

Use of Computers in Mechanics Education at Ohio State University*

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Computers offer opportunities for enhancing undergraduate mechanics instruction. Two approaches utilizing computers in undergraduate mechanics courses at the Ohio State University are presented herein. One approach focuses on requiring students to formulate the equations that define general solutions to classical mechanics problems with variable parameters. Computers are used to solve these equations and plot the results. Students evaluate their results and answer questions based on their solutions. The second use of computers involves mechanics tutorials developed at Ohio State for strength of materials. Tutorials contain theory, examples, and quizzes for students to attempt. Both approaches appear to complement traditional in-class instructional approaches.

INTRODUCTION

THE TOPIC of undergraduate engineering mechanics is taught in a sequence of three courses, Introduction to Solid Mechanics (EM 400), Dynamics (EM 430) and Strength of Materials (EM 440). Introduction to Solid Mechanics is a 5 credit hour course taken by all undergraduate engineering students. Roughly $3\frac{1}{2}$ to 4 hours of this is equivalent to a traditional statics course while the remainder is an introduction to Strength of Materials. Depending on their major, some students will continue on to take the 3-hour Strength of Materials course EM 440. This course combined with the introductory material in EM 400 is roughly equivalent to a traditional Strength of Materials course. EM 430 is a 4-hour traditional Dynamics course that many undergraduate engineering students take.

Several years ago a concerted effort was initiated to utilize computers in the teaching of undergraduate mechanics at Ohio State. It was recognized, however, that using computers just for the sake of using computers or to appear 'modern' could prove to be a detriment to teaching the fundamentals of engineering mechanics. The traditional approach of taking pencil to paper, drawing free body diagrams and struggling with equilibrium equations, kinematic constraints, etc. is still essential to grasping the fundamentals of mechanics. For this reason, every effort was made to find ways to use the computer that would augment rather than detract from traditional methods. Of the various approaches tried, this paper discusses the two that have been the most successful: computer-aided instruction (CAI) problems and interactive computer tutorials.

COMPUTER-AIDED INSTRUCTION

Problems posed in computer-aided instruction (CAI) are very similar to typical homework exercises except that solutions are obtained in terms of one or more parameters. The purpose in assigning CAI problems is three-fold:

1. to require students to use computers as a tool and be familiar with computing and plotting software;
2. to afford students some experience in solving classes of problems rather than a single problem with only one set of numerical values as in a typical textbook problem;
3. to provide students experience in formulating solutions to problems in terms of meaningful non-dimensional parameters.

Thus, the assigned CAI problems focus on parametric studies of simple problems in basic mechanics that involve numerical computations and graphing. The solution of these problems requires three distinct steps. First, the student must supply a mechanics solution to the problem containing free body diagrams, given loading and geometric conditions and whatever governing equations are needed in terms of general parameters. Second, the student must supply a numerical solution involving one or more plots in which solutions of the equations in the first step are examined in terms of one or more variables specified in the problem statement. The students are free to use any software they wish. Third, the solution requires the students to ponder or 'make sense of' the equations or numerical results by identifying some physical phenomenon or application of relevance to engineering.

A variety of problem types has been used in each course. In the Introduction to Solid Mechanics

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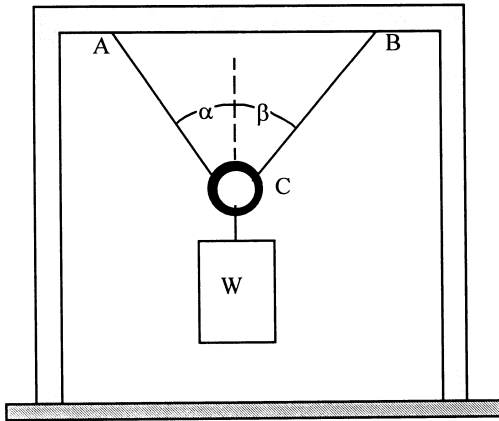


Fig. 1. Typical CAI problem involving equilibrium of a concurrent force system.

