

# **WEAVE: Web-based Educational Framework for Analysis, Visualization, and Experimentation**

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## **Abstract**

WEAVE (Web-Based Educational Framework for Analysis, Visualization, and Experimentation) is a web-based educational framework whose purpose is to allow engineering students at Duke University and potentially any student with access to the internet to perform experiments, numerical simulations, and analysis within engineering related topics from a remote location. Students are able to run “modules” that cover the specific topic that they would be covering in class. The WEAVE project began in the summer of 2001 with the goal of employing advanced web-based resources in order to create a new model in integrated instruction (WEAVE, 2008). It has progressed since its inception, but it is not integrated into Duke’s engineering education as much as is desired. Through the research mentioned in this article, several modules have been created or upgraded and a method to evaluate WEAVE’s effectiveness was also created but has not yet been executed.

## **Project Goals**

The first goal of the Pratt Fellows WEAVE project was to develop and update modules for the WEAVE framework that pertain to specific engineering related courses at Duke. The next step was to design a method for a study to determine the effectiveness of the WEAVE framework, but that study has yet to be performed. WEAVE would have been evaluated on its usefulness and effectiveness in educating engineering students and providing them with a better understanding of the topic that they might not be able to attain from lectures and conventional homework assignments alone. The expected outcome was that WEAVE would be effective, but the importance of this study would have been to find exactly how effective. Most research in this field is anecdotal and subjective; it would be desirable to ascertain some form of non-subjective, numerical values and statistics that could quantify the effectiveness of WEAVE.

## **Work to Date**

Through research as a Pratt Fellow, three WEAVE modules have been created for the Physics 62 (Introduction to Electricity, Magnetism, and Optics), EGR 123 (Dynamics), and EGR 75 (Mechanics of Solids) courses at Duke University. Also a shake table that is capable of accurately reproducing earthquake accelerations was created for a previously created module that needed to be upgraded.

## **Background on Modules**

Modules within the WEAVE framework can be either a physical experiment or a numerical simulation. These simulation programs can be written by a developer completely in the MATLAB programming language or in Java (Xue, 2005). However, MATLAB is used almost exclusively and all of the modules mentioned in this article are MATLAB based. Each module has one driver file that utilizes other associated MATLAB files. The driver file takes specific input and writes to an output and error file. These output and error files need to be formatted correctly so that the Java plotters within WEAVE can work properly and the data can be displayed through an internet browser.

Modules can have two-dimensional (two-parameter) plots, contour (three-parameter) plots, and animations (two-parameter plus time) that show position with respect to time. If the input was entered incorrectly by the user or there is an error in the calculation, an error message can be displayed.

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## **Numerical Simulation Modules**

Numerical simulation modules involve simulation programs that take user defined input and output a unique result after running a mathematical model that represents a real physical phenomenon. The three numerical simulation modules that were created have the following titles:

- “Electric Field Potentials for Point Charges”
- “Paths of Masses Due to Gravitational Attraction”
- “Shear, Moment, Deflection, and Stresses of a Loaded Beam”

“Electric Field Potentials for Point Charges” has not been published yet, but the other two can be viewed at [www.weave.duke.edu](http://www.weave.duke.edu). “Paths of Masses Due to Gravitational Attraction” has already been completed as a lab assignment by all EGR 123 students that were enrolled in the course during the spring of 2007. This lab assignment was not used as part of the study to determine WEAVE’s effectiveness and no real results were expected or obtained.

