Session 1566

Full-Body Contact Statics and Other Freshman Engineering Experiences

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Abstract

Hundreds of papers presented at ASEE meetings have described introduction to engineering courses and projects. This paper provides actual instructional materials for three inexpensive active-learning activities that can be performed by first-semester freshmen to introduce them to engineering and motivate them to learn a suite of computer applications. Two of them are in-class laboratory experiments that provide data to analyze with MathCAD or Excel. The third activity is a team design project that is best performed around Halloween. Student feedback indicates that these simple hands-on activities effectively introduce students to fundamental engineering concepts.

Introduction

The *Introduction to Engineering* course at the University of South Carolina includes the learning outcomes that the students: demonstrate knowledge of engineering; demonstrate the ability to use a suite of computer applications; and function on a team to complete a freshman design experience. An active-learning approach has been taken to develop these outcomes.

"Full-Body Contact Statics" is an in-class laboratory experiment. The students apply static loads to a simply supported wooden beam by standing on it. Support reactions are measured with bathroom scales and beam deflections are measured with a ruler. By varying the amount and location of the applied loads, the students can perform a number of experiments. After lab, the students are presented with the appropriate theory and use MathCAD to compare the theoretical and experimental results. "Head Pressure" is an in-class experiment that demonstrates the fluid mechanics principles of conservation of mass flow rate and the Bernoulli equation. This lab uses a 5 foot-tall clear Plexiglas tube that is sealed and stood on one end and filled with water by a hose at the other end. Holes drilled along the height of the tube allow water to flow out. By varying the number of unplugged holes and the height of the water column, a number of experiments can be preformed. After lab, the students are presented with the appropriate theory and use MS Excel to compare the theoretical and experimental results.

"Save the Pumpkins" is a freshman team design project performed around Halloween. Each team designs and builds an enclosure or apparatus to protect a pumpkin from damage when dropped from the 3rd story of the engineering building. The designs are evaluated (sometimes destructively) during a class period. The project grade is based primarily on the contents and appearance of a final project report, which the students must prepare with MS Word.

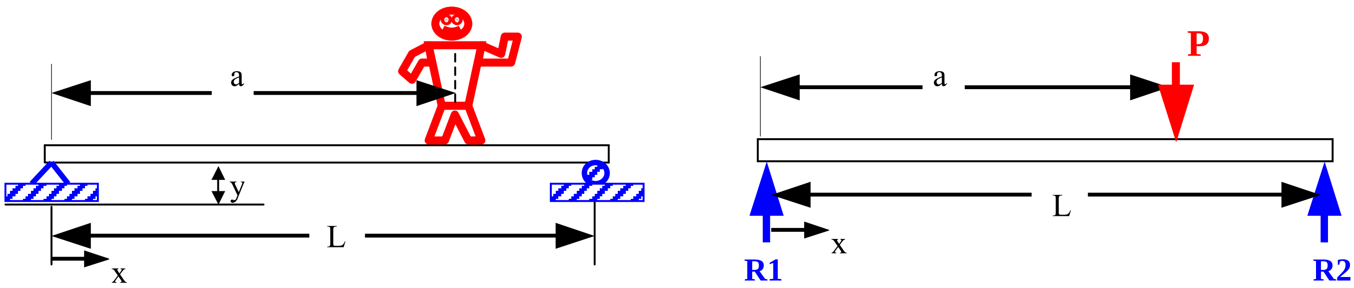
The Full Body Contact Statics Laboratory

Objective

This experiment will familiarize students with basic concepts from statics and solid mechanics. In addition, MathCAD and some of its functions are introduced.

Background

Figure 1 (a) shows a wooden beam of length 'L' that is simply supported on two bathroom scales and has a person of weight 'P' standing at a distance 'a' from the left end. We want to analyze the beam without the person or the scales in the picture. To do this, we replace the person and the scales with arrows that represent the direction and magnitude of the forces that they were applying to the beam, as shown in Figure 1 (b). Figure 1 (b) is called a Free Body Diagram.



(a) *(b)*

Figure 1. Full-body contact statics laboratory set up (a) schematic showing applied load (the person) and the support scales, (b) free body diagram for the beam.

