructional Shaking Table

By

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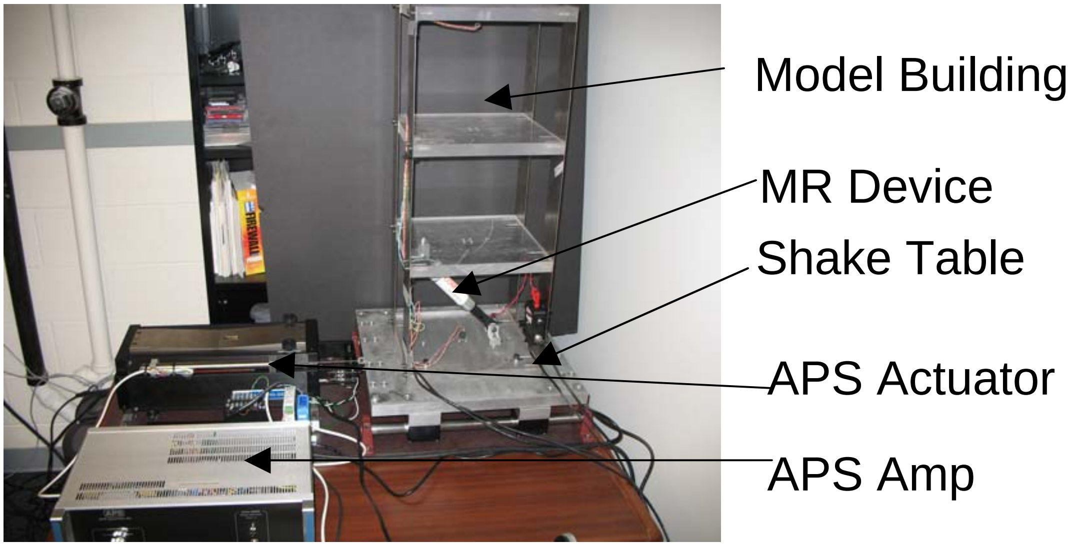
1. Motivation

The CU instructional shake table is an interactive educational outreach and teaching tool. We designed the system to enrich our on-site and off-site outreach activities by offering outreach participants hands-on control of a shake table system. During typical lab tours and demonstrations the concept of Fast-Hybrid testing is often a difficult one for people to understand. In addition to introducing participants to earthquake engineering principles, the instructional shake table provides an easy to grasp concept while showcasing the unique tele-presence and tele-operation capabilities offered by NEES.

2. Description

The shake table system consists of a small electromagnetic actuator coupled to an aluminum table resting on linear bearings. A simple LabVIEW program is used to generate an analog command signal to the actuator amplifier and read acceleration, displacement, and force data from transducers on the instrumented model building payload. Currently, the model building consists of a single-bay three-story building.

The shake table system is controlled by a LabVIEW GUI which allows the operator to select an adjustable sine wave or a recorded earthquake ground motion to excite the model structure. The operator can also control an MR type damping device through the user interface. This element of interactivity introduces the concept of earthquake mitigation equipment to the outreach participant. During the shake table test measured acceleration data is graphed allowing the participant to get a "feel" for how a building reacts to different earthquake motions.

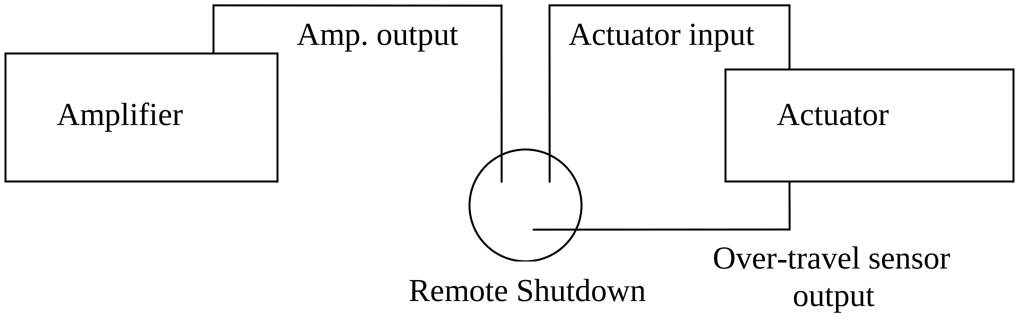


Off-site outreach activities also benefit from the instructional shake table system. Through a set of simple web based interfaces outreach participants can control and observe the shake table's behavior via the Internet. Control is provided through a web published version of the LabVIEW GUI and tele-presence is achieved using the CU NEES flexTPS server and a robotic camera.

3. Technical Details

3.1 Hardware

Our instructional shake table system consists of an APS Electro-Seis Model 113 Shaker actuator, driven by an APS Dual-Mode power amplifier, Model 114-EP. The amplifier is controlled using a LabVIEW VI which will be described later. The actuator has over-travel sensors for both directions which are wired to a remote shutdown box. In the event of an over-travel, the remote shutdown box shuts down the actuator and sounds an alarm. A reset button must be pressed before operation can resume.



