Session 1526

Hands-on Learning Tools for Engineering Mechanics

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Abstract

A team of faculty and students in the College of Engineering at Rowan University are developing hands-on and visualization tools for use in mechanics courses. 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, stresses, and shear and bending diagrams. The tools are designed to help students overcome difficulties in working with forces, moments, displacements and stresses. The tools are being developed so that critical thinking and problem solving skills of students will be improved by engaging them in the learning process through individual experimentation. The equipment will have a positive an impact on student learning in courses the Mechanical and Civil Engineering programs and the interdisciplinary design clinic sequence as well as benefit students with various learning styles.

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 investigators 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 do not know where to start a problem or how to determine which external and reaction forces must be included in free body diagrams and equations of equilibrium. Furthermore, the stresses caused in objects by axial, torsional, bending, and combined loadings are often quite difficult for students to visualize.

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 work-in-progress paper describes hands-on and visualization tools to enhance student learning in statics, solid mechanics and other engineering courses involving the concepts of forces, moments, displacements and stresses. Since statics and solid mechanics courses are core courses in the Mechanical and Civil Engineering programs and taught commonly between these programs, faculty in these programs have joined together in this effort. The tools were developed to meet the goals and objectives listed below. Descriptions of the tools and their intended uses in various courses are given along with the equipment.

Goals and Objectives

The goals of this initiative are listed below. The manner in which these objectives will be met is developed in the project description.

1. Develop hands-on and visualization tools to aid students in problem formulation and enhance learning opportunities.
2. Integrate software simulation and hands-on experiences into lectures.
3. Ensure that the equipment that is developed has an impact on core courses in Statics and Solid Mechanics as well as advanced courses in the Mechanical and Civil Engineering programs and the interdisciplinary design clinic sequence.
4. Improve the critical thinking and problem solving skills of students by engaging them in the learning process, allowing individual experimentation and providing for interchangeability of the tools.
5. Ensure material is taught in variety of ways to benefit students with various learning styles.

Development and Use of Hand-on and Visualization Tools

The development of 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 will 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. Determining the types of stresses resulting from axial, torsional and bending loads.
4. Obtaining shear and bending moment distributions in beams.

The following paragraphs describe specific tools to be developed and their use in various Civil and Mechanical Engineering courses.

Statics

The tools for Statics involve hands-on demonstrations and visualization in real time for determination and measurement of reaction forces and moments due to forces imposed onto a bar or structure by a student. Often students can solve equations of equilibrium but have difficulty understanding force and moment components. Also, students have difficulties understanding the reactions generated by specific constraints on a bar (e.g. pinned, rigid, or free). These difficulties interfere with the formulation of equations needed to solve a problem and the understanding of material that is presented later.

In order for students to experience reaction forces and moments, two simple experiments will be developed. The first experiment involves two beams, one with a fixed end constraint, the other with a ball and socket end constraint (see Figure 1). These beams will allow the students to push on the free ends of the beams and witness the effects at the constrained end.