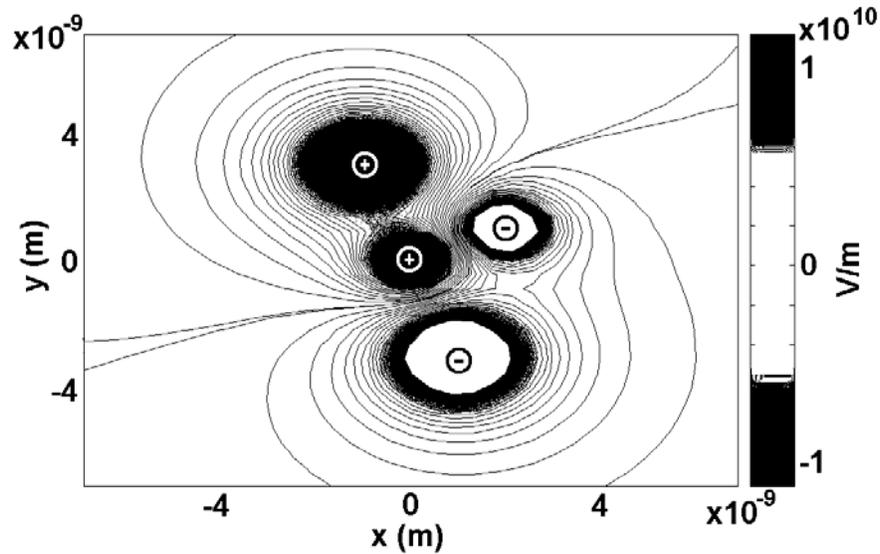
## **Physical Experiment Modules**

Physical experiment modules involve simulation programs that take user defined input to control a device used to reproduce a physical phenomenon. The accompanying MATLAB code for the module then acquires the data from the experiment and displays that data after the experiment is finished. Students are able to view the physical experiments remotely via a live webcam.

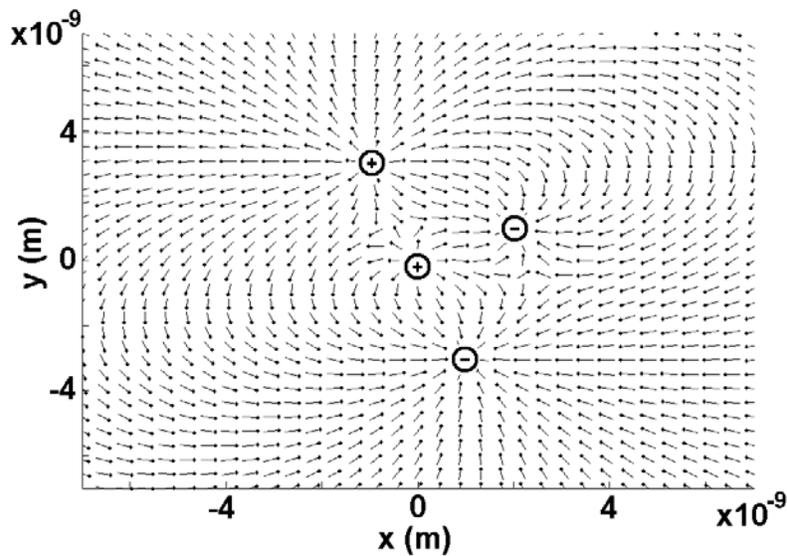
### **Electric Field Potentials for Point Charges**

The module “Electric Field Potentials for Point Charges” was the first module that was created and it was created on February 8, 2007. This module was developed for the Physics 62 course at Duke University that studies electricity, magnetism, and optics and the module allows students to investigate the electric field potentials generated by point charges. A student is able to specify the locations and magnitudes of three point charges and view the corresponding electric field potential as a contour-plot.

“Electric Field Potentials for Point Charges” has not been published yet due to scaling problems in representing the electric field potential with the Java contour plotter utilized by the WEAVE framework. The plot for this module works fine when used solely in MATLAB, but there appears to be no reasonable workaround for this module to be used in WEAVE. Figures 1 and 2 below are plots from this module that were altered for better viewing within this article.