Four accelerometers are used to measure acceleration, one on each floor of a model building. Each accelerometer is an ADXL203EB model capable of supplying 2-D acceleration data. They are connected via two Cat-5 cables to an NI SCB-68 connection box which is connected to the NI PXI-6251 M series DAQ card. This card also supplies the 5VDC required for the accelerometers.

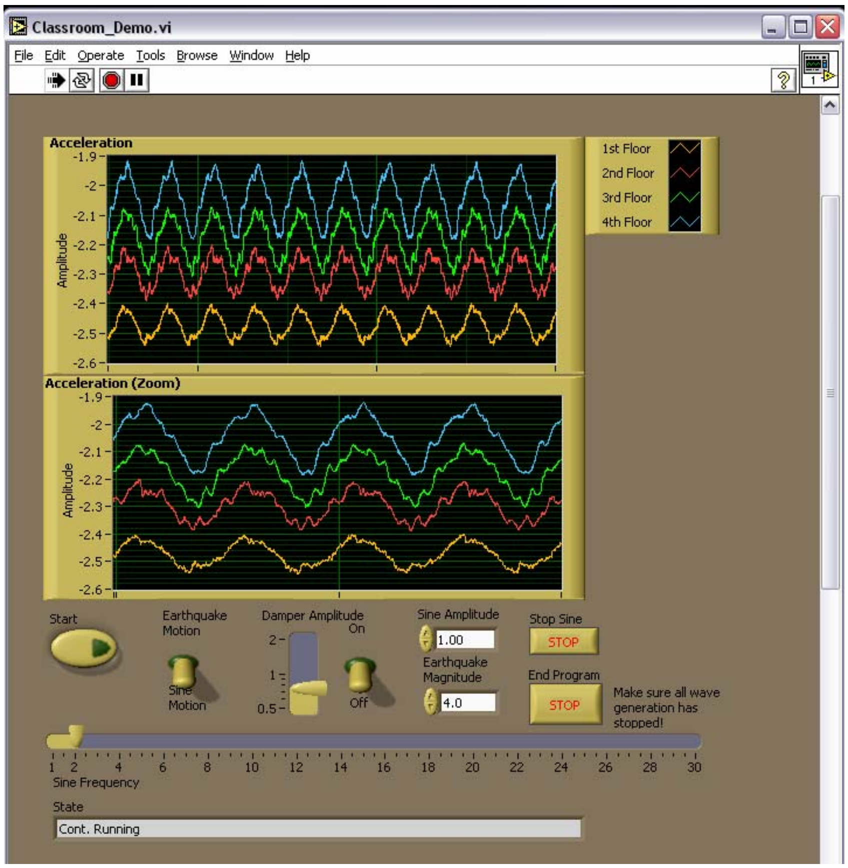
Actuator displacement is measured using an LVDT with 6 inches of travel (+/- 3 inches) from Macro Sensors with a Macro Sensors LVC-2412 LVDT conditioner. The LVDT body is mounted on the side of the actuator using two custom machined mounting blocks. The LVDT core is connected with a section of all-thread to a hollow block of steel which is screwed to the actuator arm. The output from the LVDT conditioner is connected via a third cat-5 along the same route to the DAQ card.

To add another element to the demonstration we have included a small damper in the bottom floor of the model building. It is a LORD damper, part number RD-1097-01, with about 3 inches of travel. The damper has its own controller which can be driven by a voltage supplied by the DAQ card. The damper connection is included in one of the cat-5 wires for the accelerometers.

Finally, we have a load cell located between the end of the actuator arm and the shake table. It is an Omegadyne LC202-50 load cell with a load capacity rating of 50 lbs. One end of the load cell screws into the table and the other screws into an aluminum plate which is attached to the actuator arm.

