AC 2010-322: REAL LIFE EXAMPLES IN A SOLID MECHANICS COURSE

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Real Life Examples in a Solid Mechanics Course

Abstract

Research has indicated that a good percentage of students who are dropping out of engineering are doing so because they have either lost interest or actually come to dislike studying it. This paper describes an effort to better connect students to engineering by incorporating lecture materials into a Solid Mechanics course that use example problems that students encounter in their every day lives. For example, rather than drawing a picture of an axial load being applied to a steel bar to talk about axial stress and strain, a pair of iPod headphones is shown and a discussion moderated about what kind of load would be needed to break them and how much would they stretch. The real life examples adopted in this course were first created by Eann Patterson as part of a National Science Foundation sponsored project to change the undergraduate mechanical engineering curriculum and make it more attractive to a diverse group of students. Specifically, this paper critiques the adaptation of five real life examples taken from the original project. Student response to the lecture material was measured by specific survey questions about the real life examples, survey questions about the course as a whole, interviews, and standard student course evaluation forms.

1. Introduction

A considerable amount of attention has been given to the retention of engineering students in recent years. In fact, most universities with engineering programs are currently taking major steps to boost student retention in engineering according to Dean, Anthony and Vahala.[1] There is also evidence that many students leave engineering because they have become disillusioned or have lost interest in studying it.[2] Seymour and Hewitt concluded that students who left science and engineering often did so because of the structure of their educational experience and the culture of the discipline.[3] In the past, many students have come to the university with some mechanical engineering background from their hobbies or experiences working with cars or other machinery. The students of today tend to lack some of these experiences that connect them to engineering making it more difficult to keep them interested while teaching them basic engineering principles.

In an attempt to boost retention by better connecting with today's engineering students, eight universities participated in a National Science Foundation sponsored project to change the undergraduate Mechanical Engineering Curriculum to make it more attractive to a diverse community of students.[4] One of the efforts of this project was to develop application-based lesson plans that would use real life examples to demonstrate basic engineering concepts. Specifically, Eann Patterson developed a set of example problems that could be used in an introductory solid mechanics course.[5] This paper provides an instructor review of five of these examples along with student responses to the lecture material in the form of surveys and student interviews. The specific examples used are given in the table 1.

Real Life Examples in Mechanics of Solids
1) Stress and strain in uniaxial solid and hollow bars (iPod)
2) Combined use of principles of compatibility and equilibrium (iPod)
3) Bending moment and shear diagrams (skateboard) (bending stress also discussed)
4) Eccentric loading (basketball goal)
5) Stress in cylindrical pressure vessels (cooking hotdogs)

Table 1: Real Life Examples Reviewed

The real life solid mechanics examples were added to existing lecture materials that had first been used by the course instructor in the Spring Semester of 2009 with a class of 84 students. The lecture material updated with the real life examples was used by the same course instructor in the Summer Semester of 2009 with a group of 30 students.

2. Real Life Example Problem Descriptions

Because the instructor already had a complete set of lecture notes for the introductory solid mechanics course, the integration of the real life examples was not difficult. The new student friendly examples simply replaced example problems that the students had a harder time relating to. One example of this is the demonstration of the use of compatibility to solve axially loaded statically indeterminate problems. The instructor had originally used the typical example of an axial load applied to an aluminum pipe with a brass core and calculated the forces and corresponding stresses in each material. This example was replaced by an axial load applied to the cord from a set of iPod headphones. The calculation was the same with the brass and aluminum being replaced with copper and insulation. However, every student in the class could relate to iPod headphones.

2.1 Stress and strain in uniaxial solid and hollow bars (iPod)

This example was used to demonstrate the application of axial stress, axial strain, and modulus of elasticity. The instructor started by going through the definitions and equations for axial stress and strain, and talking about stress-strain plots and modulus of elasticity. The students had just started to loose interest, so the instructor then dangled an iPod by the earphones and passed out small pieces of wire to each student with some of the insulation stripped off. A brief discussion was then initiated about what kinds of materials make up headphone wires and what magnitude of force it takes to break the wires. Most of the students had broken a set of headphones at some point in their lives, so the class came back to life. The instructor then calculated the stress, strain, and deflection caused by the iPod body hanging from the headphone wire using the definitions of stress and strain and Hooke's law (calculations shown below in equations 1-3). The magnitude of force that would break the copper wire and insulation were also calculated separately (equation 4). The stress calculations lead into a short discussion of ultimate strength and yield strength. The discussion was concluded with the fact that both the copper wire and insulation actually deformed together (although the deflections were calculated separately in the class example) and that this topic would be discussed in a future lecture.

$$\sigma = \frac{F}{A} \tag{1}$$

$$\varepsilon = \frac{\sigma}{E} \tag{2}$$

$$\delta = \varepsilon \cdot L \tag{3}$$

$$F = \sigma_u \cdot A \tag{4}$$

Incidentally, the mass of the iPod was assumed to be 30 g. The diameter of the copper wire was assumed to be 0.4 mm. The outer diameter of the insulation was assumed to be 1.0 mm. The insulation was assumed to be uPVC with a modulus of elasticity of 2.0 GPa, and a modulus of 110 GPa was used for the copper.

