AC 2010-642: STUDENT UNDERSTANDING OF NORMAL AND SHEAR STRESS AND DEFORMATIONS IN AXIALLY LOADED MEMBERS

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Student Understanding of Normal and Shear Stress and Deformation in Axially Loaded Members

Abstract

Knowledge necessary for engineering design and innovation refers to more than the ability to search for an equation that suits the situation, but the ability to understand, apply, and transfer information to new situations. Conceptual understanding describes this type of understanding. Performance on physics and engineering concept inventories in topics such as thermodynamics, statistics, and fluid mechanics indicates that students do not have understanding of fundamental engineering and physics concepts. Results from these concept inventories are useful for gauging performance and stirring interest and concern, but lack detailed information on student thinking about engineering concepts. The goal of this project is to investigate student conceptual understanding of normal and shear stress in an axially loaded member using clinical demonstration interviews. Student interviews were conducted where students completed researcher designed conceptual problems and discussed their lines of reasoning as they completed the problems. Students generally were consistent and correct in their understanding of normal stress and strain in the direction of the applied load, but displayed incorrect answers and logic relating to normal stress and strain perpendicular to the load, and shear strain and stress. Results are consistent with those from other studies in science and engineering, in that misconceptions exist and students do not have strong understandings of even fundamental concepts.

Introduction

A long line of research in physics, engineering, and mathematics suggests that students do not understand fundamental concepts in their respective fields [1-4]. Without conceptual understanding, new graduates lack the ingenuity and creativity to approach new and dynamic challenges that must be addressed in the ever evolving workplace. Most research on conceptual understanding is focused on concept inventories, non-calculational conceptual multiple-choice assessments of student conceptual understanding. These studies provide insight into what misconceptions students have, but lack rich and detailed descriptions of students understanding of integrated concepts. Physics education researchers have investigated students' conceptual understandings through in-depth interviews for more than twenty years. The purpose of this research is to investigate students' conceptual understanding of normal and shear stresses and deformations using clinical interviews.

Research and Theories of Conceptual Change

Conceptual understanding can be understood considering the term conceptual change. Conceptual change has been a topic of study for over the last two and half decades [5] through many different theoretical frameworks. Conceptual change occurs when a student has a misconception that must be repaired and replaced with the correct conception. Misconceptions are defined as student conceptions that produce systematic patterns of error [6]. Misconceptions can originate from a student's previous experiences or from formal instruction in class. This is evident from studies over the past three decades, which show that students come to science classes with pre-instructional concepts that interfere with learning [7]. An example of this is Vosniadou's study of childrens' conceptual understanding of physics who had no prior formal classroom instruction [8]. The study proved that even with children who had no prior instruction about force or mass, they still had formed concepts that they would regularly apply to answer questions. Misconceptions that persist in a student can be hard to replace according to the classical conceptual model of Posner [9]. A misconception is most likely replaced if the learner is dissatisfied with his/her prior conception and an available replacement conception is plausible. The conceptual change is then fruitful if it continues to help the learner solve other problems.

Several frameworks have been developed and used to investigate conceptual change and misconceptions that vary based on the grain size of the misconceptions. Some believe that misconceptions are based on small isolated concepts [5], others relate them to synthetic mental models [10], and some say misconceptions can exist at all grain sizes [11]. A term used to describe and advance the explanation of conceptual change is the idea of p-prims from DiSessa [5, 12]. P-prims are short for phenomenological primitives that are small elements of knowledge (small grain size) that hold a single simple truth to the beholder. P-prims are formed before formal instruction in mundane every day human experiences or with formal classroom education. A p-prim could be something as simple as ice is cold, and fire is hot. A concept is the application of multiple p-prims. For example the concepts required for a person to put out a fire could include the application of several p-prims. The p-prims could be made up of the different properties of the water and fire separately. An incorrect p-prim in any one of their material properties of water or fire could result in a misconception. For example, a p-prim that could exist (although unlikely) is that water and gasoline are liquids, gasoline gives the fire energy to burn, and therefore water will only help the fire. As you can see these incorrect p-prims would not lead to the desired result!