course, the most common types of CAI problems involve particle equilibrium (or equilibrium of concurrent force systems), rigid body equilibrium and strength of a deformable elastic body under simple loading. A typical concurrent force system equilibrium problem is shown in Fig. 1. The students are asked to obtain, from a free body diagram, expressions for the non-dimensional tensions (e.g. normalized with respect to the weight) in the two cables as a function of the angles α and β . The students are then required to make some plots for several special cases. For example, they are asked to consider the case $\alpha = \beta$ and then plot the non-dimensional cable tensions as a function of α for the range $0 \leq \alpha \leq 180^\circ$. The students are also told that they should restrict the vertical range of the plot to be between -4 and 4 . Many students neglect to do this on the first try and also forget that the default unit for angles is radians. The resulting plot looks very much like a sequence of vertical lines. When the vertical range is restricted and the appropriate conversions to radians are made, the student gets a plot with a singularity at $\alpha = 90^\circ$. This they should understand physically as representing the fact that the cables are incapable of supporting the weight as the angles approach 90° . The students are also asked to identify the range of values of $\alpha = \beta$ for which the solution is physically possible. This question is intended to reinforce the idea that the computer does not interpret physical limitations such as the fact that cables can only be in tension, never compression.

In the Strength of Materials course, the most common types of CAI problems involve plane stress from combined loading, shear, moment, slope and deflection of beams and statically indeterminate beams. Figure 2 shows a typical statically indeterminate beam problem. The students are first asked to find expressions for the moment and force reactions at the wall, the reaction force at the roller support, the internal bending moment, the slope, and the deflection in terms of the geometry and loading parameters. This is an ideal case for using symbolic algebra to find the reaction moment and forces. Several plots are required for this problem wherein the moment, slope and deflection curves are graphed for several different parameters. For example, slope and deflection curves at several values of ' b ' are plotted, comparisons of which illustrate that the maximum deflection occurs at the same location where the slope is zero.

In the Dynamics course, the most common types of CAI problems involve particle kinematics with acceleration given as a function of time or velocity, rigid body kinematics and rigid body dynamics. Generally speaking, CAI problems are very useful for providing students with insight into how variables change with time, something particularly difficult to convey in typical textbook or lecture presentations. An example of a rigid body dynamics CAI problem is shown in Fig. 3. The practical engineering motivation for the problem is provided in Fig. 3a which shows a large chimney in the process of falling after explosives have been detonated at its base. This is a classical problem that has been studied for some time [1, 2]. What usually happens is that the chimney breaks in two pieces as it falls, the upper piece hitting the ground last. One advantage of this problem is that it involves both dynamics and elementary strength of materials.

Requiring students to compare their results with those obtained by neglecting inertial effects can reinforce the importance of including dynamic effects in this type of problem. Following is a summary of the information and questions provided to the students.

1. Consider the chimney to be a uniform bar that is pinned at its base and released from rest in the vertical position. Use the coordinate system shown in the figure to define the internal

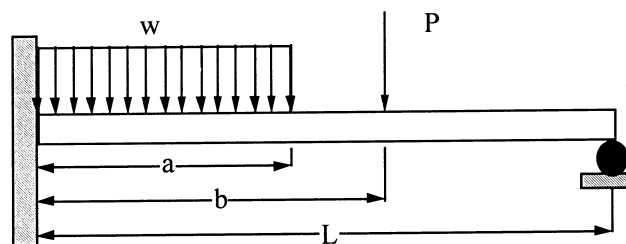


Fig. 2. Statically indeterminate beam problem used as a Strength of Materials CAI problem.