2.2 Combined use of principles of compatibility and equilibrium (iPod)

Having completed the iPod headphone example in the previous class, the instructor was able to ask the students to recall it in the next lecture when deriving the axial elongation formula as shown in equation 5. The example calculation was repeated with the values from the iPod lecture to show the students that they had really already used this equation.

$$\delta = \varepsilon \cdot L = \frac{\sigma}{E} \cdot L = \frac{F/A}{E} \cdot L = \frac{FL}{AE} \tag{5}$$

With the elongation equation presented, the instructor now used the iPod headphones one last time to demonstrate how to solve statically indeterminate problems. As promised in the first iPod lecture, the instructor now used compatibility and equilibrium to solve for the actual force present in the wire and the force present in the insulation and their uniform deflection using equations 6 and 7.

$$F_{wire} + F_{insulation} = F_{iPod} \tag{6}$$

$$\delta_{wire} = \delta_{insulation} = \frac{F_{wire} L_{wire}}{A_{wire} E_{wire}} = \frac{F_{insulation} L_{insulation}}{A_{insulation} E_{insulation}} \tag{7}$$

2.3 Bending moment and shear diagrams (skateboard)

The original intention of this demonstration was only to review shear and moment diagrams (already covered in statics) using a skateboard. The instructor began the lecture by riding in to class on a skateboard to begin a discussion about what points of the skateboard see the largest shear force and bending moment and how the largest points would need to be determined to find the largest stress. Different weight distributions and reaction forces in the wheels were considered to provide different shear and moment diagrams. During the discussion, it came up that two of the students had actually broken skateboards and were interested in what caused the boards to break. Because of the interest expressed by the students, the skateboard example was carried into example problems for bending and shear stress.

In the next lecture the instructor pointed out the fact that to calculate the shear and bending stress for the skateboard problem (and get some insight as to why skateboards break), the class would first need to review moment of inertia. The examples done were typical C-channel and I-beam cross sections, but the skateboard problem was not forgotten.

The following lecture was on bending stress in beams, and of course the skateboard example was the first one discussed. The maximum moment was taken from the moment diagram created in the first lecture, and the bending stress was calculated using the bending stress equation given in equation 8. The moment and corresponding force required to break the skateboard was then calculated using equations 9 and 10.

$$\sigma = \frac{M \cdot y}{I} \tag{8}$$

$$M = \frac{\sigma_u \cdot I}{y} \tag{9}$$

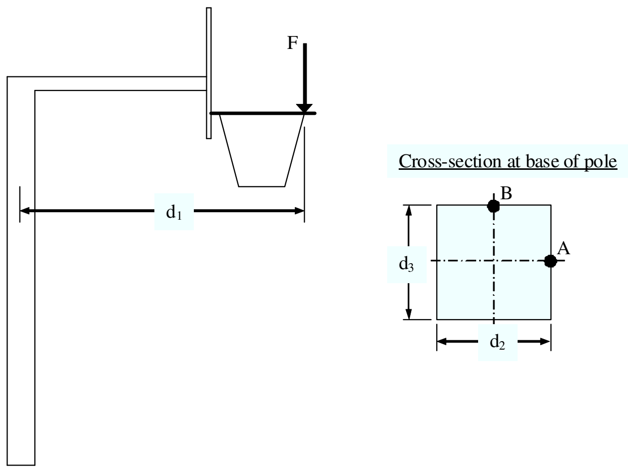
$$F = \frac{M}{d} \tag{10}$$

Using values of ultimate strength of maple plywood (most common skateboard material) of 5000 psi and cross section of eight inches by one-half an inch, it was determined that a 375 lb force acting in the center of the skateboard was necessary to break it. It was observed that one of the students who had broken their skateboard only weighted 150 lb. A short discussion then occurred about the difference between static and dynamic analysis.

Stresses in a skateboard surfaced one more time during the semester when average shear stress in beams was discussed. During the development of the theory, it was discussed that shear stress varies in beams with large widths relative to their depth so it would not be a good idea to analyze the shear stress in a skateboard using the equation that was being developed for average shear stress. It was also discussed that bending stress would be the major factor in the breaking of the skateboard.

2.4 Eccentric loading (basketball goal)

This example introduced the students to eccentric loading problems and how they create multiple stresses. The instructor began by showing a two minute YouTube video showing a series of NBA slam dunks. A class discussion was then initiated discussing what types of stresses the basketball support structure was subjected to. Calculations were then presented for axial and bending stress at two different points (A and B below) for a very simplified model of a basketball goal as shown in figure 1 with equations 11-13. A follow-up discussion was also facilitated reminding the students of the difference between static and dynamic analysis (first explored in the skateboard example).



