

Combining Laboratory Innovation and a Design Experience into Tools for Mechanics

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Abstract

Hands-on laboratories and the engineering design process are valuable experiences by which to enhance undergraduate engineering education. This paper discusses the integration of an NSF sponsored Course, Curriculum and Laboratory Innovation project, the multidisciplinary design experience and teaching tools for statics and solid mechanics courses. A team of faculty in the College of Engineering at Rowan University proposed development of hands-on and visualization tools for use in mechanics courses. This proposed project was then developed by a group of students in the Junior-Senior Engineering Clinic, an upper level, multidisciplinary design course. The student teams consisted of Mechanical, Civil and Electrical Engineering students. The developed tools consist of physical simply-supported and cantilever beams that are instrumented with load cells. The students can apply various loading conditions to the beams and for the simply-supported case, also move the location of the supports. A data acquisition card is used to import the measurements from the load cells and displacement transducers and a Labview graphical user interface allows the user to find reaction loads and plot deflections, shear and bending diagrams.

Introduction

Statics and Solid Mechanics are typically taught at the sophomore level in lecture format. Several multimedia courseware initiatives in these subject areas have been developed that focus on theory, problem solving, or drill and practice.^{1,5,9,10} Hands-on or computer-aided simulations have also been used in engineering education.^{2,4,6,7,12} The authors have found that curriculum improvement is needed in the areas of problem formulation and integration of hands-on force input with computer visualization tools. In entry-level engineering courses, students often have difficulties determining the external and reaction forces and moments that must be included in free body diagrams and equations of equilibrium or solving for stresses and deformations.

Enhancement of these topics can be brought about through development of visualization and hands-on learning aids to supplement the theory taught in the classroom. Because Statics and Solid Mechanics form the foundation of a large portion of upper-level engineering courses, it is

critical that students have a strong working knowledge of concepts in these subjects. Recognizing that students learn in a variety of ways, it is important to employ various formats for learning along with the traditional lecture.^{3,6,8,11} Incorporating the use of touch and visualization into the learning process by having students pull, bend and twist a structure and view the resulting reactions, deformations and stresses will aid in development of student skills in problem formulation, solving and analysis.

This paper discusses the multidisciplinary design experience undertaken by the group of undergraduate students in the development of hands-on and visualization tools. These tools were designed to enhance student learning in statics, solid mechanics and other engineering courses involving the concepts of forces, deformations, moments and shear. Since statics and solid mechanics courses are core courses in the Mechanical and Civil Engineering programs and taught commonly between these programs, faculty and students in these programs have joined together in this effort. The tools were developed to meet the goals and objectives listed below.

Development of the Tools

The hands-on and visualization tools are primarily for use in the core courses of Statics and Solid Mechanics and secondary use in upper level courses in Mechanical and Civil Engineering and the Engineering Clinics. The tools are used to address the following difficulties students often have:

1. Determining reaction forces and moments required for stability of a system.
2. Visualizing the deformation of a structure under applied loads.
3. Obtaining shear and bending moment distributions in beams.

Two teams of junior and senior students were chosen for each of the two beam scenarios (cantilever and simply-supported). Each group divided the project into four phases: design, analyze, build and test, then formulated lists of tasks and goals to accomplish the project. Additionally, students were hired throughout the academic year to modify and improve the tools and build multiple units, which provided them with employment and hands-on experience.

Physical Models

Construction of one cantilever test-stand (Figure 1) requires six load cells, one torque cell, supporting fixtures and an acetyl beam. Dual tension-compression load cells rated to 100 lb measure loads needed to compute bending moments perpendicular to the beam direction and axial loads. Ball slides were used to allow vertical motion of the beam, and a 50 lb tension-compression load cell measures loads applied in vertical direction perpendicular to the length of the beam. A rotational bearing was used to isolate forces from a 100 lb-in rated torque cell used to measure torsional moment about the beam axis. The bar was chosen to be acetyl C with a circular cross-section of 1.5 in. diameter and length of 15 in.

The cantilever beam was designed for analysis of concentrated loads or moments applied to the beam. Currently the deflection, shear force diagram and moment diagram for bending have been programmed in the graphical interface to display this figures. Plots of stresses due to combined axial, torsional and bending loading conditions will be added to the interface at a later date.