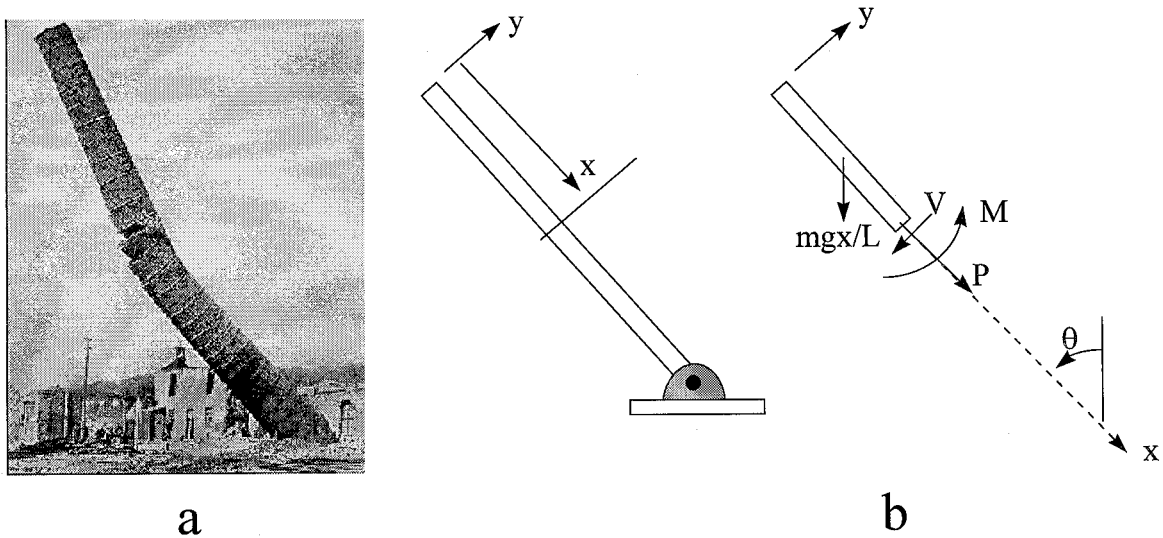


Fig. 3. A falling chimney used as a rigid body dynamics CAI problem.

bending moment M , the vertical shear force V , and internal axial force P .

2. Determine expressions for M and P as functions of x and θ . You may do this either manually or with the help of Maple[®] (or other software).
3. Plot M/mgL as a function of x/L for $\theta = 0, 15, 30, 45, 60, 75,$ and 90 degrees. All seven curves should be displayed on a single graph.
4. Plot P/mg as a function of x/L for the same values of θ as above.
5. With the sign conventions established in the figure, the maximum tensile stress in the chimney at any cross section will be given by:

$$\sigma_x = \frac{Mr}{I} + \frac{P}{A} \quad (1)$$

Here r is the outside radius of the chimney, I is the

area moment of inertia of the cross section, and A is the cross-sectional area. Define the normalized stress $\sigma_N = \sigma_x/|\sigma_m|$. This is the ratio of the maximum combined axial and bending stress at a given cross-section to the absolute value of the compressive stress ($|\sigma_m|$) at the base of the chimney due to its weight alone ($|\sigma_m| = mg/A$).

6. For a chimney with radius $r = 0.02L$ and $r_{inside} = 0.75r$, plot σ_N as a function of x/L for $\theta = 0, 15, 30, 45, 60, 75,$ and 90 degrees. Use this plot to estimate the values of x/L and θ for the chimney to break if failure occurs when the maximum tensile stress is equal in magnitude to $3 mg/A$.

Figure 4 shows a typical result for the plot required for Step (6) in the abbreviated problem description above. In order to estimate the values of x/L and θ for failure, the student needs to