The overarching idea is that understanding is expanded through connections of correct p-prims to generate a larger whole of knowledge [6]. A persons' ability to relate p-prims creates a higher level of understanding as they are able to apply this knowledge to multiple situations. DiSessa believes p-prims are loosely organized in the conceptual system of a novice, and students who display efficiency in relating p-prims display evidence of conceptual understanding. The misconceptions framework suggested by DiSessa has not been applied to investigating misconceptions in engineering mechanics. The goal of this research is to apply this framework to investigate students' conceptual understanding of fundamental concepts of mechanics of materials.

Research Questions

1) What misconceptions do students have related to normal and shear stress and deformations in an axially loaded member?
2) Is there evidence for the existence of mechanics p-prims?

Methodology

Analysis of students' conceptual understanding will be carried out as a qualitative study and will utilize semi-structured interviews to capture students' conceptual understandings. Promising results have been shown with clinical interview tactics using the Piagetian tradition to gather data on student understanding [13]. The most valuable information resulting from these interviews is from the different forms of responses. For example, the measure of the individual's level of understanding is enhanced by verbal and non-verbal responses, and answers can come in the form of a verbal response, a drawing, or an interaction with physical models. Similar techniques have been used previously [8, 14], focused on the cognitive development of children and their references to the earth's shape and mass. Multiple models were used for the children to interact with, along with verbal explanations of reasoning. The drawings, explanations, and interactions with physical models all are representations and expressions of the individuals underlying conceptions, which are used to triangulate an individual's level of understanding. This approach of multiple mediums of answers to investigate a students understanding is used in this research.

Selection of Interviewees

Sophomore level engineering students who were currently enrolled in Mechanics of Materials (MOM) and had received instruction on the topics of interest in this research were interviewed. Twenty students were interviewed from Washington State University, and five were interviewed from the University of Idaho. Interviewees were sampled across course grade in MOM.

Interview Protocol and Conceptual Questions

The focus of the interviews was on normal and shear stress and deformation in an axially loaded member. An interview packet was developed with a multitude of questions with different approaches to every concept. The interviews were conceptually based and did not contain any questions that included or required equations, numbers, or numeric answers. Instead, the questions focused on students' reasoning. The interviews were designed to cover each topic separately at first. Then as the interview progressed topics would be combined. This enhanced the ability of the interviewer to determine if a student had proficient level of understanding on individual topics and provided evidence of interactions of understandings among concepts. For example, a student may be able to determine if normal stress is present and how it is acting. However, the scenario becomes much more complex when a student is then asked to explain if normal and shear stress are present and how they are acting in relation to each other.

The packet itself had open questions that required the student to explain their level of understanding through a verbal response. Ranking tasks have previously been utilized to probe students' conceptual understandings [15] and were used for this purpose in this research. Ranking tasks are comparative exercises that require ranking of a selected criterion in a physical situation where one or more variables are changed in each scenario. For example, students were asked to rank different locations and stress element orientations in the member based on normal and shear stress. The packet also contained questions that required the student to draw and visually describe how the stresses and strains were acting on stress elements. The third medium of interaction was a stretch band, shown in Figures I and II. The stretch band was utilized as an additional scenario to probe understanding of the relationships between an axial load and the normal/shear stress and strains that occur.

The first portion of the interview focused on clarifying assumptions that would be used throughout the interview. Initially it was made clear that the axially loaded member was a homogeneous material, with the forces being evenly distributed throughout the member with no stress concentrations.

The first concept addressed was normal stress. The questions utilized different scenarios to inquire about normal stresses in the direction of the applied load of an axially loaded member, including a ranking task. The student was asked to explain how the dimensions would change and discuss stresses in the directions parallel and perpendicular to the load. A ranking task was used with five elements randomly placed throughout the axially loaded member, and the student was asked to rank the elements based on magnitude of normal strain. A stretch band was then given to the student and they were asked to draw a horizontal stress element on the band (shown in Figures I & II) and describe the normal stress behavior when the band was pulled horizontally. This process was repeated but with an element oriented at a 45-degree angle.