**Figure 1.** Contour plot with magnitudes of electric field (V/m) and equipotential lines.



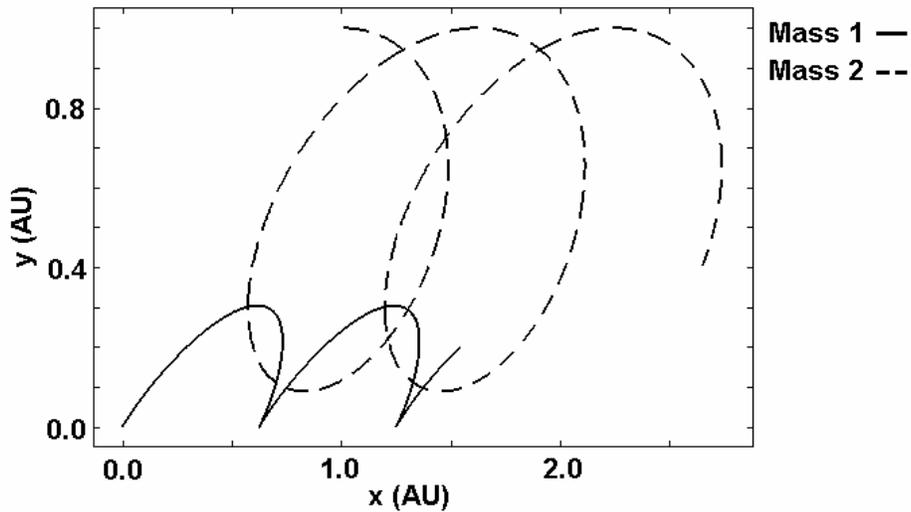
**Figure 2.** Quiver plot showing the direction of the electric field.

### **Paths of Masses due to Gravitational Attraction**

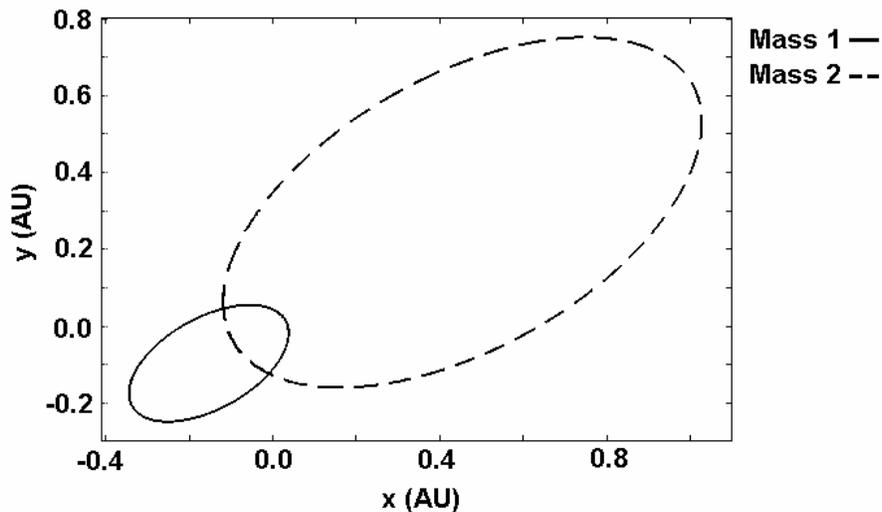
The module “Paths of Masses due to Gravitational Attraction” was the second module that was created and was created on February 20, 2007. This module was developed for the EGR 123 course at Duke University that studies dynamics. Students who have used this module had the opportunity to examine how the gravitational pull between two masses affects their paths through space.

This module takes values for mass, position, and velocity for two different masses and a time span to plot the paths over. The plots show the absolute position of the masses over the time span and their relative position over the time span. The animation has the added advantage of allowing the user to see the change in velocity that the masses have over the time span and how energy between the two masses changes from potential energy to kinetic energy. Figures 3 and 4 below are plots from this

module that were altered for better viewing within this article.