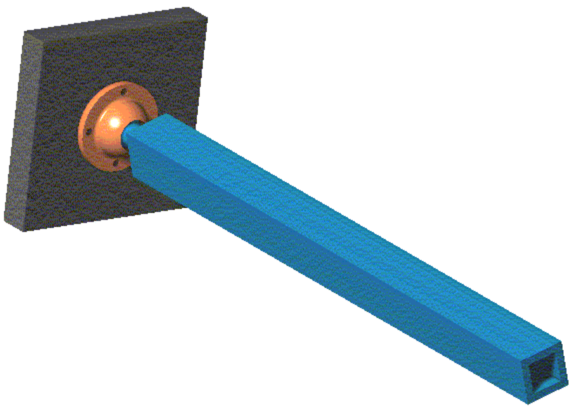

Figure 1: Beam with Ball and Socket Constraint

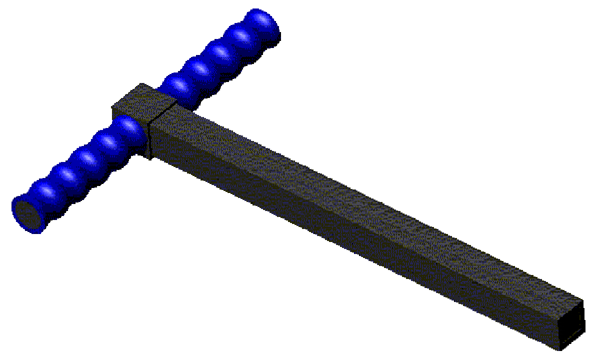

Figure 2: Beam with Reaction Handles

The second experiment is simply a rod with handles (Figure 2.) One student holds the handles, while another student applies a force at the opposite end of the rod. The student holding the handles feels the reaction force and moment necessary to prevent the rod from moving. Both of these experiments are designed to improve students' ability to sense reaction forces and moments intuitively.

The major component of this work is the second set of tools: the Visual Simply Supported Beam (VSSB) and the Visual Cantilever Beam (VCB). These beams involve hands-on experience and visualization of reaction forces and moments, as well as deformations and stresses. Both beams are instrumented with load cells, which measure force and moment reactions that occur at the support(s). In order for students to analyze a variety of configurations, beams of different cross-sections can be interchanged in both the Cantilever and Simply Supported set-ups, and the placement of the simple supports along the length of the beam can be changed. The force and moment measurements will be interfaced with a graphical representation (free body diagram, FBD) of the beam such that the reaction moments and forces will be drawn on the FBD. Discrete or continuous visualization of the reactions due to user-generated load inputs and interaction in changing constraints and loading conditions will be available in real time.

Solid Mechanics

The focus in Solid Mechanics is the visualization of stress/strain contours on prismatic bodies resulting from user-generated single or combined loadings. Major concepts include

1. Axial stress and strain
2. Torsion - shear stress and angle of twist
3. Beam deflections, bending moments, bending stress
4. Combined loadings

The Visual Cantilever Beam (Figure 3) and the Visual Simply Supported Beam (Figure 4), both interfaced with computer visualization software, will enhance teaching of these concepts. The Simply Supported Beam will be used specifically for illustrating concepts of beam deflection, bending moments and bending, shear and combined stresses. The Cantilever Beam will be used for individually illustrating axial, torsional and bending deformations and stresses as well as combinations of these loading conditions.