3.1 Software

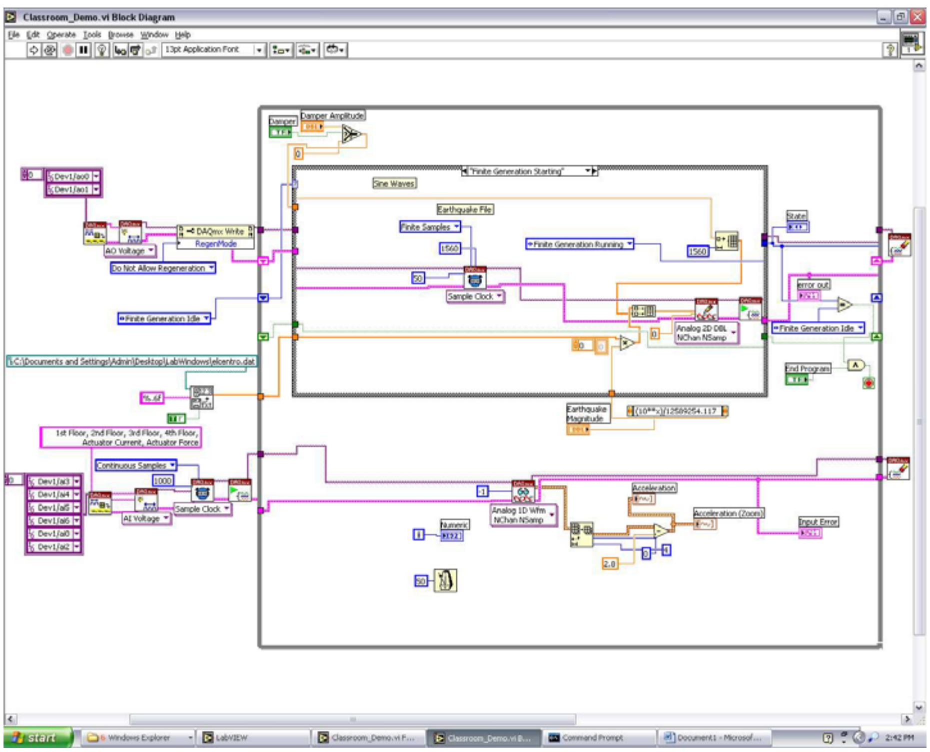
The LabVIEW VI interface is easy to use and very flexible. It allows two modes of operation to for exciting the shake table. The first mode simulates an earthquake using data from the El Centro earthquake record. Amplitude of the earthquake can be controlled on a logarithmic scale to help outreach participants relate to the Richter scale. In this mode, the earthquake motion will start when the user presses the start button and stop only when the entire earthquake has played out. The second mode outputs a sine wave to the actuator. The user can control the frequency and amplitude of the sine wave on-the-fly. Frequency range is limited to values between 1 and 30 Hz and amplitude is limited to a factor of 2.9 to prevent any accidental over-travel.



In either mode the user can turn the damper on and off to see how it affects the motion of the building. Note however that when in earthquake mode all damper and amplitude settings must be set prior to starting the test. Damper amplitude can also be controlled. On the low end the damper is very loose gradually moving to near complete stiffness as the amplitude is increased.

Acceleration data is provided on two brightly colored graphs. One provides a large scale view over several seconds, while the other graph is more zoomed in allowing students to see phase differences between the accelerations on each floor.

The VI architecture is fairly simple. First we setup DAQ-MX channels to read and write data, then move into a single while loop to do the reading, writing, and graph generation. All controls are placed in the loop. Command output is managed with a state machine with 7 states. The default state, “Finite Generation Idle” just waits for the user to select an output mode and press start. The state machine then moves to the correct state depending on which mode is selected. “Finite Generation Starting” initializes and begins writing earthquake data to the actuator. “Finite Generation Running” continues output of the data until output is complete. “Finite Generation Stopping” stops output and moves to the Idle state. “Cont. Starting” initializes and starts the continuous sine wave generation. “Cont. Running” continues sine wave generation until the user presses the stop button at which point the state machine moves to “Cont. Stopping”. Here output is stopped and the channel is reset before moving back to the Idle state.



4. Future Work

The instructional shake is a very effective outreach took in its current state. However, improvements in the tele-observation and tele-operation aspects would offer significant improvements while maintaining a more “NEES-like” look and feel. The real-time data graphs could be viewed using RDV by writing data from LabVIEW to the Data Turbine WebDAV interface. Second, if NEES developed as useable tele-operation protocol with a control panel like web interface, it could be used to control the table over the Internet instead if using the National Instruments web publishing tool.

5. Part Description

Part	**Model Number**	**Vendor**	**Cost**	**URL**
Actuator	APS-113	APS	$6000	http://www.apsdynamics.com/modal-test-excitation.html
Actuator Amplifier	APS-114-EP	APS	$3000	http://www.apsdynamics.com/modal-test-excitation.html
18x18 Shaking Table	Custom Built	University of Colorado	$1500	
DAQ Card	MSeries PCI-6221	National Instruments	$500	http://sine.ni.com/nips/cds/view/p/lang/en/nid/201761
Connector Block and Cable	SCB-68	National Instruments	$500	http://sine.ni.com/nips/cds/view/p/lang/en/nid/201761
Accelerometers	ADXL203EB	Analog Devices	$30x4	http://www.analog.com/
LVDT	PR-750-3000	Macro Sensors	$400	http://www.macrosensors.com/
LVDT Conditioner	LVC-2412	Macro Sensors	$400	http://www.macrosensors.com/
Load Cell	LC202-50	Omega	$400	http://www.omegaengineering.com
Load Cell Conditioner	DRF-FR	Omega	$130	http://www.omegaengineering.com
Damper	RD-1097-01	Lord	$300	http://www.lord.com/tabid/3363/Default.aspx
Damper Control	Wonderbox	Lord	$100	http://www.lord.com