Newton's Second Law states that a body at rest will remain at rest as long as the sum of forces acting on the body is zero. As a result, for our,

$$R1 + R2 = P \qquad (1)$$

In addition, for the beam not to rotate the total moment (force times distance) about any point must be zero. Therefore by summing moments about the left end,

$$P \cdot a = R2 \cdot L \qquad (2)$$

As a result, R1 and R2 can be written as functions of a and P,

$$R1 = P \cdot (1 - \frac{a}{L}) \qquad (3)$$

$$R2 = \frac{P \cdot a}{L} \qquad (4)$$

The deflection of a beam is a function of the load P, the location of the load a, the beam material and the crossection of the beam according to equation 5 and 6.

$$y(x) = \frac{P \cdot (L-a) \cdot x}{6 \cdot L \cdot E \cdot I} \cdot (x^2 + (L-a)^2 - L^2) \quad \text{for } 0 < x < a \qquad (5)$$

$$y(x) = \frac{P \cdot a \cdot (L-x)}{6 \cdot L \cdot E \cdot I} \cdot (x^2 + a^2 - 2 \cdot L \cdot x) \quad \text{for } a < x < L \qquad (6)$$

where E = Modulus of Elasticity (resistance to deformation) of beam material
I = Moment of Inertia (resistance to deflection/bending) of beam crossection

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Experimental Procedure

1. Measure the weight of the person who will be the load, P, during each test.
2. Put the beam on the scales and zero calibrate the scales
3. Measure the deflection of the beam without any load in table 1, y(mm) before.
4. Put the load at different locations on beam according to table 1 and record the deflection under the load and the magnitude of the end reactions (R1 and R2) in Table 1.
5. Put the load in the middle of the beam, a = 4ft, and record the deflections in Table 2.

Report Requirements

- In MathCad, plot theoretical R1 and R2 vs. a (equation 3 and 4) with a ranging from 0 to L and P being the same as in test 1-9. Add the experimental data points as circles (see Appendix A) and make the R1 line and circles red and the R2 line and circles blue.
- Using the if function, graph the theoretical deflection, y(x,a,P), under the load (x =a) for test 1-9 and add the experimental values in Table 1 as data points.
- In MathCad, use the if function to plot y(x,a,P) with P and a being the same as in table 2, and add the experimental data points from table 2
- Discuss in a textbox in MathCad, possible uncertainties and errors that can have caused the theoretical and experimental values to differ. Also, include any suggestions to improve the experiment.
- Save the MathCad file as yourusername.mcd and email it to the instructor.

Table 1. Data Sheet

Test	P (lb)	a (ft)	R1 (lb)	R2 (lb)	y(mm) before	y (mm) after
1						
2						
3						
4						
5						
6						
7						
8						
9						

Table 2. Data Sheet.

x (ft)	1	2	3	4	5	6	7
y (mm) before							
y (mm) after							

Beam Properties

L = 8 ft

$E = 1.5 \cdot 10^5$ psi

$I = 9.45$ in^4

The Head Pressure Laboratory

Objective

This experiment will familiarize students with fluid mechanics concepts and terminology. In addition, the will become familiar with comparing experimental and theoretical data with Excel.

Background

Tap water and hydroelectric power plants are common examples of flowing fluids, as is the flow of air over the wing of an airplane wing. From the concept of energy and its conservation, probably the most useful idea of all of science, Bernoulli (an eighteenth-century Swiss scientist) proposed an energy balance of fluid flow:

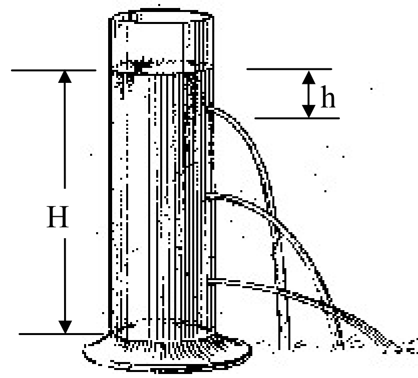


Figure A. What's wrong with this picture of a water column?

$$\frac{p}{\rho \cdot g} + \frac{V^2}{2 \cdot g} + h = \text{constant on a streamline} \qquad (1)$$

where p = pressure, ρ = density of fluid in streamline, ρ_{water} = 1.0 kg/dm^3, g = gravitational constant, 32.2 ft/s^2 , V = velocity of fluid, and h = elevation of fluid.