**Figure 3.** Absolute paths of masses due to gravitational attraction.



**Figure 4.** Relative paths of masses due to gravitational attraction; note that this is the same as Figure 3, but relative to the center of mass of the two masses.

As previously mentioned, “Paths of Masses due to Gravitational Attraction” was assigned to the Spring 2007 EGR 123 class as a lab assignment. The students completed this assignment, but no data was collected from this trial run. The purpose of assigning this to the class was to see if there would be any problems that would surface in the process. The following problems occurred and will eventually need to be corrected:

- After running a module several times, the web browser will sometimes freeze.
- The survey portion of each module does not provide individual results.

These problems will be especially difficult to correct since they are problems with the way that

WEAVE is set up. To do this, one would need to be fluent in dynamic webpage programming languages such as PHP and the database computer language SQL. It is unknown whether there is any documentation written by the person who wrote the code for the WEAVE framework. Some investigation into these problems was done, but investing time into these issues instead of making progress in other areas would not be as beneficial to WEAVE.

Even though these problems arose, this module was well received by the professor of EGR 123, Dr. Earl Dowell, William Holland Hall Professor of Mechanical Engineering and Materials Science and Dean Emeritus at Duke University. Dr. Dowell wrote in an email following the lab, “In grading the lab reports, a number of student comments were offered about the WEAVE module. Overall the students found it a very good experience and they especially appreciated the animated graphics and ‘real time’ simulation experience.” Collin Anderson, Pratt School of Engineering ’08, commented, “In a recent Engineering Dynamics course, the WEAVE module ‘Paths of Masses due to Gravitational Attraction’ was an intelligently designed tool for simple theoretical practice by all engineering students. The class studied the motion and orbits of masses in relation to one another to visualize relevant coursework on physical attraction between objects. By running the module under different values of distances, initial velocities, and number of masses, WEAVE was extremely helpful and fun program for furthering the understanding of theoretical dynamics.”

### Shear, Moment, Deflection, and Stresses of a Loaded Beam

The module “Shear, Moment, Deflection, and Stresses of a Loaded Beam” was the third module that was created and was created on March 19, 2007. This module was specifically developed for the EGR 75 course at Duke University that studies the mechanics of solids. The goal of this module is to allow students to develop intuition about the shapes of shear and moment diagrams in response to a specific load case.

In this module, a student can enter as many point loads, moment loads, and uniform loads as they desire and these loads can be placed anywhere on a beam with any magnitudes. There can also be as many supports anywhere along the beam that the user wants and they can specify whether these supports are moment resisting or not. The height, length, width, and Young’s Modulus can also be varied and the width able to be varied for different portions of the beam. When input is provided by the user, this module will display a diagram showing how the beam is loaded and supported, plot shear and moment diagrams for the beam, the deflected beam shape, and several contour plots of the stresses throughout the beam. After using this module, students should understand the relationship between shear, moment, curvature, and deflection. The relationships are shown below in Eqs. 1, 2, and 3. The relationship between shear force and distributed load is:

$$\frac{dV}{dx} = -w \quad (1)$$

where  $V$  is the shear force,  $x$  is distance along the length of the beam, and  $w$  is the distributed load on the beam. The relationship between moment and shear force is:

$$\frac{dM}{dx} = V \quad (2)$$

where  $M$  is the moment in the beam. The relationship between deflection and moment is:

$$EI \frac{d^2v}{dx^2} = M \quad (3)$$

where  $EI$  is Young’s Modulus multiplied by the moment of inertia and  $v$  is the beam’s deflection. Figures 5 and 6 are plots from “Shear, Moment, Deflection, and Stresses of a Loaded Beam” that were altered for better viewing within this article. Note that the relationship between shear and moment as expressed in Eq. 2 is evident in these plots.