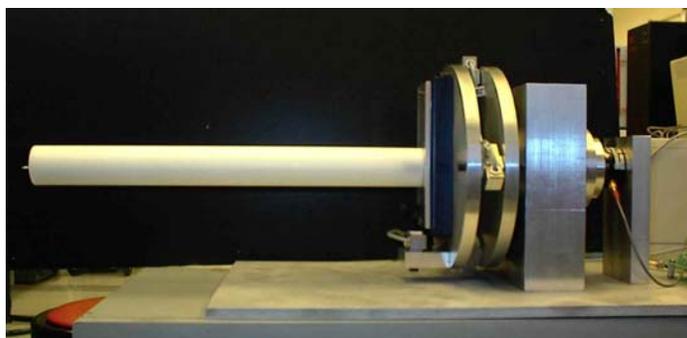


Figure 1: Visual Cantilever Beam

One simply supported test-stand (Figure 2) requires two tension-compression load cells rated to 100 hundred pounds, supports and acetyl beams of various cross-sections. To achieve these support conditions, hinges were designed and fabricated and linear slides were purchased, both of which allow the beam to pivot and slide at the supports. The hinges were mounted on supports to ensure the load cells are subject only vertical load. A track system with locking thumbscrews was installed to allow the user to move either support to the desired position with ease. A hanger was created that allows the user to add standard gym weights to a point load without interfering with the supports system. This allows the user to remove the load or move it anywhere on the bar.

A solid square bar, a hollow square tube, and an I-beam were selected to illustrate how the arrangement of mass in the beam (moment of inertia) affects strength and therefore performance. An important constraint of the beam shape was that the width and height were at least 10 times the length of the beam to ensure the long, slender beam assumption for beam theory. Acetyl-C and PVC materials were chosen for the beam since they are lightweight, easy to machine and allow for some visible deflection.



(a)



(b)

Figure 2: Visual Simply Supported Beam a) Solidworks drawing, b) physical model

Shear force, moment and deflection equations were determined to accommodate the following configurations of a simply supported beam with a single point load, P, Figure 3.

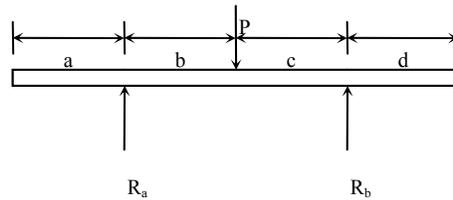


Figure 3 – Simply supported beam loading

Where ‘Ra’ and ‘Rb’ are the reaction forces of the two supports; ‘P’ is the point load; and ‘a’ and ‘d’ and ‘b’ and ‘c’ are the distances from the ends to the outside forces and the distance between the outside forces and the inside force respectively.

1) *Newton’s 2nd Law: entire bar*

The point load can be written in terms of the reaction forces by summing the forces and summing the moments at a certain point.

$$\Sigma F = -R_a + R_b - P = 0 \quad \longrightarrow \quad P = R_b - R_a$$

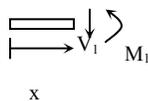
$$\Sigma M_A = -P(b) + R_b(b+c) = 0 \quad \longrightarrow \quad P = R_b(b+c)/(b)$$

Since the reaction forces are known from the load cells, the magnitude and placement of the point load can be found with these equations.

2) *Newton’s 2nd Law: sections of bar*

By taking four “slices” of the bar and taking the sum of the forces and the sum of the moments at each slice, the shear forces and the moments can be found.