In this lab, a water column similar to Figure A is used to demonstrate the Bernoulli equation. The pressure is constant (atmospheric pressure) and the water on the top is stationary (V = 0). Thus, the velocity of the water exiting a hole depends on the head distance 'h' shown in Figure A, per:

$$V = \sqrt{2 \cdot g \cdot h} \qquad (2)$$

In addition, the flow rate out of the hole, is defined by equation 3:

$$\text{Flowrate} = V \cdot \text{holearea} = V \cdot \frac{\pi \cdot d^2}{4} \qquad (3)$$

where d = hole diameter. From the theory of conservation of mass, it is known that if the mass of a control volume (i.e. the tube used in this lab) stays constant, the flow rate into the volume must equal the flow rate out of the volume (equation 4).

$$\text{flowrate}_{in} = \text{flowrate}_{out} \qquad (4)$$

Which means if the water level in the tube drops, the flow rate out is greater than the flow rate in, and vice versa. To calculate the time for the water coming out of a hole to hit the ground, the equation for motion of a freely falling object can be used (assuming air resistance is negligible).

$$x = v_0 \cdot t + \frac{g \cdot t^2}{2} \qquad (5)$$

where, x = distance traveled and v_0 = initial velocity. The initial velocity v_0 equals zero because the water has no vertical velocity at the hole. As a result, the time for the water to hit the ground is:

$$t(x) = \sqrt{\frac{2 \cdot x}{g}} \qquad (6)$$

By substituting h in equation 2 with H-x, an equation for the distance, s, that the water hits the ground at as a function of x is established.

$$s(x) = V(x) \cdot t(x) = 2 \cdot \sqrt{\left(H \cdot x - x^2\right)} \qquad (7)$$

Experimental Procedure

1. Fill up water to marked level with the corks in the holes.
2. Take out the top three corks in the tube and try to keep the water level constant (45") by adjusting the tap.
3. Use a bucket to collect water from each hole and record weight, time and h (average) on the data sheet (Table 1). Put back the corks.
4. Repeat the measurements for the bottom two holes in the tube and the can.
5. For the tube, let the water level drop 3" to 42" and take out the corks in the top, middle and bottom holes. Keep water level constant. Record H and x for all the holes, and with the tape measurement, record the distance from the tube that the water hits the ground, s.

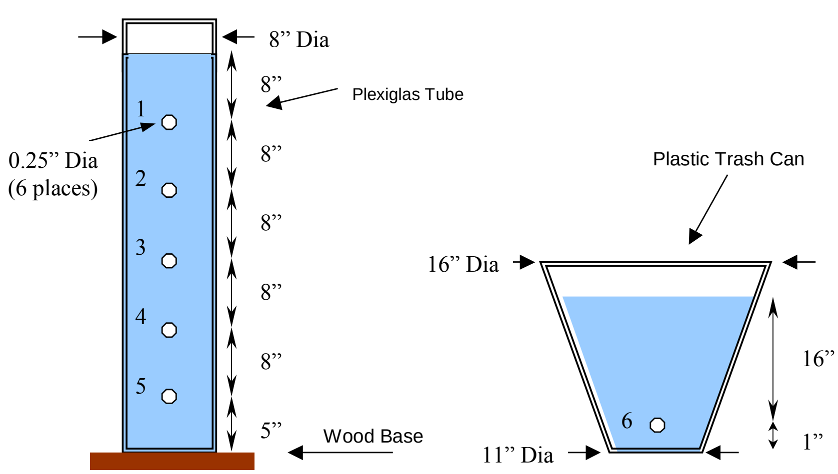
Report Requirements

- Assuming constant water level, calculate the flow rate into the tube from the flowrate out of the holes. From the flow rate out of each of the seven holes, calculate the velocity of the water as it exits each hole. Using Excel, plot the velocity vs. the square root of h and add a linear regression curve. What is the equation of your regression line? What is the theoretical line using equation 2? Does the velocity seem to depend on hole diameter or the diameter of the tube?
- Plot the data for the distance, s, from the tube that the water hits the ground depending on x (and H) together with a theoretical curve. Do the experimental data points coincide with the theoretical curve (equation 7)? Using the results, what is wrong with Figure 1?
- In Word, discuss the accuracy of the experimental data and answer all the questions above. Also, what uncertainties and experimental errors can have caused the experimental data to differ from the theoretical values?