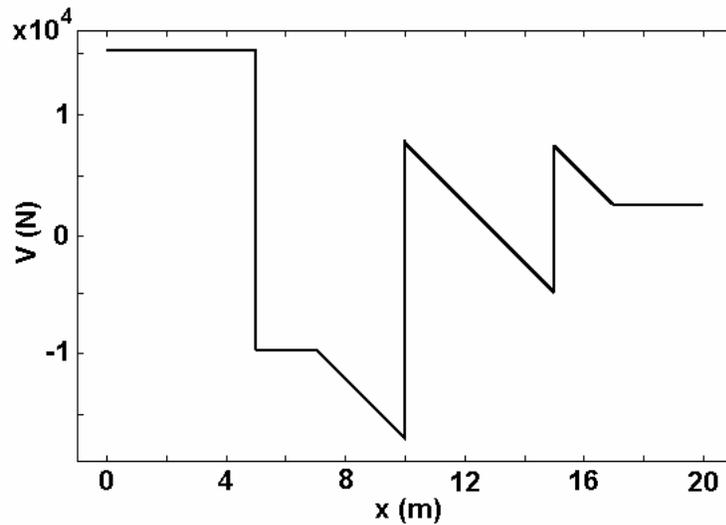


Figure 5. Shear diagram of a loaded beam.

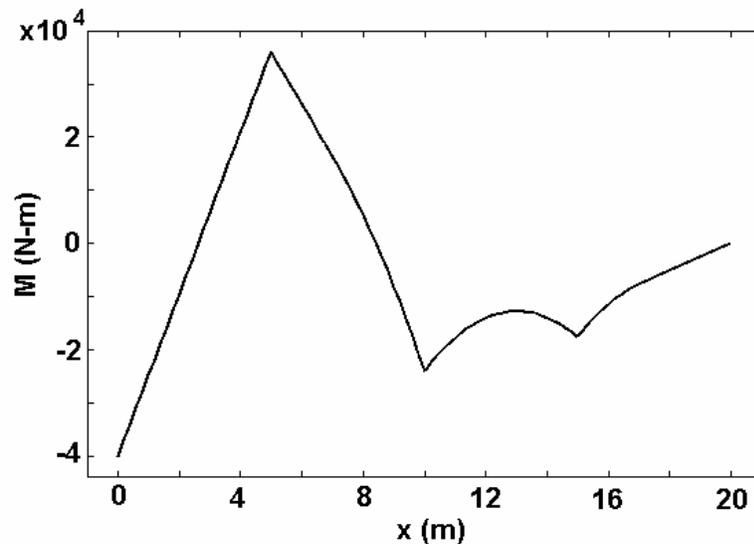


Figure 6. Moment diagram of the same loaded beam from Figure 5.

“Shear, Moment, Deflection, and Stresses of a Loaded Beam” uses several MATLAB files that were created by Dr. Henri Gavin, Associate Professor of Civil and Environmental Engineering at Duke University. By themselves, these scripts are capable of finding shear, moment, and deflection at specified points along a beam. However, they are not capable of providing continuous plots that display this information over the span of an entire beam nor do they yield output to create such plots without very long, tedious input generated by the user. The input needed to do this would need to represent many small beams that are connected at their ends and form the entire beam that is being analyzed. The existing code was edited and a driver file was created that has the ability to generate the necessary input for the driver file for Dr. Gavin’s code from very basic input from the user. With this form of input and the changes made to the existing code, this simulation program becomes a finite element analysis tool. The driver file also keeps track of all of the data and outputs it in a way that is

compatible with WEAVE so that the plots can be displayed.

This module has been published, but has not yet been assigned. With the permission of the course's professor, this module will be assigned to a future EGR 75 course. Even though this module has not yet been used by a course at Duke, it has still proven useful to students who have become aware of it as a tool to analyze beams under specific loading conditions. Matthew Yung, Pratt School of Engineering '08, has used this module to help him with his CE 192 capstone project in which he and his group must design the structural system for a research building. Regarding this module, Matthew commented, "WEAVE is an incredibly versatile tool for analysis. In the case of our senior design project, we used WEAVE to calculate maximum moments in a beam subject to varied loading. We also used WEAVE to very simply confirm a derived theoretical formula for maximum moment for a common load case in our structural design. WEAVE's precision and range of use makes it an invaluable aid to our work as engineers."