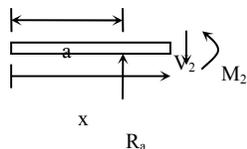
Section 1



$$\Sigma F = -V_1 = 0 \quad \longrightarrow \quad V_1 = 0$$

$$\Sigma M = M_1 = 0 \quad \longrightarrow \quad M_1 = 0$$

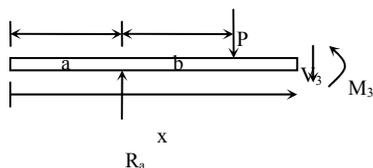
Section 2



$$\Sigma F = R_a - V_2 = 0 \quad \longrightarrow \quad V_2 = R_a$$

$$\Sigma M = -R_a(x-a) + M_2 = 0 \quad \longrightarrow \quad M_2 = R_a(x-a)$$

Section 3

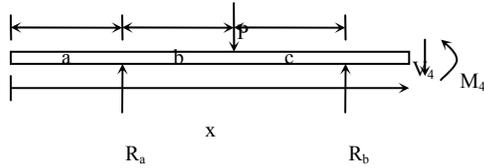


$$\Sigma F = R_a - P - V_3 = 0 \quad \longrightarrow \quad V_3 = R_a - P$$

$$\Sigma M = -R_a(x-a) + P(x-a-b) + M_3 = 0$$

$$\longrightarrow M_3 = R_a(x-a) - P(x-a-b)$$

Section 4



$$\Sigma F = R_a - P + R_b - V_4 = 0$$

$$\rightarrow V_4 = R_a - P + R_b$$

$$\Sigma M = -R_a(x-a) + P(x-a-b) - R_b(x-a-b-c) + M_4 = 0$$

$$\rightarrow M_4 = R_a(x-a) - P(x-a-b) - R_b(x-a-b-c)$$

Where 'x' is the distance from the left end, V is the shear force, and M is the moment. Note that each equation only works for the section it is in.

3) Solve for deflection

Since $M = E I \frac{d^2y}{dx^2}$ where E is the modulus of elasticity and I is the moment of inertia of the cross-section, the deflection y of each section can be attained by integrating each of the moment equations and applying the appropriate boundary and matching conditions.

$$y_1 = (a-x)(b^3R_a + 3b^2cR_a + 3bc^2R_a - c^3R_b) / (6(b+c)EI)$$

$$y_2 = -(a-x)(-b^3R_a - 3b^2cR_a + a^2(b+c)R_a + c^3R_b - 2a(b+c)R_ax + cR_ax^2 + bR_a(-3c^2 + x^2)) / (6(b+c)EI)$$

$$y_3 = (a+b+c-x)(a^2(b+c)R_b + b^3(R_a + R_b) - b^2(3R_a + 2R_b)x + cR_bx(c+x) + bx(-c(3R_a + R_b) + R_bx) + a(b+c)(b(3R_a + 2R_b) - R_b(c+2x))) / (6(b+c)EI)$$

$$y_4 = -(a+b+c-x)(2b^3R_a + 6b^2cR_a + 3bc^2(R_a - R_b) - 2c^3R_b) / (6(b+c)EI)$$

These equations are used in the graphical interface to plot deflection, shear force and moment along the length of the beam.

Graphical Interface

A 10 V power supply, data acquisition card, one computer with a large screen monitor, and LabView™ software make up the common hardware for interfacing the beams and computer graphics. The complete set-up for the simply-supported beam is shown in Figure 3.

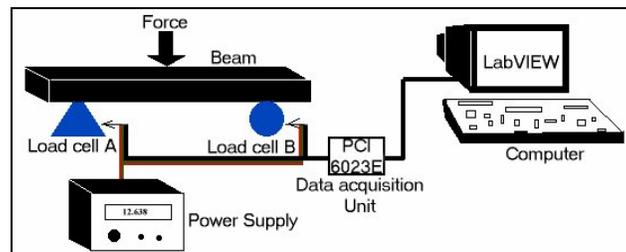


Figure 3: Setup of the Visual Beams apparatus

The 10 V power supply is used to power the load cells. A PCI-based ADC card manufactured by National Instruments (PCI-6023E DAQ) is for the data acquisition. This card has 12-bit resolution, 200 kS/s sampling rate and 16 analog input channels and is easily used with the LabView™ software. Measurements from the load cells taken through the data acquisition card are imported for use in various LabView™ virtual instruments (VI), which graphically display deflection, moment and shear corresponding to the physical visual beam setup.

The front panel for the first VI consists of an ‘X-Y chart’ that displays the bending of the beam as shown in Figure 4. For the simply-supported beam, the user needs to input four values 1) position of the supports A and B 2) position of the weight, 3) scaling factor along the Y-axis, 4) number of points to be used in the display.