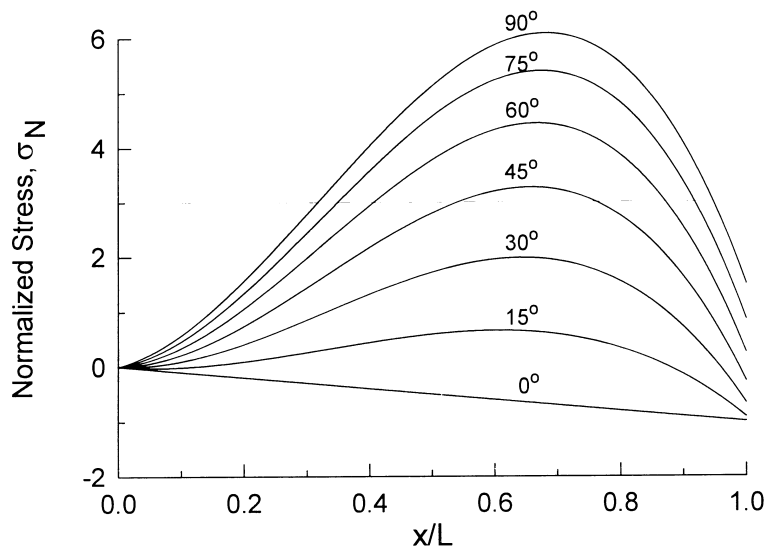


Fig. 4. Typical results showing the normalized stress as a function of x and θ in the falling chimney problem.

visualize how the curves in the figure unfold as time (and θ) increase. With this in mind they should see that failure will occur for an angle θ where the maximum point on the curve just touches the horizontal $\theta_N = 3$ line (dashed line in Fig. 4). The maximum point for the $\theta = 45^\circ$ curve has just exceeded the failure stress indicating that the failure angle is somewhere around 40° or so. At this point, most students will proceed with a trial and error approach, generating another graph like that in Fig. 4 and guessing values of θ until the maximum point on the curve reaches a value of 3. Students having more experience with programming languages such as Maple[®] or MathCAD[®] will find more efficient ways to arrive at the answer.

INTERACTIVE COMPUTER TUTORIALS

The second approach to using computers to enhance engineering mechanics education at The Ohio State University involved the development of interactive computer tutorials. This approach was motivated by the fact that the concepts taught in introductory engineering mechanics courses are often difficult for students to visualize and fully grasp. According to Owens and Helps [3], an effective multimedia program should clarify abstract topics that are difficult to understand using traditional teaching media and focus on teaching concepts rather than entertaining students with shallow special effects. Software is currently being developed for strength of materials which focuses on illustrating theory, presenting relevant examples, and supplying quizzes for users to work. Exploration-based education is beneficial if the explorer has a basic idea of what to look for and where it is located. Many students first encountering mechanics have problems identifying what is wanted, how to decompose the problem into simpler segments, and what information they need to solve the problem. For these students, a directed learning procedure similar to that presented as examples in texts is an appropriate procedure. Software using an exploration-based shell supported by a directed-education base can benefit both the self-confident and the unsure beginning student.

Establishing confidence and competence with a topic is sometimes complicated by missed or incomplete information, and a feeling of being judged by persons presenting the material. Computer software will unerringly supply complete information as often as requested, may be less intimidating than a teacher when a student is first learning a topic, and is never judgmental. Moreover, because screen sizes are limited and the amount of text, figures, and equations contained on each screen is small compared to that of a book, students who have difficulty assimilating text material are likely to spend more time interacting with a computer program

where information can be repeatedly presented in smaller segments. This provides an easier, more relaxed environment when attempting to master a concept. Using interactive computer software, a student can review missed or confusing material, explore examples, and work quizzes as often as needed to master a topic.

The computer software under development is intended to reinforce skills defined in the Bloom Taxonomy of Education Objectives [4]:

- knowledge (not repetition of memorized information);
- comprehension (repetition with understanding);
- application (use of information to solve problems);
- analysis (explaining or modeling system behavior);
- evaluation (critical thinking, evaluating criteria and choosing among alternatives) [5].

The computer software package contains four primary modules representing major topical areas. Within each primary module is a series of related topics, each containing sub-topics that include theoretical developments and examples. A series of quizzes accompanies each related topic. Examples and quizzes use randomly generated dimensions and forces so numerical answers are different with each use. Table 1 illustrates the components of the program.