$$\sigma_{axial} = \frac{F}{A} \tag{11}$$

$$\sigma_{bending} = \frac{M \cdot y}{I} \tag{12}$$

$$\sigma_{total} = \sigma_{axial} + \sigma_{bemding} \tag{13}$$

Figure 1: Stress Calculations for a Basketball Goal

2.5 Stress in cylindrical pressure vessels (cooking hotdogs)

This example began by the instructor asking if the students in the class had ever cooked hotdogs in the microwave and had them split open. Of course, all of the students had experienced this phenomenon, so they were then asked which way did the hotdogs split. The class agreed that they split along the length of the hotdog, but no one could explain why. The theory for hoop stress and longitudinal stress in cylindrical pressure vessels was then presented, and it was pointed out that the hoop stress was twice the longitudinal stress, as seen in equations 14 and 15. Therefore, the tangential force was greater causing the hotdogs to split. Although it was not really necessary, a microwave was then brought into class and some hotdogs split to demonstrate this fact.

$$\sigma_h = \frac{p \cdot r}{t} \tag{14}$$

$$\sigma_l = \frac{p \cdot r}{2t} \tag{15}$$

3. Student Response

Student response to the real life examples was overwhelmingly and exclusively positive. The instructor originally agreed to adapt some of the examples into the lecture material because it did not require a huge effort to implement and seemed like it could have a positive impact on student learning. The actual response of students was much more positive than anticipated.

3.1 Instructor's Observations and Unsolicited Response

The best endorsement for the use of real life examples in class comes directly from the students taking the introductory solid mechanics course. In ten years of teaching, this was the first time the instructor had multiple students on several occasions directly approach after a lecture specifically to state how much they enjoyed the material in the lecture that day. In the past, students had often made comments of appreciation on evaluation forms or personally at the end of a semester, but not multiple students about specific examples immediately after a lecture.

Another positive endorsement was observed in the attitude of the class during the lectures. This course was taught immediately following lunch, but the students remained awake and attentive during lectures without any extra effort by the instructor. After the first iPod example was discussed in class, the students began to ask more questions about example problems (even the more traditional problems) without being prompted. Based on the questions that were asked in lectures, there was a noticeable improvement in the awareness of students. They were now looking for applications of the basic concepts that were being presented and asking about them in class, rather then just copying down the examples that were being done.

A third example of positive student motivation came from two students near the end of the semester. They specifically stayed after class one day to tell the instructor that they found this course extremely interesting, and that because of this course they were going to arrange their elective courses to concentrate in mechanics.

3.2 Student Surveys

The instructor of this course often assesses student understanding and satisfaction about one-third of the way through a course by having students answer questions anonymously on note cards. During the semester without the real life examples students had been asked "What do you think is the best part of this class?" and "What do you think is the worst part of this class?". Three out of eighty-four students mentioned that they liked the fact that a lot of example problems were done, but did not mention anything specifically. Five out of eighty-four students had some criticisms about the types of example that were done, or how the examples were presented. The same questions were asked of students during the semester with the real life examples. Nine out of thirty students mentioned they liked the example problems either collectively or pointed out a specific example they liked. None of the students mentioned anything negative about the example problems done in lecture.

Because these real life example problems were first created as part of a National Science Foundation grant, the students were asked to fill out a survey at the end of the semester specifically addressing their value. The surveys were completed by 29 students—24 male and 5 female.

The surveys began with general questions about the course. When asked if there were topics/activities included in the course that **did not** contribute to mastery of course content, seven students said that yes there were. However, none of the students mentioned the real life examples. Two of the seven students specifically criticized the lab (not taught by the lecture instructor), one cited Mohr's Circle, and one said they did not like proofs. When asked if there were any course activities that increased interest in mechanical engineering, seventeen students responded yes. Nine of the seventeen students specifically cited the real life examples. When asked if there were any course activities that increased knowledge of a specific course topic, ten students replied yes. Seven of the ten students cited the real life examples.

After the general course questions, students were asked about each of the specific real life example problems that were used. They were asked to rate overall value, contribution to understanding, and student participation of each of the examples. A five point scale was used for all responses with 1 being “very high”, 3 being “medium”, and 5 being “very low”. The average score for each of the examples in each category was always under 3 (always toward the high side of overall value, understanding, and participation).

3.3 Student Course Evaluation Forms

At the time this paper was prepared, only summary information was available from the departmental student course evaluations. Therefore, no specific student comments about the real life examples can be included. The summary information did show that students who attended the course with the real life examples rated the instructor at least 20 percent higher in the areas of explanation of course material, preparation for class, and course organization.

4. Summary and Conclusions

The instructor originally agreed to include the real life examples created by Eann Patterson in an introductory solid mechanics course because there was the possibility of increasing student interest and understanding, and because it was easy to integrate the examples into the current course lectures. The instructor did not anticipate the overwhelmingly positive response from students. If there were students who did not like the real life examples, they did not mention it (not even on anonymous surveys).

Connecting students to basic engineering concepts through examples from their own lives is a powerful way to help engage students. It helped to deepen student understanding of course material, and got students to start asking questions about other applications of engineering principles rather than just reproducing calculations. It also helped to get students more involved in lectures and helped turn the lectures into active learning exercises. This experience has led the instructor to reexamine some of the examples that are used in other classes to see how they could better connect to students.

5. Bibliography

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