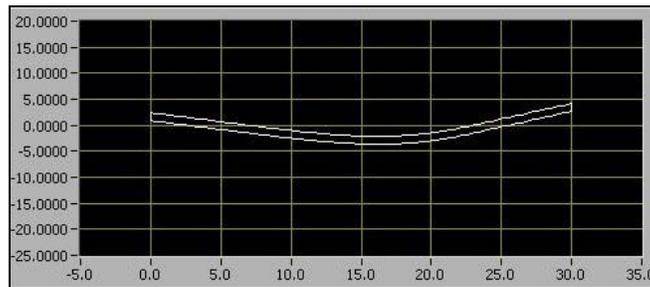


Figure 4: Bending diagram of beam

In the wiring diagram, the VI is divided into three sections that execute in sequence. The first section acquires all the data from the user and processes it to create the variables that are used in equations for deflection, shear and moment. These variables are then passed to the second section. The second section initially creates an array of numbers going from 0 to 30 (length of the beam). This is the X input to the chart that plots the bending diagram. For each value of X, this section calculates the corresponding value of Y. This calculation is done by a VI called ‘Decision.vi’.

This VI takes as input, the position variables and the reactions at the two supports. It contains the generalized form of the beam bending equations. Based on these equations, the deflection is calculated and sent back to the second section of Combined_Graph.vi. The X and Y values are then sent to the front panel to be displayed. The third section of the Combined_Graph.vi is simply a wait function that waits for 0.5 seconds after each screen update. This wait function was introduced only to give the operating system some time to clear the RAM after the calculations had been performed.

The VI for displaying the shear and moment diagrams is called again using the inputs of position of supports and position of the weight. Generalized equations for moment and shear force as a function of the position along the beam length are used to compute the value of shear force and moment along the length of beam. The front panel of this VI displays the shear and moment diagrams for the simply-supported case (Figure 5).

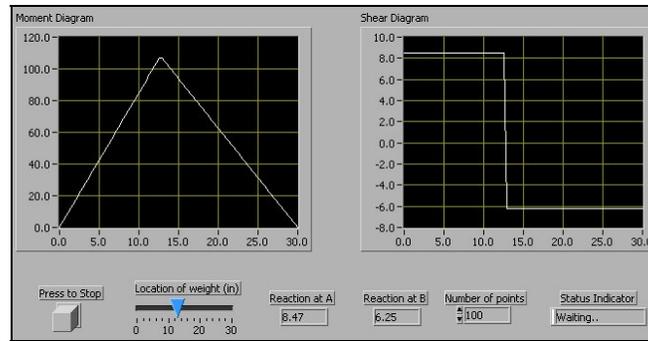


Figure 5: Shear and Moment Diagrams

Summary

The experience of integrating a Course, Curriculum and Laboratory Innovation (CCLI) proposal, the multidisciplinary design experience and teaching tools for statics and solid mechanics courses was successful for all involved. A team of faculty in the College of Engineering at Rowan University proposed the development of hands-on and visualization tools for use in mechanics courses through the NSF-CCLI program. This project was then developed by a group of students in the Junior-Senior Engineering Clinic, an upper level, multidisciplinary design course. The student teams consisted of Mechanical, Civil and Electrical Engineering students, each bringing various strengths and skills to the project. The students designed, built and test the systems that consist of physical simply-supported and cantilever beams that are instrumented with load cells and a Labview graphical user interface allows the user to find reaction loads and plot deflections, shear and bending diagrams. This positive experience allowed the students to solidify the fundamental concepts of statics and solid mechanics in their minds; to design, build and test and working system; and to work together and learn from one another in a multidisciplinary team.

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Biographical Information

JENNIFER KADLOWEC is an assistant professor of Mechanical Engineering, who has taught Statics, Solid Mechanics and Dynamics courses. She has a variety of experience in the development of laboratory courseware through NSF projects and has authored ASEE publications of these works. Her research interests include experimental investigation and modeling of mechanical behavior of materials.

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PARIS VONLOCKETTE, ERIC CONSTANS, BEENA SUKUMARAN, and DOUGLAS CLEARY are faculty in the College of Engineering, Rowan University and co-investigators of the NSF CCLI grant for this project.