AC 2009-2214: A NEW APPROACH TO TEACHING MECHANICS OF MATERIALS

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A New Approach to Teaching Mechanics of Materials

Abstract

Mechanics of materials is one the most fundamental topics in a number of engineering disciplines including civil and mechanical. This course introduces concepts associated with the behavior of elastic solids subject to applied loads and provides tools for the analysis and design of structural and machine components. The number of equations introduced in this course is limited; however, the importance of these equations in analysis and design cannot be overstated. These equations which relate applied forces to the stresses within and deformation of solid bodies are introduced throughout the course allowing students to conduct stress analyses and design simple components.

Traditionally, the load-deformation equations are taught in a specific order, allowing students to comprehend and apply one equation at a time. In general, some of the more important equations such as flexural and shearing stress formulas are introduced at the end of the semester. This does not provide adequate time for students to implement the equations in problems dealing with the combined loading conditions so common in engineering practice.

We propose a revised organization of the topics in mechanics of materials that will introduce all of the basic equations early in the semester along with combined loading. This will be followed by an extended treatment of the analysis and design of more complex structural and mechanical components and systems subject to combined loading.

To determine the effectiveness of this revised approach, we have compared its student learning outcomes with those from the traditional approach. Based on a limited sample, the revised approach leads to a better understanding of combined loading.

Introduction

Traditionally, Mechanics of Materials at the introductory level covers a number of topics in an order to make it possible to students to understand the theory and apply it in analyzing and designing simple structural and machine components. Most of the homework assignments in this course are simple analysis and design problems. Often, many homework problems are accompanied by answers, making it easier for students to arrive at a solution without a through comprehension of the theory or its applications to real world problems. Most of the time, students do not have an opportunity to design a complex system, that requires the synthesis of several analytical techniques. As a consequence, students do not have a comprehensive picture of the design process including: material selection, load-path design, load determination, systematic component design, and design codes.

While the traditional approach to teaching mechanics of material courses has served reasonably well in educating students and preparing them for the subsequent courses, emphasis of system design requires a different approach in teaching this subject. In the traditional approach, the required topics for this course are covered throughout the semester in detail and with some redundancy. For example, the compatibility equations as well as the energy methods for different types of members and loads are covered separately in different chapters. In general, some of the most important topics such as bending and shearing stresses in beams, buckling, and deflections are covered towards the end of the semester, preventing the instructor from assigning a project that combines a majority of these topics in a single, comprehensive, open-ended design problem.

The authors propose the revision of the traditional approach in an attempt to provide a more effective overall picture of the design process and to improve the students' understanding of combined loading and the systematic approach to design. The proposed method was implemented in the fall of 2007 and fall of 2008 in the Idaho State University (ISU) Mechanics of Materials course. The student learning outcomes were assessed indirectly by conducting a survey at the beginning and the end of semester. In addition, a survey was conducted among the senior students in different disciplines who completed the Mechanics of Materials course under different instructors including the author. The goal of this survey was to evaluate the knowledge of combined loading that students brought to upper division design courses.

Topics in Mechanics of Materials

Traditionally, the major topics covered in the typical introductory mechanics of materials course are limited to the following topics:

- The concept of Stress and Strain and application in tension and compression members
- Engineering material properties
- Hooke's Law and extension of Hooke's Law to two-dimensional problems.
- Thermal induced stresses
- Torsion of circular shafts
- Shear and bending moment diagrams and bending and shearing stresses in beams
- Concept of stress at a point and Mohr's Circle for plain stress
- Pressure vessels
- Combined loading
- Column buckling
- Deflections

There are many other relative topics covered within the above mentioned major topics as follows:

- Stress concentration
- Energy method
- Indeterminate structures and the use of compatibility equations
- Welded connections
- Shear center
- Unsymmetrical bending of beams
- Power transmission
- Torsion of thin-walled tubes
- Composite materials
- Flexural stresses in curved beam
- Torsion of thin-walled tubes and shear flow
- Flexural stresses in beam of two materials
- Yielding and fracture
- Yield criteria

In many of the available textbooks, subtopics are addressed within the major topics and, in some cases, addressed repeatedly in several chapters. For example, the use of compatibility equations in solving indeterminate structures is often addressed in both the chapter on tension members and that on torsion. While the subtopics listed above are important, the relevance of these topics to combined loading and the determination of principle stresses is limited. However, the inclusion of these subtopics early in the semester delays the introduction of critical topics and combined loading.