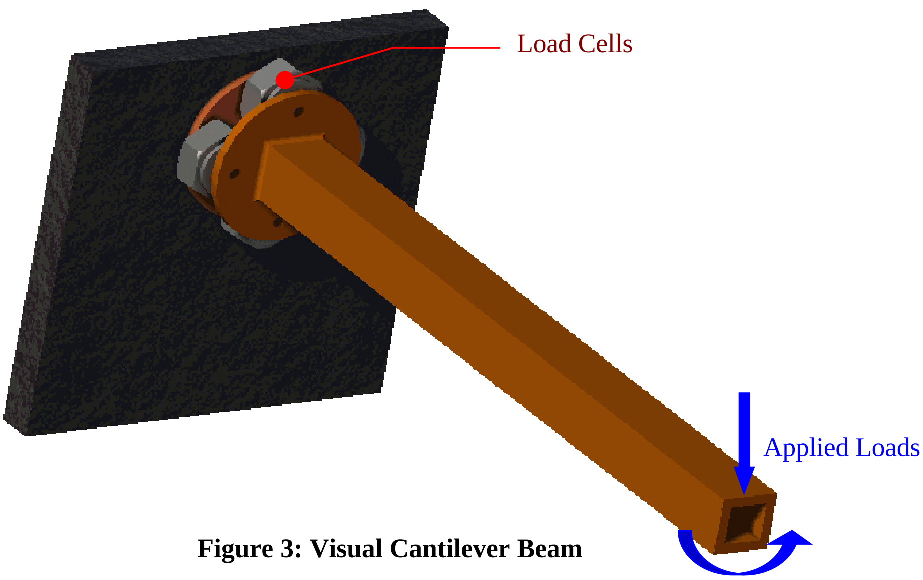

Figure 3: Visual Cantilever Beam

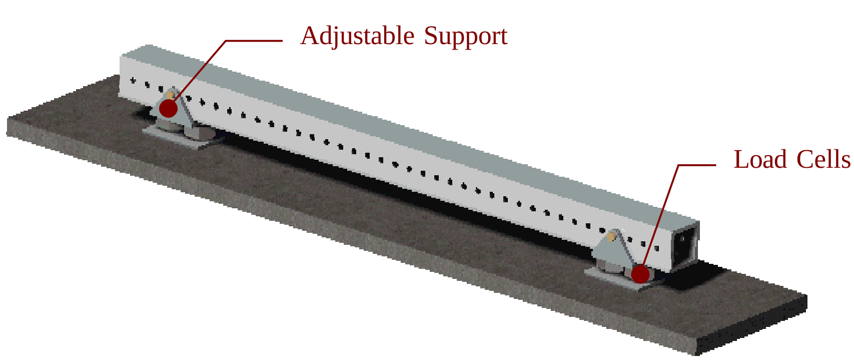

Figure 4: Visual Simply Supported Beam

Load cells are applied at the fixed end of the Cantilever Beam and at the supports of the Simply Supported Beam. The force and moment measurements from the physical beam are interfaced with a graphical representation of the beam such that the reaction moments and forces will be drawn on the FBD. The measurements of forces and moments are used as inputs for analytic expressions for deformations and stresses within the beams. A three-dimensional model on the computer screen will show stress or strain distributions along the bar in real-time.

The VSSB and VCB will allow students to see variations in stress levels that follow in-class equations for bending, torsion, and axial loading cases. It is also desirable to have the students see and apply loads to bars of various materials and cross-sections and see how these differences change the patterns of stress and strain. For this reason, physical beams of different materials and cross-sections (solid, square tube, I-beam) are available. Note that the reaction force and moment measurement units for both beam configurations remain the same, so the various beams are interchanged as needed. These tools will allow the student to experiment with loading conditions of their own and analyze the effects that changes in cross-section, size and material have on deformations and stresses and compare these with theory taught in class. Using the computer interface, the students will also be able to check bending moment and shear diagrams at user-specified points along the bar.

Machine Design

One major component of the Machine Design course at Rowan is stress analysis in shafts. Central to the correct solution of shaft design problems is visualization of stresses under complex loading conditions. As shown in Figure 5, a typical gearshaft is subject to torsional shear stresses, bending stresses in two planes and an axial thrust load (from the helical gear). The Visual Cantilever Beam will aid tremendously in developing students' physical intuition and insight into the complex loading conditions found in most Machine Design problems.

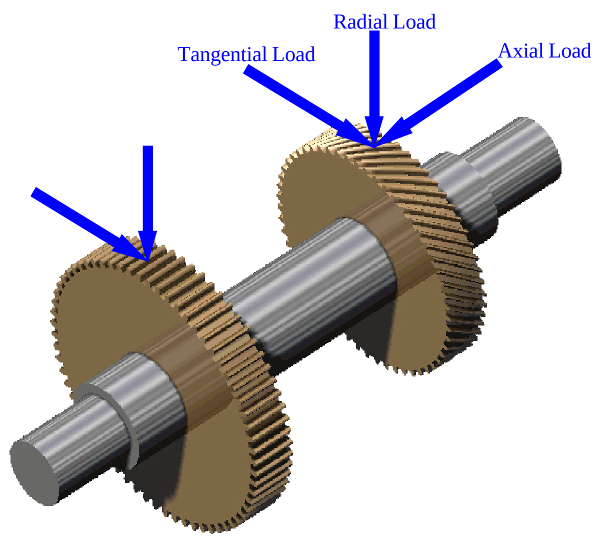

Figure 5: Typical Shaft Analysis Problem

Continuum Mechanics

The visualization system will provide an invaluable resource for upper-level continuum mechanics courses. In continuum mechanics the quantities of interest, which include spatial variations of tensor fields, are not visible to the naked eye. Stress and strain are a clear example: although the effects on a body are visible, the quantities themselves can never be visibly perceived. Often stress, strain, and other *invisible* variables are removed from modes of learning that involve sight. The ability to visualize the components of deformation dependent, general tensor fields can be incorporated into the system to augment the learning process by addressing visual learning modes.

