

# Unified Lecture Software for Mechanics of Deformable Bodies

Scott L. Hendricks<sup>1</sup>, L. Glenn Kraige<sup>2</sup>, and Don H. Morris<sup>3</sup>

**Abstract** – Newly developed lecture software designed to supplement an undergraduate course in mechanics of deformable bodies is presented. The software is primarily designed to be used by the instructor as an in-class lecture supplement. The students are also able to view the same software online. The Flash-based lecture software provides a concise review of the theory and numerous examples. Animation is used heavily to help the student visualize and understand key concepts in the course.

*Keywords:* Lecture software, animation, deformable bodies

## BACKGROUND

The College of Engineering at Virginia Tech consists of eleven departments with about 1200 incoming freshmen engineering students per year. The Department of Engineering Science and Mechanics has been responsible for teaching three undergraduate mechanics service courses (statics, dynamics, and mechanics of deformable bodies) to the students in most of these departments. Recently, the department has reluctantly changed from small (50 student) classes to large (up to 300 student) classes due to budgetary constraints.

In order to effectively teach the mechanics service courses in large classrooms, we decided to develop unified software for all three courses. A primary design consideration has been the ability of the instructor to project the material so that it can easily be seen from any seat in the largest lecture hall. The software for statics and dynamics has been reported previously [6, 7]. In this paper we report on the current status of the software for the mechanics of deformable bodies class. During development, we realized that the software was inherently useful in small classrooms as well. And thus we now present this software as being pedagogically beneficial for use in classrooms of any size.

The use of computer software to enhance learning in mechanics classes has had mixed results. A survey [2] of approximately 50 different computer software tools finds that approximately half of the tools did not significantly increase student performance on tests. The software that did make a difference was interactive, of high quality, and relied extensively on student feedback for improvement. We have sincerely attempted to follow this pattern as we have developed our software.

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## DESCRIPTION OF THE SOFTWARE

The authors are continuing the development of departmental lecture software for the mechanics service courses. In this paper we report on the software for use in the undergraduate mechanics of deformable bodies course. The software can be shown in any classroom with a computer-driven projector, and it can be placed on the internet for student use at any time. A typical module starts with a concise review of the theory, including animation wherever appropriate. Numerous example problems, often with student input options, are included. The chosen software platform is Macromedia's Flash.

The history of the present software dates back to the early 1980's when student-owned personal computers first became a factor in engineering mechanics education. This effort represents the third generation of mechanics software. The first in the 1980's was DOS-based [3, 4], while the second iteration in the 1990's was based on the Authorware platform [5]. Beginning with the second generation, professional input on design and navigation strategies has been received.

The desired properties of the software include readability in all sizes of classrooms, ease of navigation, ability of the instructor to control the pace of unveiling, absence of long wordy passages, and the use of animation when that feature would be useful. Anything that looks like a button is a button.

The table of contents page for this software is shown in Figure 1. The arrangement of chapters generally follows that of the standard sophomore-level textbooks [1]. Clicking on any of the chapter buttons immediately brings up the chapter-opening page for that particular chapter. As an example, the opening page for the second chapter (Stress, Strain, and Material Response) is shown in Figure 2. The topics are in yellow, indicating that clicking will take the student to that section.



Figure 1 Table of Contents



Figure 2 Opening Page – Second Chapter

Figure 3 shows a page in the section on Normal Loads and Deflections. As a typical text page, it shows the chapter and article in the upper gray bar, along with buttons to take the user back to the main menu or to the chapter menu. The lower gray bar has a page indicator with forward and backward buttons. The lower gray bar is also used to provide any additional instructions that the user might need in order to operate the software (none in this example page). The design strategy here is that the upper and lower gray bars belong to the instructor (the operator) in class, while the main blue field belongs to the student. In the main section of this page is a button labeled "Increase Force  $P$ ". When the user clicks on this button, the force  $P$  is gradually increased; the bar stretches longitudinally and shrinks transversely. The user watches this happen in an animation. Figure 4 shows the final state of the animation.