### **Building Vibration – Physical Experiment**

Throughout this current research, only one module that uses a physical experiment has been worked on. This module is titled "Building Vibration - Physical Experiment" and was created on July 14, 2004 by Dr. Gavin. This module involves a shake table that can accelerate a small structure in a way that mimics real earthquakes. Through this module, students will be able to investigate the effect of a wide variety of artificial earthquake ground motions on a three-story building model with certain stiffness and damping properties. The building model has rigid floors and flexible columns.

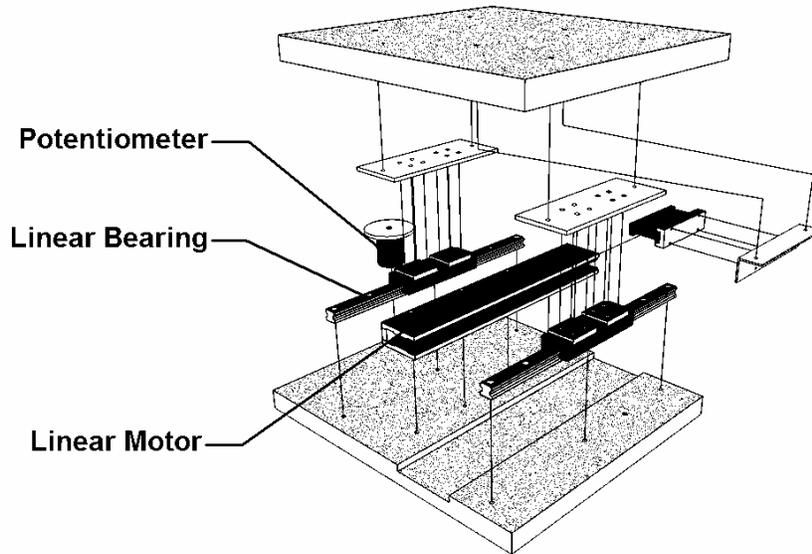
### **Early Shake Tables**

An important aspect of the shake table project was to create a shake table that can be built inexpensively with easily attainable components and with a relatively limited skill set. This allows others to either do research within the field of earthquake engineering or expose young students to the field at a reasonable cost.

Originally, this physical experiment was set up with the building model resting on a linear slide that was driven by an amplifier. This was the case for several years, but the amplifier's fuse blew out too often and the system did not provide very large displacements, which in return did not provide very good data. The motion was unperceivable over the webcam that was intended to let students view the experiment as it was running.

A couple of years ago an attempt was made to use another approach to creating a shake table. This shake table involved a linear motor and plastic rails for the tabletop to slide upon. It also included elastic bands to provide a restoring force to keep the tabletop centered. This table did not perform very well due to the high amount of friction in the system.

The first shake table design built during this current research, version 3.0, involved a linear motor that drove a tabletop that rested on top of two linear bearings. A potentiometer was attached to the side of the table top to measure displacements. Originally, this shake table was designed to be controlled by a computer running the DR-DOS operating system using the C programming language and a PWM amplifier was used to power the linear motor. Because of this, a feedback loop was able to be implemented where the displacement data could be used to determine the control of the tabletop. This allows the table top to be centered through control of the linear motor instead of using elastic bands like the previous version. With elastic bands the restoring force provided has essentially a linear relationship to the displacement of the top, but using the potentiometer's feedback allows for a non-linear response which could also be desirable. Version 3.0 of the shake table is shown below in Figure 7.



**Figure 7.** Exploded view of shake table version 3.0.

This version of the shake table did a very good job at accurately replicating the desired accelerations, but there were some minor problems concerning the alignment of the linear bearings and the linear motor. The table in this state was never used with the three-story building model resting on it.