The authors examined a total of fourteen textbooks [1-14] to identify the order of presentation of topics as shown in table 1. In nine of these textbooks, the concept of stress at a point, Mohr's Circle, and combined loading was covered in the later chapters. In three of the textbooks, these topics were covered in chapter two and in the remaining books it was covered in the middle of the book.

The majorities of instructors teaching mechanics of materials usually follow the textbook and cover the topics in the order in which they appear in the book. While this approach allows the students to understand the topics presented, it postpones some of the main topics such as flexural and shearing stress formulas. In some cases, the instructor may not have enough time to cover the state of stress at a point and Mohr's Circle to determine the principle stresses. The concept of the state of stress at a point is quite difficult for the students to digest early in the course; it takes a lot of practice and applications in real world problems to understand the concept. Therefore, covering this topic at the end of the semester will not offer many students an opportunity to fully understand this crucial concept.

Table 1: Mechanics of Materials textbooks with the chapter covering combined state of stress and the total number of chapters in the book.

No.	BOOK	CHAPTER
1.	Strength of Materials (Fourth Edition) Ferdinand L.Singer/Andrew Pytel	9 (14)
2.	Intermediate Mechanics of Materials (2001) J.R BARBER	4(12)
3.	Mechanics of Materials (2002) Madhukar Vable	9(11)
4.	Mechanics of Materials (Fifth Edition) Ferdinand P. Beer, E. Russell Johnston, Jr.	7(11)
5.	Mechanics of Materials (Seventh Edition) R.C.Hibbeler	9(14)
6.	Mechanics of Materials (Seventh Edition) James M. Gere , Barry J. Goodno	7(12)
7.	Mechanics of Materials (2000) Anthony Bedford, Kenneth M. Liechti	5(12)
8.	Introduction to Mechanics of Materials (1989) William F. Riley, Loren W. Zachary	7(11)
9.	Mechanics of Solids (1995) Gerald Wempner	2(9)
10.	Mechanics of Materials (Fourth Revised Edition) James M. Gere, Stephen P. Timoshenko	6(10)
11.	Mechanics of Materials (Sixth Edition) William F. Riley, Leroy D. Sturges, Don H. Morris	2(10)
12.	Mechanics of Materials (Second Revised Edition) Roy R. Craig, Jr.	8(12)
13.	Mechanics of Materials (1985) David Q. Fletcher	2(14)
14.	Mechanics of Materials (Second Edition) E. P. Popov	8(16)

The Proposed Approach:

In an effort to test the proposed approach, the instructor attempted to cover the major topics including the state of stress at a point and Mohr's Circle in the first half (eight weeks) of the semester. The topics incorporated into this approach are as follows:

- The concept of stress and strain and applications to tension and compression members
- Engineering material properties
- Hooke's Law and extension of Hooke's Law to two-dimensional problems.
- Thermal induced stresses
- State of stress at a point and Mohr's Circle
- Pressure vessels
- Torsion of circular shafts
- Shear and bending moment diagrams and bending and shearing stresses in beams
- Combined loading
- Column buckling
- Deflection

In each of the above topics, the state of stress at a point and superposition of stresses for combined loading were introduced, and small analysis and design problems were assigned. For example, after covering the pressure vessels, a combined loading involving internal pressure and axial load was introduced. When torsion of circular shaft was covered, a design problem involving axial load, internal pressure, and torsion was introduced. Specifically, a pressure vessel subject to internal pressure, axial load, and torque was analyzed, and the effect of torsion on changing the direction and the intensity of the induced stresses was examined and compared to a previous example lacking applied torque. The same approach was continued with other topics such as bending and shearing stress formulas.