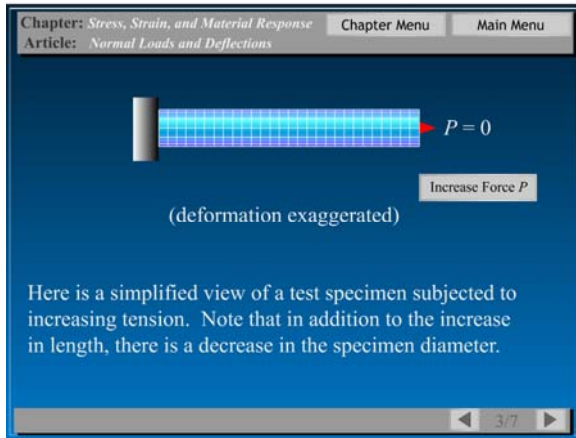


Figure 3 A Typical Page in the Second Chapter

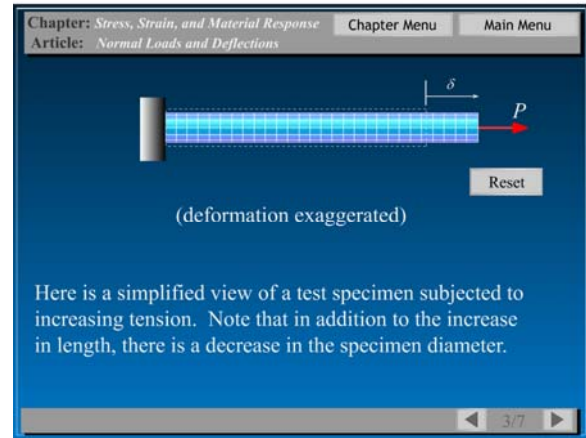


Figure 4 The End of the Animation

In order to explain the concepts of stress and strain we introduce three bars (Figures 5) made of the same material, but with different cross-sectional areas, or different lengths. The user can then see the force versus deflection curves for these bars in animation. The end of the animation (after each bar is subjected to the same force) is shown in Figure 6. The user discovers that each bar requires its own force-deflection curve. Several pages are then used to define and explain the concepts of stress and strain (not shown here). In Figures 7 and 8 we see the same three bars, but this time we plot (and animate) stress versus strain. The user sees and appreciates that all three cases follow the same stress-strain curve. The user can now increase the force (and animate the result), or reset and run the animation again.

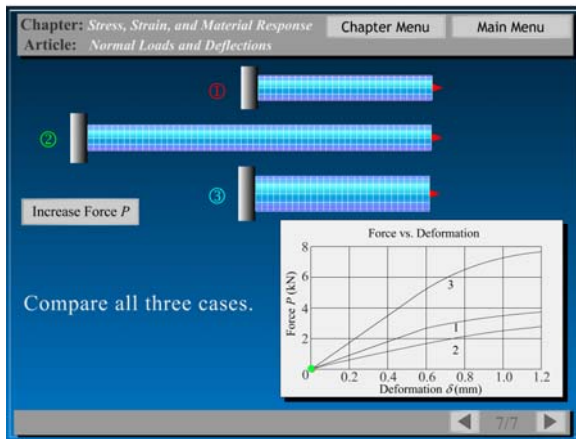


Figure 5 Comparison - Three Bars

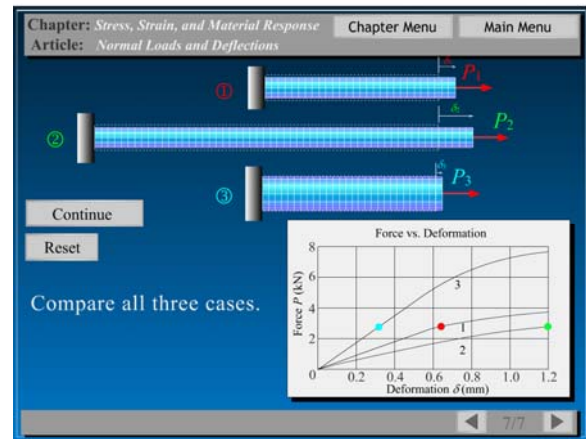


Figure 6 Force vs. Deflection - Three Bars

To teach material response (the last section in the second chapter) we have synchronized: a model of a structural steel bar in tension; the associated stress-strain curve; and an actual movie produced in our materials laboratory. In Figure 9 we see the system before the load is applied. In Figure 10 we see the end of the animation after the steel bar has progressed through its elastic region, through its necking phase, and through failure.

This software includes user input whenever appropriate. In Figure 11 we show a uniform bar that may be loaded in different ways. The user can choose from 27 combinations of “+”, “-” or “0” loads at three locations on the bar. In Figure 12 we see the end of the animation that results from one combination of user choices.