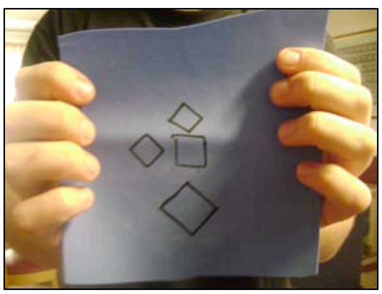


Figure I-Un-stretched Band

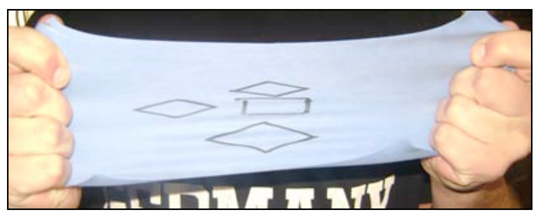
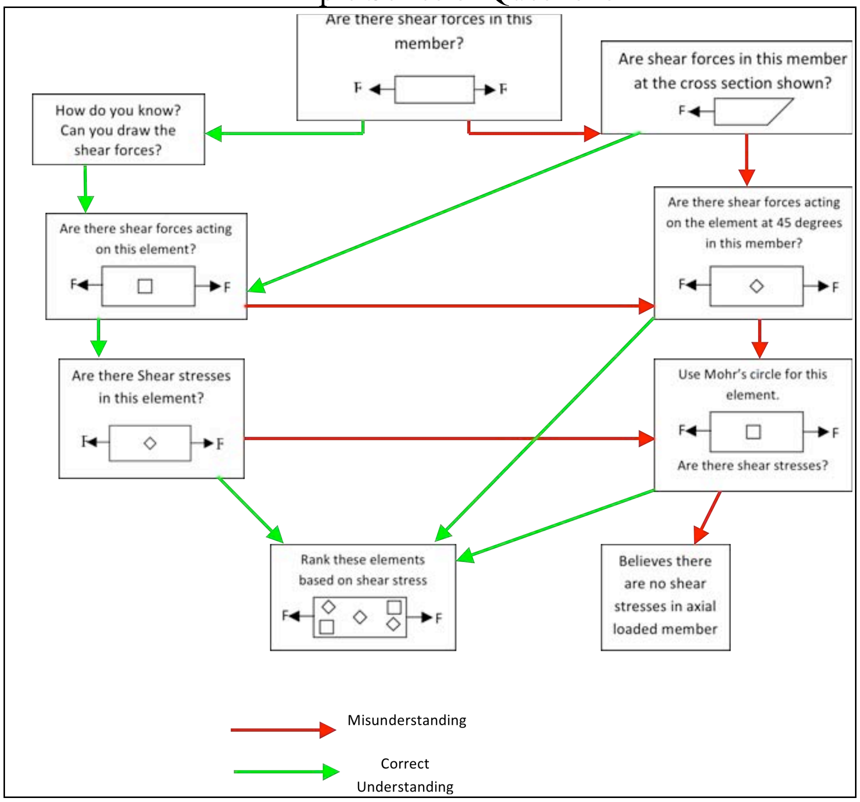


Figure II-Stretched band

The next section focused on the concept of shear stress. The first questions asked the student to discuss the distribution of shear stresses in an axially loaded member and at a cross section perpendicular to the load of an axially loaded member. The next questions asked the student to draw and explain the stresses acting on an element oriented at an arbitrary angle in an axially loaded member. Three ranking tasks followed involving five different stress elements oriented at different orientations from the applied load, requiring ranking based on the magnitude of shear stress. Next, the student was provided the stretch band and asked to describe the shear stress of elements oriented at random angles. The last question showed the results of the failure of a compressive concrete cylinder test. The student was then asked how the concrete cylinder failed.

Interviews were semi-structured, with a base set of questions that were asked of each student. Then, depending on the student's response specific probing questions followed. Probing questions were chosen by the researcher in order to gain a deeper insight into a students understanding and were somewhat unique to each student. Shown in Figure III is an example of how questioning with several different scenarios was used to probe understanding of the interviewee from multiple perspectives. The first question at the top and center of the figure, is a question that was asked to all students. Then, depending on a student's response the following questions would be determined. This allows for a broad and diverse investigation of students' mental representations of the core concepts.

Figure III
Example Series of Questions



The interviews were carried out in controlled environments on a one-on-one basis to ensure privacy. The students were made aware that all information divulged would be held anonymously. The researcher was a participant-observer and would ask interview questions and then observe and record interviewee responses. After each interview was finished, the researcher would go over the packet and review the student's responses. The researcher would make slight adjustments to the interview process for future interviews for refinement. Probing questions were removed or added in order to make the student responses more conducive to the study. This hermeneutic cycle of interviewing, review, and refinement optimized the ability to obtain the best results from the interviews.