The goal of the instructor was to cover these topics in eight weeks; however, in the two trials of teaching this course, it took about ten weeks to cover all the topics listed. In the remaining six weeks, the other subtopics such as stress concentration, stresses in composite materials, welded connections, flexural stresses in beam of two materials, bucking and deflection were introduced. While covering these topics, small analysis and /or design problems involving combined loading were assigned as homework problems. In addition, the students were divided into teams of two or three. Each team was required to select a real world problem and design the system components by the end of semester.

Introduction to Design process:

Often, textbooks on mechanics of materials do not incorporate a systems approach in example or homework problems. As a consequence, these texts fail to provide an overall picture of the design process. In most cases, students do not have an opportunity to make decisions regarding materials selection or load-path identification. Neither do they develop an appreciation for design codes and specifications. These topics are generally covered in upper division design courses such as machine design and structural design. Unfortunately, there is a significant temporal gap between exposure to theory and component design in mechanics of materials and introduction to the design process in upper division courses.

In introductory mechanics of materials textbooks, problems are generally limited to a simple elements or structures. The problems are well defined, and the parameters and unknowns explicitly listed. Often, the answer is provided for some selected problems. In most cases, students can arrive at the answer by substituting the known quantities into the equations provided in the related section. In the worst cases, students perform an "answer analysis", working backward from the answer to develop a solution. The existing approach employed in many texts deprives students of an opportunity to understand the design process; they never become thoroughly familiar with: conceptual design, analysis, material selection, load identification, load-path selection, and design codes.

The proposed approach to the instruction of mechanics allows the students to better understand the design process and the systems approach to design. Students are required to select an open-ended design project and work together with other students under the instructor's supervision in completing the design. During this process, the available design methods, tools, and resources are introduced. The goals of the new approach are:

- To familiarize students with different types of realistic loads and the sources that may be used to estimate these loads.
- To introduce different design methods such as Allowable-Strength Design and Ultimate-Strength Design.
- To introduce the design process and systems approach to design.
- To develop an understanding of load-path identification and selection in design.
- To introduce a full spectrum of mechanics principles early in the semester and apply these principles to increasingly complicated structures.
- To familiarize students with design codes and specifications including but not limited to the International Building Code (IBC), American Society of Testing Materials (ASTM), American Institute of Steel Construction (AISC), American Concrete Institute ACI.

Assessment of the New Approach and Course Evaluation

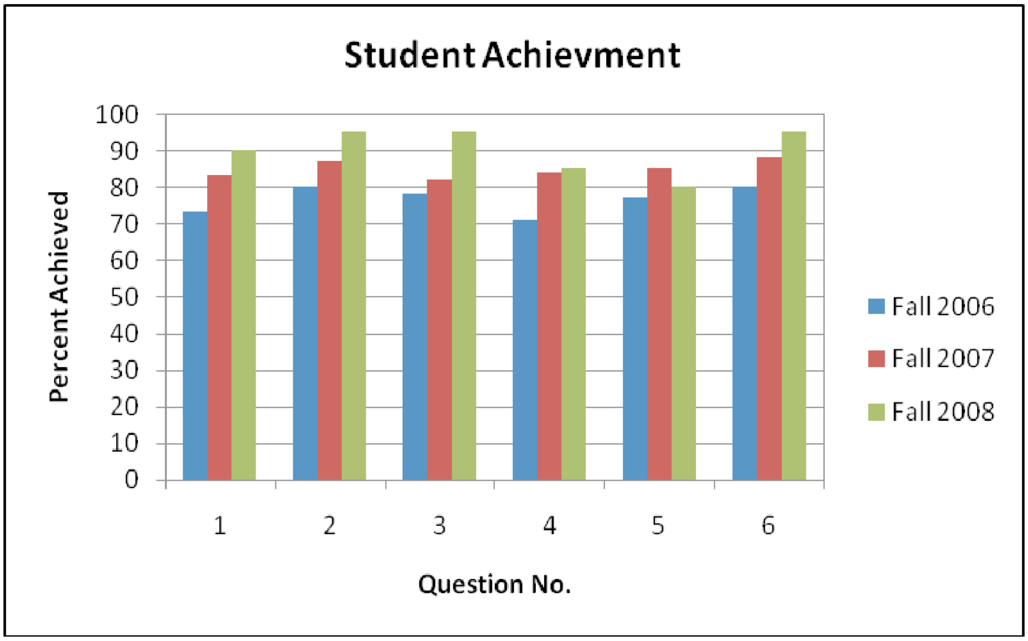
The effectiveness of the proposed approach was measured using a set of questions at the end of the semester. In addition, a survey was conducted among the senior-level engineering students who took Mechanics of Materials with the authors or some other instructors.