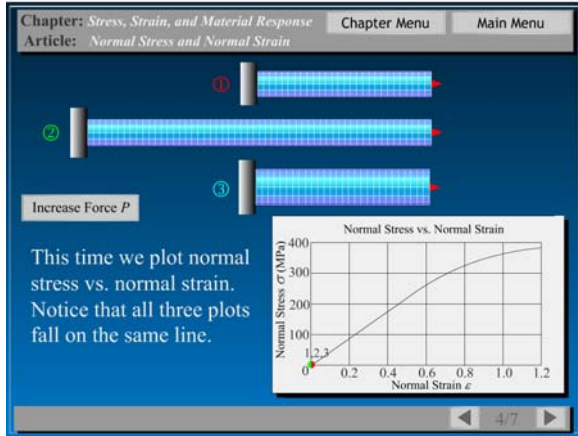


Figure 7 Comparison – Three Bars

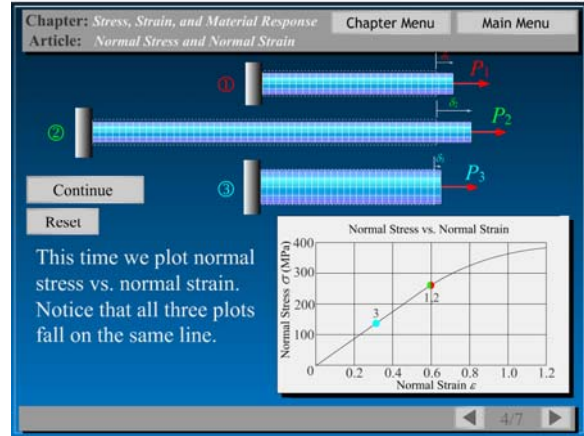


Figure 8 Stress vs. Strain – Three Bars

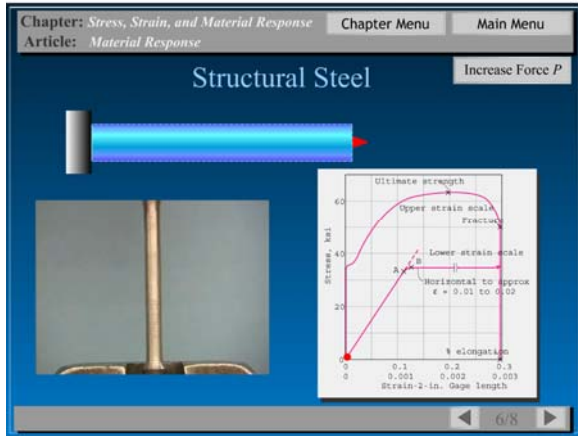


Figure 9 Structural Steel Response

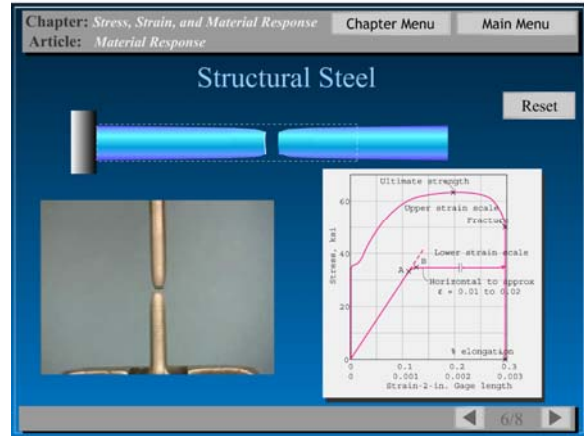


Figure 10 Structural Steel Failure

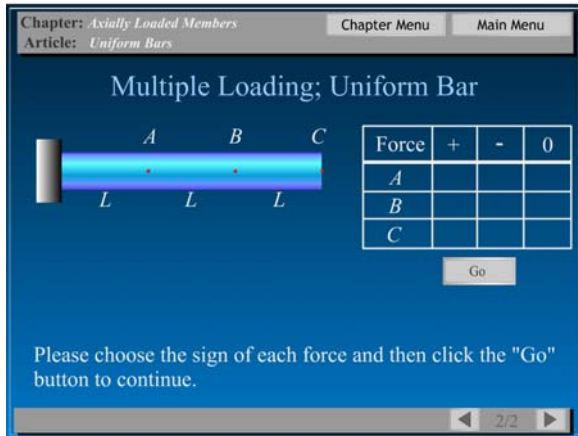


Figure 11 Multiple Loading; Uniform Bar

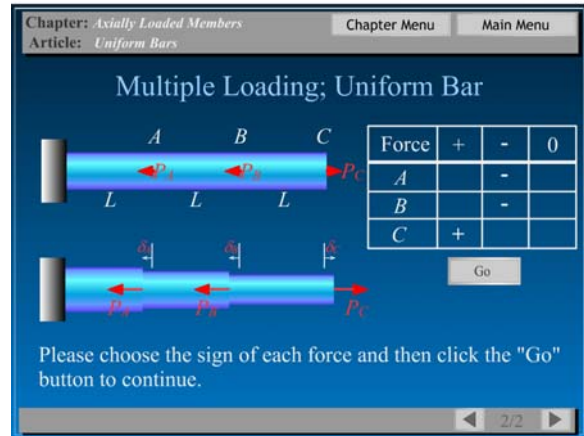


Figure 12 Load vs. Deflection

In Figure 13 we see a bar which is constrained at both ends. If the bar is heated, it has a tendency to expand; however, the constraints prevent expansion. One way to understand the physics of this process is to remove one of the constraints (Figure 14), heat the bar so that it expands (Figure 15), and then introduce a constraint force to provide