Structural Engineering I

Structural Engineering I is the first course in the Civil and Environmental Engineering curriculum following Statics and Solid Mechanics. The course content is primarily Reinforced Concrete Design. Fundamentals required from Statics and Solid Mechanics include construction of shear and moment diagrams, stress calculations, and the ability to visualize stress patterns. The development of shear and moment diagrams and calculation of stresses is required in order to design or analyze sections. The visualization of stress patterns is particularly important because the direction of the principle tension stresses greatly influences the placement of reinforcing steel. The ability to visualize the stress patterns is an immense aid in understanding the reasons for the various locations of steel within a beam. Visualization of deformed shapes in beams, columns, and frames is necessary in order to develop pattern-loading schemes that result in worst case loading conditions. The visual beams will particularly useful in reviewing this material.

Structural Engineering III

The third course in the Structural Engineering sequence deals extensively with design and analysis of steel frames. Similar to Structural Engineering I, the visualization of deformation and stress patterns provides a designer with valuable insight into behavior of the frame. This knowledge is very useful in the decision making process required for selection of bracing systems and the selection of the type of connections. Further, an understanding of the rotational constraints required and the forces the designer wants the connection to transfer facilitate the design of connections. The students can return to the simpler hand-held bars and the visual beam devices at appropriate points during the Structural Engineering III course to refresh this understanding.

Engineering Clinics

The eight-semester Engineering Clinic sequence will benefit from these tools. Freshmen and sophomore clinics involve measurement and basic engineering analysis. Since many topics are covered in these courses, the use of hands-on and visualization tools will be useful in teaching material typically taught in statics and solid mechanics. Having these tools available in the Materials, Dynamics and Systems Laboratory will allow students in the junior and senior level clinics as reference materials to refresh their knowledge of statics and solid mechanics concepts needed for solving design problems.

Implementation and Equipment

The Visual Cantilever and Simply-Supported Beams, along with associated computer interfaces, have been developed by junior and senior students at Rowan University through the Junior/Senior Engineering Clinic course. Additionally, students were hired throughout the academic year and the summer to help in development of the tools, which will provide them with employment, experience and further capabilities in Statics and Solid Mechanics.

Construction of one cantilever test-stand requires six load cells, one torque cell, supporting fixtures and an acetyl beam. Dual tension-compression load cells rated to 100 hundred pounds have been chosen to measure bending moments perpendicular to the beam direction and axial loads. Two fifty pound tension-compression load cells have been chosen to measure loads applied in two orthogonal directions perpendicular to the beam. A 100 lb-in rated torque cell measures moment about the beam axis. One simply supported test-stand requires two tension-compression load cells rated to 100 hundred pounds, supports and acetyl beams of various cross-sections. Aluminum stock was purchased and machined for the support fixtures and acetyl bars were used for the beams.

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 graphics. The complete set-up for the simply-supported beam case is shown in Figure 6.

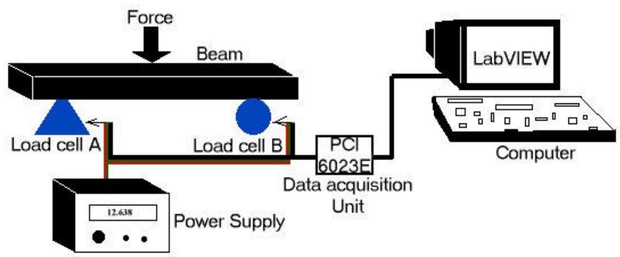

Figure 6: Setup of the Visual Beams apparatus

A PCI-based ADC card manufactured by National Instruments (PCI-6023E DAQ) is for the data acquisition portion of the project. This card has12-bit resolution, 200 kS/s sampling rate and 16 analog input channels. One of the main reasons for acquiring the PCI-6023E was that it comes with a National Instruments driver that can be used with the LabView™ software. Graphical user interfaces in LabView™ allow the students to view beam deflection as well as shear and bending moment diagrams.