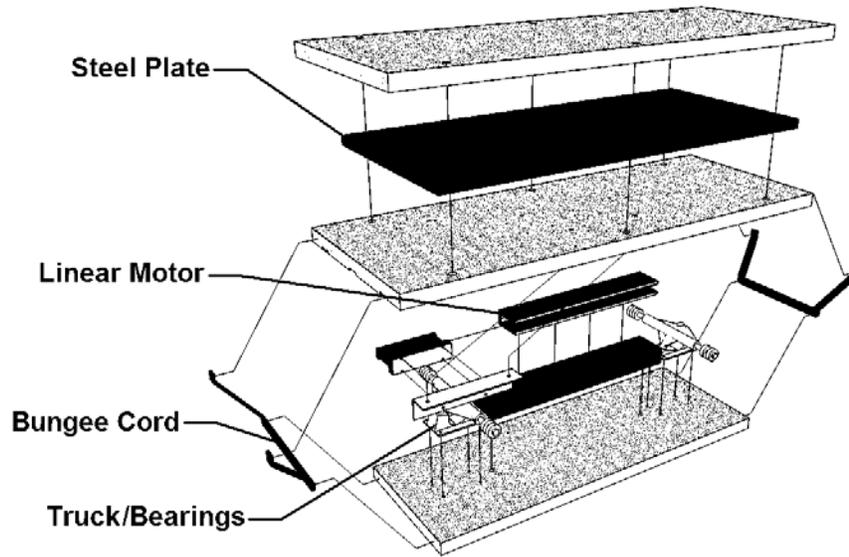
Unfortunately, in order to use DR-DOS with the WEAVE framework it is necessary to network the computer running DR-DOS to the WEAVE server and this was unable to be accomplished due to problems associated with the IP addresses of the computers. Because of this, the linear motor would have to be controlled by MATLAB code on the WEAVE server. This meant that the potentiometer could not provide feedback as the table was running since MATLAB cannot implement feedback at the necessary sample rate to run the table at the ground motion frequencies that were desirable. Any restoring force would have to come from some type of elastic band or spring, so the potentiometer was abandoned, bungee cords were added to the design, and version 3.1 was created.

Once again, unfortunate circumstances prevented this design from working. As the final changes were being made to the associated MATLAB files used to run the table, an error was made in which the output voltage values to be sent to the table appeared to be correct, but were in fact scaled by a factor that was unseen due to the way that MATLAB displays data in the command window. When the signal was sent to the table it was many times larger than it should have been and this caused the linear motor to make the table shake violently, causing the carts from the linear bearings to fly off their rails, easily breaking the screws that were in place to prevent this from happening, and causing all of the ball bearings from the linear rails to scatter across the lab. It was decided that a new shaking table would be designed instead of purchasing new linear rails and rebuilding this model.