Table 1. Data Sheet

Hole #	D (in)	h (in)	Time (sec)	Weight (kg)	x (in)	s (in)
1						
2						
3						
4						
5						
6						

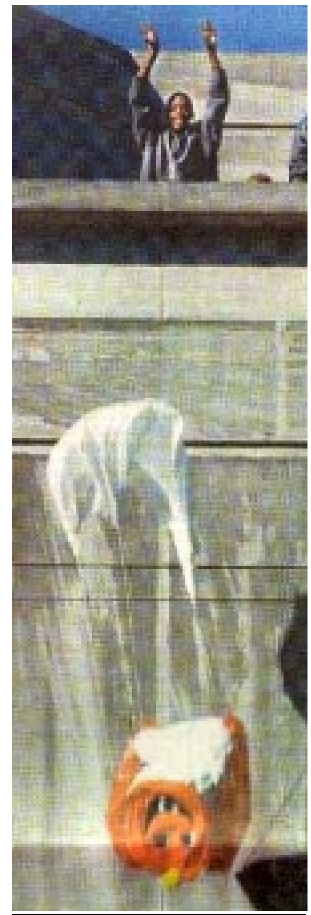
Equipment Schematics



The Save The Pumpkins Design Project

Statement of Need
The goal of this design project is to design an enclosure or apparatus to protect a pumpkin from damage when dropped from the top of the engineering building.

Design Constraints
- A device must be designed to prevent the pumpkin from breaking - there will be no "Biggest Splat" entries allowed.
- Pumpkins must be at least 10 inches in diameter or larger.
- Pumpkin and protective structure weight is limited to 60 pounds.
- The designed pumpkin container can have dimensions no greater than 30 x 30 x 60 inches.
- A retail cost of $50 cannot be exceeded.
- The inside of the pumpkin may not be altered (e.g. no freezing or adding chemicals)
- Pumpkin must free fall (e.g. no bungee cords).
- No Styrofoam peanuts or other small, non-biodegradable packaging fillers are allowed.
- Package must be designed so that the pumpkin can be removed for inspection by the ground crew within 30 seconds of hitting the ground.
- No electrical sources are allowed.
- The protective structure around the pumpkin must be designed with public safety in mind. Pumpkin enclosures that might splatter fragments or liquids toward the viewing audience will not be allowed. No heavy, sharp and/or protruding hard (e.g. metal) parts are allowed. The instructor for the course will have the final say on whether or not an entry is safe to drop. Such a decision by the instructor will be final.
- Team must clean up the drop site within 30 minutes of the drop.


Typical design concept. (source: The State)

Design Performance Criteria
- Durability (was the pumpkin protected?)
- Cost
- Weight (of the structure plus pumpkin)
- Accuracy (how close it came to the target)
- Safety
- Aesthetics

Design Report Requirements
The design report must show evidence that all steps of the design process outlined in the specified section of your textbook has been followed. The report must include the following sections:
- Coversheet (Project title, team member names, course name and number, date).
- Abstract, Table of Contents, Problem Statement.

- Background (Cite sources of information with footnotes).
- Alternative Designs Considered (Each team must document in detail at least 3 designs considered. Such documentation must include sketches of each design, and a written discussion of the extent that each design meets the design criteria stated above as well as any other criteria deemed important by the team).
- Final Design (Describe the final design, materials and methods. Also include appropriate engineering analysis, a qualitative assessment of the design, detail scale drawings that show the major components of the final design, and a parts list with source and cost information for each component. If any on-hand materials are used, you must still include source and cost information).
- Design Evaluation (Discuss the procedures and physical environment used to evaluate the prototype, and discuss the performance of your prototype during the test.
- Conclusions and Recommendations (Explain what you believe to be true as a result of your work. Make recommendations for selling the design as is, or for improving the design).
- Appendix (Include brief descriptions of the contributions of each member to the team and notes from team meetings. Also include any relevant supplemental information).

Design Project Grading

The grade for each student on the team will be based on a combination of the team grade and the contribution of each student to the team's work. A team grade of zero (0) shall be assigned if one or more of the Design Constraints stated above are violated, a working prototype and a draft of the design report are not delivered for evaluation on the specified date and time, or a written Final Design Report is not delivered to the instructor on the specified date and time. The team grade for the design project will be assigned based on:

- Degree to which the final design meets the Design Performance Criteria (30%).
- Adherence to the Design Report Requirements (60%).
- Professional Appearance of the Design Report (10%).

Concluding Remarks

The three activities described above have been used successfully with first-semester freshen students at the University of South Carolina. According to student survey results, students in the course sections that used the laboratory data as the basis of the computer tool training component found the experience more interesting than those that did not. Student comments noted that through the labs, they actually got to see engineering principles in action instead of just reading about them. Most students thought the design project was the best part of the course, but this may have been influence by the amount of media attention (4 local TV stations and the local newspaper) at the prototype testing event.

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