The results of the survey for three consecutive years are presented in Table 2, and Figure 1 depicts the results using a bar chart. In the fall of 2006, the course was taught in the traditional fashion for 22 students, while in the fall of 2007 and 2008 the course was instructed using the proposed approach for 21 and 13 students, respectively. The comparison of the results indicates that the students had a better understanding of the subject using the revised approach.

Table 2: Results of Course Learning Outcome for 2006, 2007, and 2008

No.	Question	Fall 2006	Fall 2007	Fall 2008
1	I can apply the knowledge of mathematics, science, and engineering to design simple structural and machine components and systems.	73.0	83.0	90.0
2	I can identify, formulate, and solve simple problems related to mechanics of materials.	80.0	87.0	95.0
3	I am familiar with some of the engineering materials and have ability to select an engineering material for design purposes.	78.0	82.0	95.0
4	I am familiar with some of the testing and design standards.	71.0	84.0	85.0
5	I have the ability to perform stress analysis and design components using working stress procedures.	77.0	85.0	80.0
6	The overall effectiveness of this course exceeded my expectations.	80.0	88.0	95.0

Figure 1: Results of Course Learning Outcome for 2006, 2007, and 2008



A survey was conducted among senior engineering students in civil, mechanical, and nuclear engineering to identify the utility of mechanics of materials in the upper level courses. The survey was also intended to evaluate the use of Mohr's Circle and combined loading in different engineering disciplines and to determine if emphasis of the concept of the state of stress at a point for combined loading and the use of Mohr's Circle to determine the principle stresses produced a better understanding of mechanics of materials. The following questions were sent to students via email:

1. How beneficial was the knowledge of Mechanics of Materials in your other courses?

   Very beneficial: _____ Beneficial: _____

   Somewhat beneficial: _____ None: ______

2. Did your instructor cover the concept of stress at a point (stress block) and the use of Mohr's circle to find principle stresses for combined loading condition?

   Yes: _____ No: _____

3. Did you have a need for the use of Mohr's circle and combined loading in your other courses?

   Yes: ______ No: _____

4. Would teaching the concept of stress at a point and Mohr's circle at the beginning of the semester help to learn more about combined loading in Mechanics of Materials?

   Yes: ______ No: ______

There were 12 responses. Nine of them had the course with the author who used traditional method as well as the new approach. The survey results indicate that the subject of mechanics of materials is very important for civil and mechanical engineering students, but it is somewhat less important for nuclear engineering students. All students those in civil and mechanical engineering disciplines indicated that understanding the concepts of stress at a point, combined loading, and Mohr's Circle was very helpful in their upper-division design courses. In addition, the students who took the course in the fall of 2007 indicated that the emphasis on the concepts of the state of stress at a point, combined loading, and system design helped them to function more effectively in their design courses.

Conclusions:

The results of the course learning outcome assessment and the survey result indicate that the emphasis of the concepts of stress at a point and combined loading early in the semester allowed the students to better understand mechanics of materials. Introduction of major equations early in the semester enabled the students to spend a significant part of the semester on system design. The proposed approach allowed the students to better understand the design process and system approach to design; this, in turn, helped them in their later design courses.

Of course, the proposed approach has been implemented only twice over the past two years, and some flaws remain with the course delivery. It will take several more trials to iron out the problems with the new approach. Additional assessment will be required to better document the benefits of the new approach and evaluate student understanding of the subject and its impact on the students' overall education.

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