Users can selectively navigate to a topic, explore sub-topics, work quizzes or simply view the solution. Students can reinforce concepts through directed exploration in which a general problem is defined with various aspects of the solution investigated at the student's discretion. Presentations can be structured so that each step in the solution procedure can either be viewed or skipped. For example, the primary module, 'Load-Stress Relations', contains 'Pure Bending' as a related topic. Within the 'Pure Bending' topic is the sub-topic of 'Eccentric Loading', for which an example is an option. Figure 5 represents an initial screen for the example of eccentric loading. The user has the option of selecting from three

Table 1. Strength of materials modules and related topics

PRIMARY MODULE	RELATED TOPICS
Stress, Strain, and Displacement	Concepts of Stress General Stresses Axial Stress and Strain
Load-Stress Relationships	Torsion Pure Bending Transverse Loading Stress Analysis
Transformations of Stress and Strain	Plane Stress Plane Strain Stress-Strain Analysis
Beams and Columns	Beam Analysis Beam Deflections Energy Methods Columns

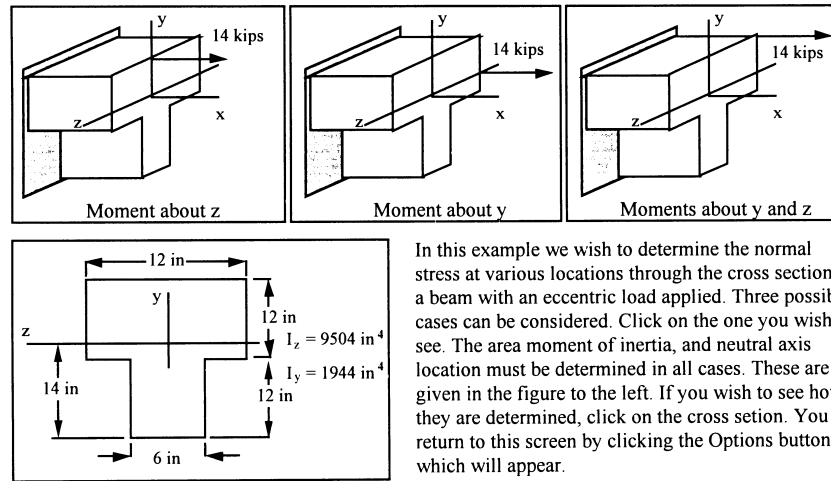


Fig. 5. Introduction screen for an example of eccentric loading.

different eccentric loads, each producing a different result. In addition, the user can reinforce his/her understanding of area moments of inertia by clicking on the cross section showing dimensions, which presents the computation of I with respect to both axes. After demonstrating the computation of I , the user is returned to the screen in Fig. 5, at which time the loading condition of interest can be selected.

Assume the user selects the option of exploring moments about the y - and z -axes. The next screen the user sees demonstrates the calculation of moments and shows a section of the beam with all applied loads and moments along with points (represented as material elements) which the user can randomly select for evaluation. In addition, an equation showing the normal stress as a function

of y and z is given. If the user selects, for example, point H, an element representing that point is displayed along with the calculation of the stress, as illustrated in Fig. 6. All points identified on the section can be accessed with similar calculations and elements presented for each. In addition, the user may select the Stress Distribution option, which provides a tabulated summary of the calculations for defining the normal stress at each point, and a visual display of the stress distribution through the cross section. The user is directed through the example by having the basic framework (geometry, dimensions, loads, etc.) defined for them, while being afforded the opportunity to explore different aspects of an extended problem.

Exploration is only one of the many options that can be used to demonstrate and reinforce concepts.

$I_y = 1944 \text{ in}^4$ $I_z = 9504 \text{ in}^4$
 $A = 216 \text{ in}^2$

The eccentric 14 kip load produces the bending moments shown. The normal stress at any point in the cross section is given by

$$\sigma_x = \frac{P}{A} + \frac{M_z y}{I_z} - \frac{M_y z}{I_y}$$

$$= \frac{14 \text{ kip}}{216 \text{ in}^2} + \frac{(140 \text{ kip-in})y}{9504 \text{ in}^4} - \frac{(84 \text{ kip-in})z}{1944 \text{ in}^4}$$

The normal stress on nine elements can be examined. Click the element (A, B, C, etc.) on the cross section for which you wish to see the stress computation. Click the Stress Distribution button to see the stress distribution over the entire cross section.