the correct boundary condition (Figure 16). As the student then proceeds to the next screen (not shown) to review the associated mathematics, he or she retains the memory of the animation to aid in the learning process.

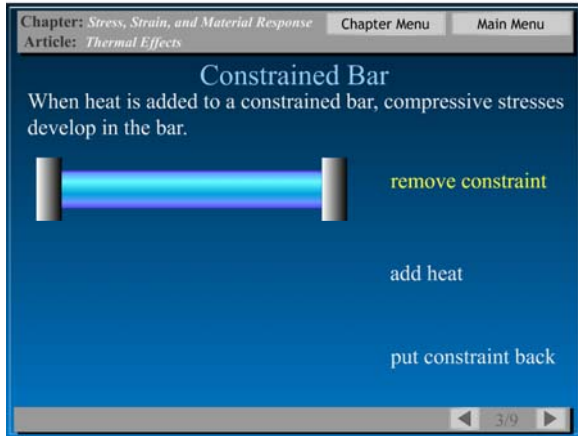


Figure 13 Constrained Bar

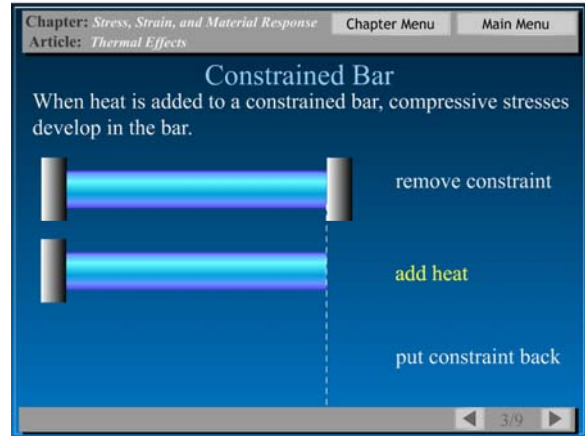


Figure 14 Constraint Removed

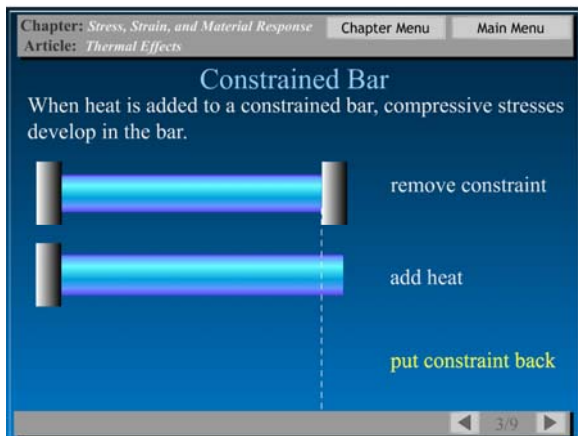


Figure 15 Heat Added

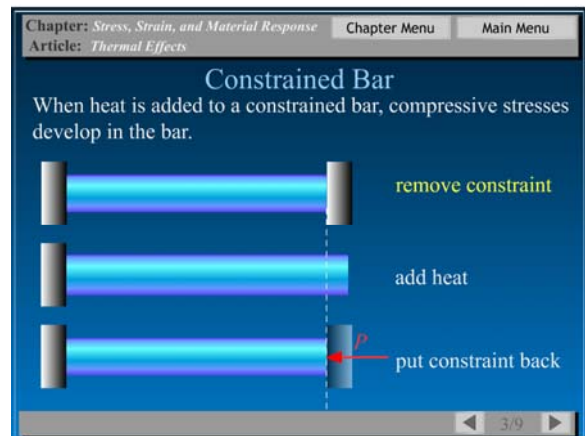


Figure 16 Finished Problem

In the area of torques applied to stepped circular rods, one example allows the student to choose from nine different settings to show the rotations that result from combinations of torsional moments. In Figures 17 and 18 we see the endings of the animations associated with two of these choices applied to a stepped bar.