### **Current Shake Table**

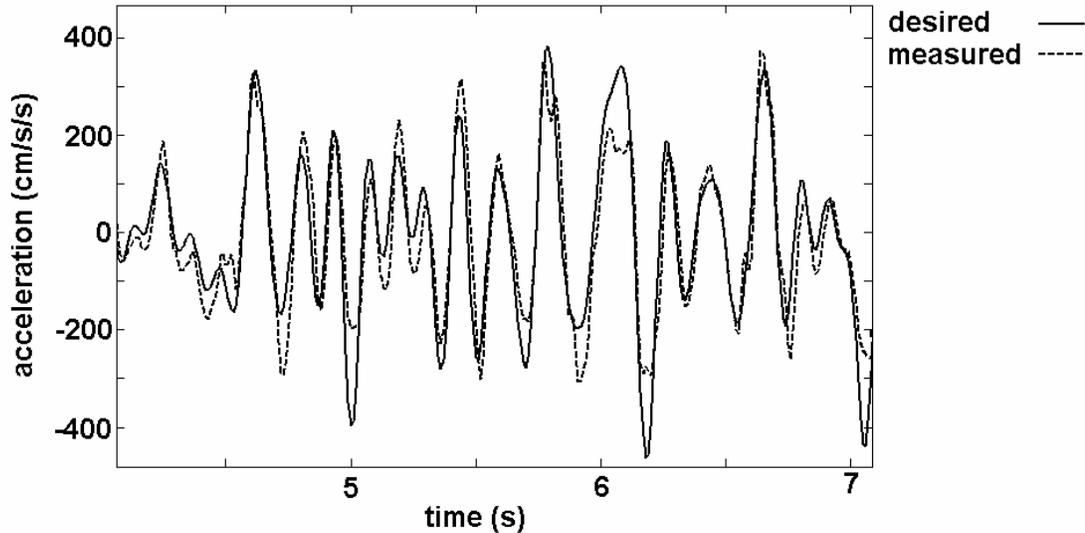
The current shake table, version 4.0, involves the same linear motor that existed in previous versions. Instead of the tabletop resting on linear bearings, this design uses two inverted skateboard trucks to allow for movement with relatively low friction. Skateboard trucks are much less expensive and easier to find than linear bearings. The bearings that are on the trucks are set into grooves that were cut out of the tabletop in order to keep the tabletop aligned. The table is also longer than previous versions, allowing for greater amplitude of displacement. The current table uses the same PWM amplifier as the previous version and the same MATLAB code, except the current setup has properly scaled output voltages.

This current design also has a critical new feature: a steel plate was added to the tabletop to increase the mass of the tabletop. This feature makes the mass of the structure resting on top of the table smaller relative to the tabletop and the dynamic response of the structure due to the driving force from the table will have less effect on the motion of the tabletop itself. The current design is shown below in Figure 8.



**Figure 8.** Exploded view of shake table version 4.0.

Like shake table version 3.0, this shake table accurately produces desired tabletop accelerations. However, unlike the previous version, this shake table is capable of doing so with the three-story building model resting on top of it. Figure 9 shows a representative three second sample of acceleration with respect to time and it shows how the desired and measured accelerations compare to one another. Acceleration was measured by an accelerometer that was connected to the three-story model's base.



**Figure 9.** Comparison of desired and measured tabletop accelerations.

### **Proposed WEAVE Evaluation Method**

The original goal of this project was to evaluate the effectiveness of the WEAVE framework in educating engineering students. The goal was to do this in a non-subjective, non-anecdotal way and to produce actual numerical statistical values and statistics that would represent its effectiveness as a teaching tool. The following was proposed as a method to accomplish this.

*A professor will ask his or her students to find another student in the class of their choice to form groups of two, and then the assignment would be revealed to them. The assignment would have one of the students use WEAVE and the other student would do another assignment without WEAVE. Both assignments will be designed to be as equal in workload as possible and cover the same subject. Within each group the students would have to decide who does which assignment. In the end the students would share the overall grade. We would then be able to compare individual students performances on tests administered after the assignment was done between a control group and a group that used WEAVE.*

The benefit of this method is that it eliminates most of the bias or potential unfairness in the eyes of the students. If the professor made the assignment extra credit then only the most studious students or the students most in need of points within that class would do the assignment and the collected results would be biased. If the professor assigned it to the whole class then there would be no control group. If the professor randomly assigned half the class to one assignment and the other half the other assignment then the students might not find this fair.

Even though this evaluation method was not used, it has the potential to be used in the future to determine the effectiveness of WEAVE.

### **References**

Qiang Xue, H. P. Gavin, "A Guide for WEAVE Module Developers," Duke Univ., Dept. of Civil and Env. Eng., August 3, 2005.

"WEAVE," <http://www.weave.duke.edu> Accessed Apr. 5, 2008.