Stress Distribution

The coordinates of point H are $y = -8 \text{ in}$ and $z = 3 \text{ in}$

$$\sigma_x = \frac{14 \text{ kip}}{216 \text{ in}^2} + \frac{(140 \text{ kip-in})(-8 \text{ in})}{9504 \text{ in}^4} - \frac{(84 \text{ kip-in})(3 \text{ in})}{1944 \text{ in}^4} = 64.81 - 117.85 - 129.63$$

$$\sigma_x = -182.66 \text{ psi}$$

Element H

click another element, or Continue

Fig. 6. Computation of stresses at point H.

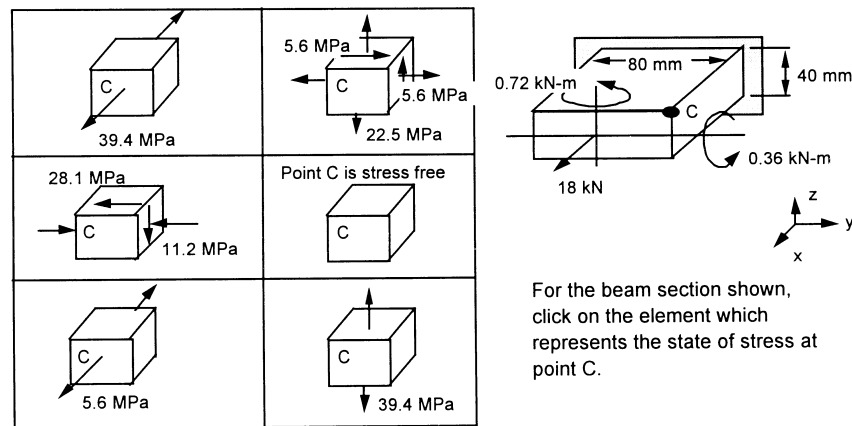


Fig. 7. Screen for identification of a state of stress.

An effective measure of a student's depth of understanding is the ability to identify a state of stress given only a loaded structure. Figure 7 illustrates a screen in which the user is asked to identify the state of stress at a point in a component, given the loads and dimensions. With each incorrect selection a comment such as ". . . will a force in the direction shown result in a shear stress?" appears on the screen. When a correct answer is selected, a calculation of the state of stress is presented.

The software is available at several computer labs in the College of Engineering at Ohio State University. The software has not been completed; however, preliminary feedback has been obtained. Some users claim that they derive no benefit from the program, while at the other end of the comment spectrum, one user claimed that he relied entirely on the software and, if the program had been completed, would have sold the textbook if his class had not had homework assigned from it. Most comments from student users indicated that they found the software useful. Different comments indicate that not everyone finds the same presentation styles useful.

Once completed and tested, the software will be made available to mechanics students outside Ohio State University. Plans for broad distribution of the software have not been finalized, but possible mechanisms include a general supplement that may be used with a variety of textbooks or as an incentive for a specific textbook.

CONCLUSIONS

This paper presented a summary of two approaches that have been used to integrate computers into undergraduate mechanics instruction at Ohio State University, computer aided instruction (CAI) problems and interactive computer tutorials. Both approaches had the aim of augmenting rather than detracting from a traditional approach to teaching mechanics. CAI problems were introduced with the goals of requiring students to use computers and plotting software, giving students some experience and appreciation of solving classes of problems, and introducing students to the basic ideas of analyzing problems in terms of non-dimensional parameters. These problems generally demand a considerable amount of time from students, a significant portion of which is devoted to learning how to use the software. Nevertheless, the response from students has been very positive, especially from above average students who seem to appreciate the challenge.

The interactive computer tutorials appear to enhance the understanding of mechanics of materials concepts for those students who choose to use them. A better assessment of the tutorial's effectiveness will be available once the software has been completed, students have been provided broader access to the tutorials, and appropriate evaluation schemes have been developed.

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