In Figure 19 we have a beam without any load. The student then applies the load (Animate) and watches the beam deflection grow as the load increases. In Figure 20 we see the end of the animation. In Figures 21 and 22 we see two of the ten pages of mathematics associated with this case.

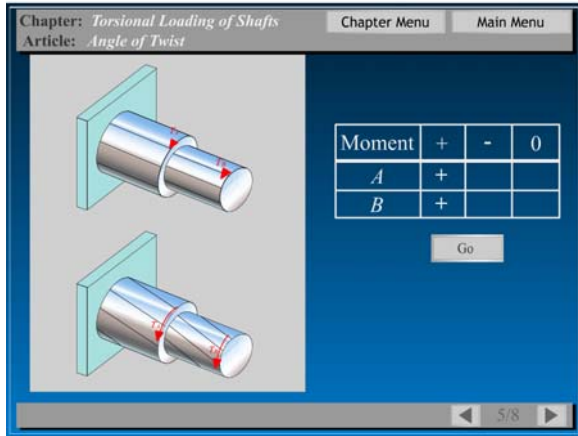


Figure 17 Angle of Twist

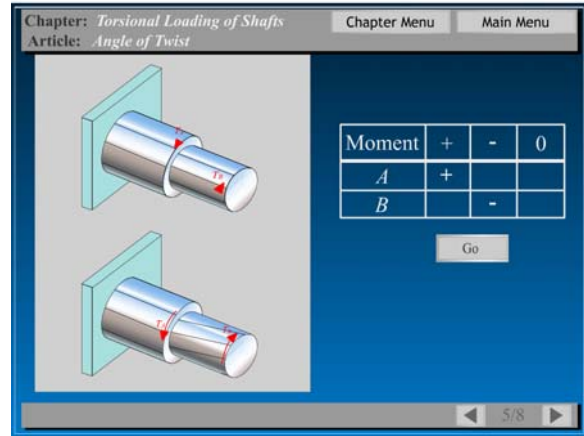


Figure 18 Angle of Twist

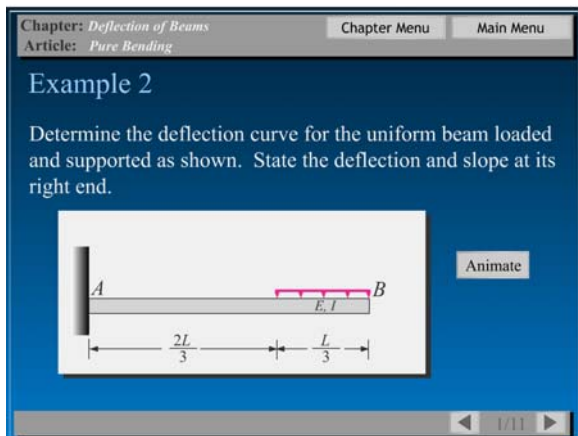


Figure 19 Unloaded Beam

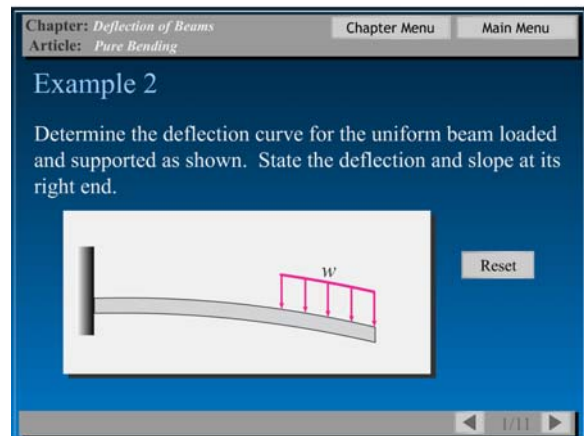


Figure 20 Loaded Beam

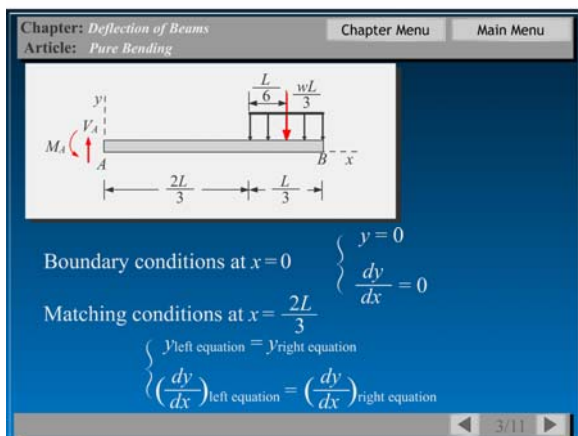


Figure 21 Beam Deflection Mathematics

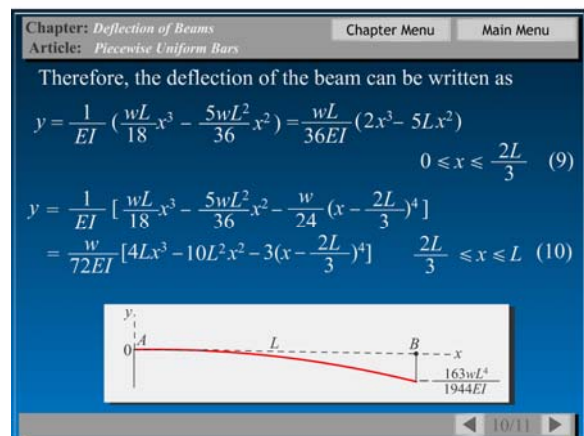


Figure 22 Beam Deflection – Final Result

The user can apply a bending moment to a beam and watch the longitudinal lines bend into circular arcs. The lines which stretch (red) are discussed first. Then the lines which shrink (yellow) appear. Finally we illustrate the one line which does not change length (green) and so illustrate the concept of the neutral surface. The final result of this animation is shown in Figure 23. Next the user can watch the transverse lines (which remain straight) converge to a point as shown in Figure 24. It is then easy to define the radius of curvature and the flexural strain (Figures 25 and 26) and to develop the rest of the formulas associated with bending. The user is able to watch the animation as these formulas develop and hence gain a greater appreciation for and understanding of the bending formulas.