Results

Interviewees displayed consistent and correct understandings of normal stress and strain in the direction of the load. All students were able to identify that normal stress was acting on the faces of a stress element perpendicular to the applied load.
All but four students were able to correctly describe how an axially loaded member would deform. Interviewees all understood the axial load would lengthen the member in the horizontal direction but 50% did not think it would shrink in the vertical direction. For example, John believed that no strain existed in the vertical direction because there is no shear force or moment.

Interviewer: Does this member have normal strain?

John: there would be normal strain-yes
Interviewer: OK, and how is it acting?
John: Well it's in tension so its acting outside, so basically this is in tension so its in the x-direction
Interviewer: Can you describe how the vertical & horizontal dimensions are changing?
John: So there will be strain in the x-direction-ok in the x-direction
Interviewer: OK, will there be any change in the y-direction
John: No
Interviewer: There is no change in the y-direction?
John: No change in y cause there's no moment and there's no shear force so its gonna be only in the x-direction

Sixty percent of students knew that the member would shrink in the direction perpendicular to the load and reasoned that the member was shrinking in the vertical direction as a result of stresses in that direction. In the quote below, Suzy explains her reasoning for the presence of stresses perpendicular to the load.

Interviewer: Describe the stresses that you've drawn
Suzy: They are gonna be normal in the x-direction because the forces are pulling that way and then I think there are gonna be stresses in the vertical because its shrinking in the middle

This may be evidence of a primitive and simple conceptions (p-prims) that some students may hold related to axially loaded members, change in a direction = stress in that direction. In the portion of the interviews on normal stress and strain, especially using the stretch band, students would refer to personal experience and intuition, providing further evidence that notions of relations between load and normal stress and strain exist outside of experience gained in the classroom. Forty percent of interviewees did not understand the presence or change in magnitude of normal stresses when an element was oriented at an angle other than perpendicular to the load.

Shear stress was a difficult topic for all students, and often students were less confident in their answers. Students had limited understanding of how normal and shear stresses would change magnitude in stress elements at different orientations. The student below indicates no change in stresses exist at different orientations.

Researcher: What stresses did you draw there?
Paul: These are shear stresses and these are normal stresses
Researcher: OK, and explain your reasoning?
Paul: Well normal cause you have sigma's pulling it out, and shear if you were take a cut I believe that's the way those would go to calculate the shear stress
Researcher: OK, and so how would the stresses change as your element changed orientation?
Paul: The stresses would not change

Additionally, Paul did not indicate the correct types of stresses on the horizontal element. When discussing shear stress, students made no reference or mention of previous experience or intuition. They either knew very little, or relied on symbols and equations from their MOM course. It is likely that students have limited p-prims related to shear stress. This would make sense as everyday experiences with shear stress are uncommon.

The representativeness of our sample to the larger population was addressed using saturation[9]. From our sample, saturation was determined by developing a case study model with a case for each individual student. For each student a critical path was created which mapped their conceptual understanding. Once the critical paths of students started to match those from previous students, saturation had been reached.

Conclusions

The results presented above indicate that students do have misconceptions on normal and shear stress and deformations in axially loaded members. Analyzing these misconceptions through the lens of p-prims provides a useful lens to investigate students' conceptual understanding. The phenomena of a member shrinking in the vertical direction when pulled horizontally is a physical display that may have been witnessed prior to classroom instruction and is an example of a p-prim. Students may have lacked the existence of p-prims for shear stress.

A difficulty with representing conceptual understanding through p-prims is identifying what exactly constitutes a p-prim. Previous work has identified some examples of p-prims in other contexts, but the application of p-prims to engineering mechanics courses is relatively new. Results indicate that p-prims originating outside of formal instruction may only exist for observable concepts like normal stress and deformation, and not shear stress. If p-prims related to instruction exist for shear stress, they appear to be very abstract and not easily applied by students. For example, students know that arrows parallel to a stress element represent shear, but little else. More work is needed to examine the presence and origins of p-prims related to loads and stresses.

This study portrays challenges students face with conceptual understanding in mechanics of materials curriculum. By using specific terms that have grown from others in this developing field of study, we gain the potential of efficiently describing not only students' conceptual understanding, but how to bring conceptual change to those with misconceptions. Results can be used to directly inform instruction in MoM.

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