Summary

A set of hands-on and visualization tools for use in mechanics courses is under development at Rowan University. These tools consist of simply-supported and cantilever beams, which are instrumented with load cells and a Labview graphical user interface that allow the user to find reaction loads and plot deflections, stresses, and shear and bending diagrams. The tools are designed to help students overcome difficulties in working with forces, moments, displacements and stresses. Currently the simply-supported and cantilever beams have been built and instrumented with load cells. The computer interface has been completed for the simply-supported case, while the interface for the cantilever beam is still under construction. Both will be completed and used in Fall 2002 in the statics and solid mechanics courses. It is hypothesized that this set of tools will have a positive an impact on student learning in courses the Mechanical and Civil Engineering programs and the interdisciplinary design clinic sequence as well as accommodate the various learning styles of the students.

Acknowledgements

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Bibliography

1. R. Abbanat, K. Gramoll and J. Craig (1994) "Use of Multimedia Development Software for Engineering Education Courseware", Proceedings of the ASEE Annual Conference, p. 1217- 1222.
2. S. Cooper and G. Miller, (1996) "A Suite of Computer-Based Tools for Teaching Mechanics of Materials", *Computer Applications in Engineering Educatio*n, 4(1), p. 41-49.
3. R. Felder and L. Silverman, (1998) "Learning and Teaching Styles in Engineering Education", *Engineering Educatio*n, p. 674-681.
4. K. Gramoll (1993) "Interactive Beam Analysis Program for Engineering Education," *ComputerApplication in Engineering Educatio*n, Vol. 1, No. 6, p. 469-476.
5. S. Holzer and R. Andruet (1998) "Learning Statics with Multimedia and Other Tools", Proceedings of the ASEE Annual Conference, Session 1658.
6. S. Kresta (1998) "Hands-on Demonstrations: An Alternative to Full Scale Bench Experiments", *Journal of Engineering Educatio*n, p. 7-9.
7. M. Rucki, G. Miller and S. Cooper (1998) "Direct Manipulation Visualization of the Behavior of Framed Structures in the ‘Dr. Frame’ Environment" Proceedings of the ASEE Annual Conference, Session 1268.
8. B. Solomon (1995) in Keys to Success, by Carol Carter and Sara Lyman-Kravits, Prentice Hall.
9. G. Staab (1998) "An Interactive Computer Tutorial for Strength of Materials" Proceedings of the ASEE Annual Conference, Session 2668.
10. R. Toogood, B. Lipsett, S. Lorimer, T. Hrudey, A. Peterson and S. Varnhagen (1998) "Computer Based Learning for Engineering Mechanics: If we build it, will they come?" Proceedings of the ASEE Annual Conference, Session 3666.
11. P. Wankat and F. Oreovicz (1993) Teaching Engineering. Toronto: McGraw-Hill.
12. J. Zecher, (1996) "An Interactive Graphics Oriented Beam Analysis Program", Proceedings of the ASEE Annual Conference, Session 3520.

Biographical Information

JENNIFER KADLOWEC is an assistant professor in the Mechanical Engineering Department, who has taught Statics, Solid Mechanics and Dynamics courses. She has experience in the development of multimedia courseware for dynamics and vibrations and authored ASEE publications of these works. She has further interests in development and assessment in multimedia curriculum and has participated in numerous workshops on teaching and learning. Her research interests include experimental investigation and modeling of mechanical behavior of materials, particularly rate and temperature dependence in elastomers.

PARIS VONLOCKETTE has a strong interest in undergraduate education, which began while working as an instructor in the PREP program, which provides introduction to college level physics and math for high school students who express an interest in engineering. He recently co-authored a paper on the Rowan Engineering Sophomore Clinic Program. He is also interested in the use of visualization tools in various applications. In addition to educational interests, Dr. von Lockette is an active researcher in the field of computational and theoretical polymer science and has published in *Macromolecules* (1999) and *Acta Mechanica* (1999).

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