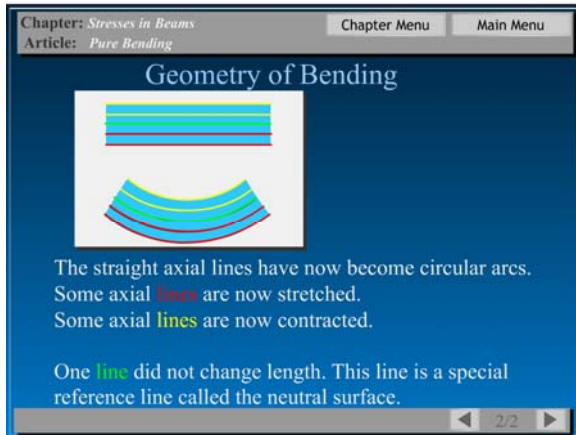


Figure 23 Longitudinal Lines

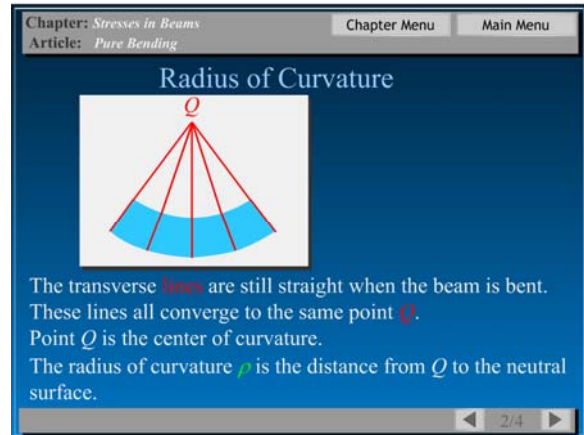


Figure 24 Transverse Lines

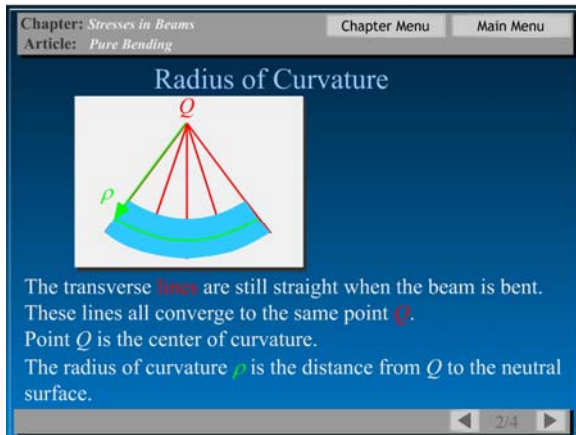


Figure 25 Radius of Curvature

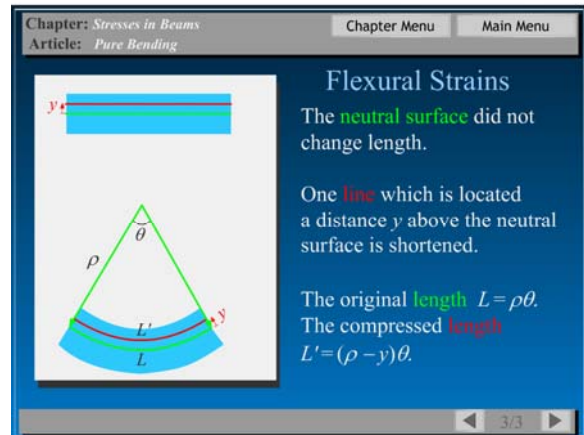


Figure 26 Flexural Strains

Using the software, the instructor can show Mohr's Circle synchronized with the rotation of the actual physical element. The user can rotate to principal directions, or to an orientation to show maximum shear stress. In Figure 27 we see a typical element and associated starting points on Mohr's Circle. In Figure 28 we see the element and Mohr's circle at the end of the animation when the element has rotated to an orientation that corresponds to maximum shear stress.

In a second example, the orientation that corresponds to maximum shear stress occurs out-of-plane. In Figure 29 we see the original orientation. When the user clicks the button "Show Maximum Shear Stress", three relevant Mohr's circles appear, and the element changes into a three-dimensional picture as seen in Figure 30. In Figure 31 we see the end of the animation after the element has rotated to the orientation that corresponds to a state of maximum shear stress. The rotation from the original orientation in Figure 29 to the final orientation in Figure 31 occurs in two

steps: first a rotation to principal directions (about the original z-axis); then a rotation about the axis corresponding to the intermediate principal stress. The animation vividly illustrates the three-dimensional rotation necessary to find the critical orientation.

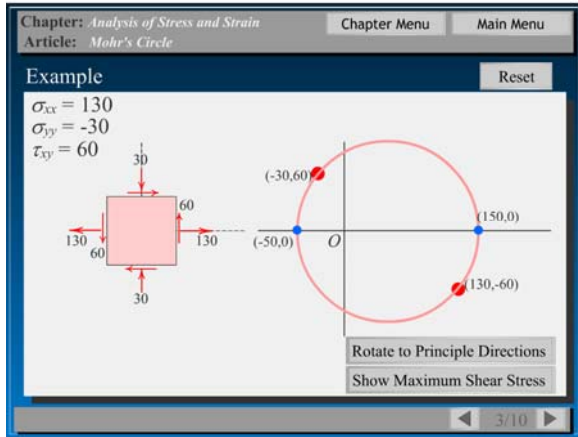


Figure 27 Mohr's Circle – First Example

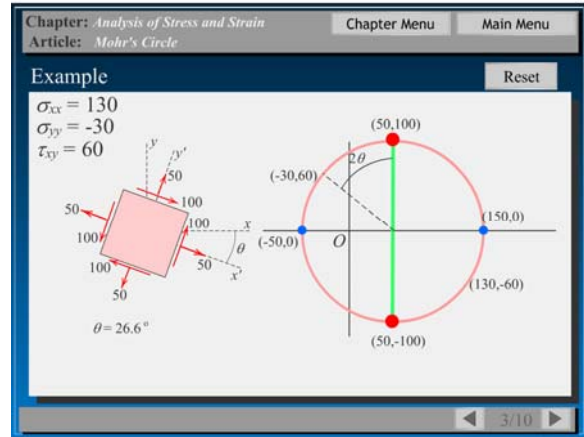


Figure 28 Orientation Showing Maximum Shear

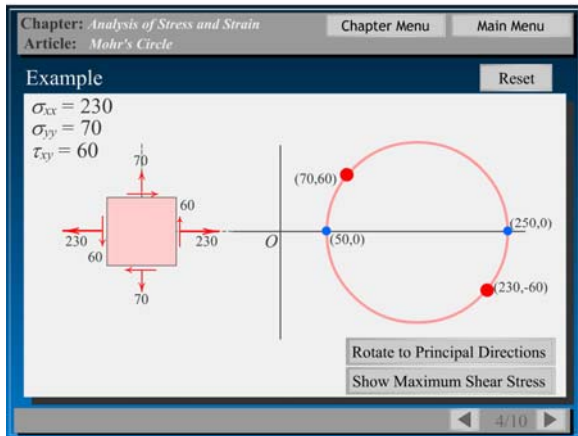


Figure 29 Mohr's Circle – Second Example

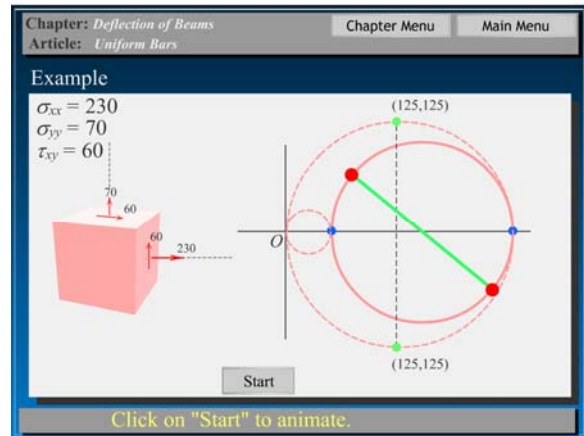


Figure 30 Show Maximum Shear Stress

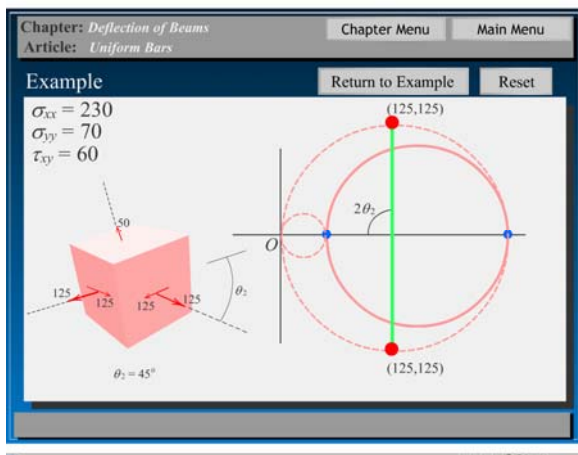


Figure 31 State of Maximum Shear Stress



## STUDENT REACTION

We continue to concentrate on the development of this software and to date have completed no structured assessment. Here are a few comments from students who have used the similar software developed for statics and dynamics:

“The software was great for test review since it hits on the major point of each section.”

“Personally, I found the software to be a very useful tool. It helped me understand concepts and ideas that were difficult to understand from the book. The interactive and multimedia nature of the program is what makes it so effective.”

“My main concern with electronic teaching aids is that it encourages the student to learn by watching and not by trial and error. I understand that the software is intended to be supplemental but I also know that people will make it a primary source for education.”

In addition, we asked one student who has completed the mechanics of deformable bodies course to comment on the present software. Here are a few of his thoughts;

“I like how the article “Normal Loads and Deflections” in the chapter “Stress, Strain, and Material Response” has an animation to show the decrease in diameter of the specimen as it increases in length because many students like me learn through visualization well.”

“The 3-D shear stress and deflection animation is excellent because 3-D visualization is difficult at times.”

“Throughout the example problems with steps on how to solve them, I like the colored steps and the ability to click each step – students who don’t understand one particular step can click just that step instead of proceeding through the entire problem.”

“The buttons that allow the user to proceed to the next page could be outlined in green or filled with green to emphasize moving forward. Buttons outlined or filled with yellow could provide a hint, another way of looking at the concept, or additional information to help the student to emphasize waiting and further thinking. Buttons outlined or filled with red could take the user back a page or to the menus to emphasize moving backward.”

## SUMMARY

The authors have begun the development of lecture software to aid in-class presentation and out-of-class review of the theory and examples needed to teach the standard mechanics of deformable bodies class. Flash-based software for this course is more than 50% complete. Prime features of the software include professionally prepared figures, font sizes chosen for use in the largest (up to 300 student) classrooms, fast navigation, fine user control of progress within a page, a concise review of the theory, numerous sample problems, and significant use of animation.

## ACKNOWLEDGMENTS

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