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Quick-Response Drill for Training in the Identification of Stress Conditions

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Abstract

Courses or sequences of courses in solid mechanics typically provide students with the theory and skills necessary to calculate stresses in loaded parts. The requisite skill set includes load analysis and the application of equations for stress appropriate to the loading situation (axial load, torsion load, bending, etc.) Solving for stress is easiest for students when the loading situation is unambiguous or familiar. However, some students struggle with identifying the type and direction of stress at various locations on a part given a new loading condition. A method is proposed that trains students in identifying stress conditions for loads applied at different places and directions. The method uses images of simple parts with applied forces or moments, requiring the students to quickly identify the type and direction of stresses at a given point. A large variety of loading conditions can be covered quickly, and students receive immediate corrective feedback.

Introduction

Solid mechanics is a broad field that includes properties of materials, and how materials respond to loads. A typical textbook and course that teaches solid mechanics presents in sequence a variety of loading conditions, including the calculation of stresses associated with those loading conditions. For example, Beer et al.[1] presents pure shear, axial loading, torsion shear, and bending in that order. Problems and examples are presented within each chapter. This means that, as students are learning the appropriate equations for calculating stress, they do not need to consider what type of load is being applied. If they are learning about torsion shear, it is given that the load is a torsion load, and that they will use the equation

$$\tau = \frac{Tc}{J}$$

In terms of Bloom's Taxonomy of Educational Objectives, this work is at level 3, or application.[2]

However, exams often include problems with several different loading situations. Higher level courses such as Machine Design may present problems with a combination of loading conditions. In actual engineering practice, an engineering graduate is rarely told what stress equations apply to a situation. For all of these reasons, it is important that students develop the ability to discern what stresses are generated by a variety of loading conditions. In terms of Bloom's Taxonomy, this work is at level 4, or analysis.[3]

Engineering educators have long recognized the need for supplementary training in the visualization of stresses induced by various loading conditions. Examples include:

Authors	**Visualization mode**	**Students'Activity**
Zecher et al.[4]	3-D images, animation	Observe, solve problem
Salehpour and Antoline[5]	Rapid Protoyped parts	Build physical model of problem
Gao, Varma, and Asa[6]	Various 2D and 3D multimedia	Observe examples

All of these examples report that students learned better when exposed to visual images of the problems presented. All of these examples also involve a significant amount of time to prepare each visualization. This tends to limit the number of examples that will be presented with enhanced visualization. Moreover, they do not necessarily provide an opportunity for analysis instead of application.

For example, Zecher et al. created a multi-media presentation specific to a specific problem. The presentation included 3-dimensional images of the part and animations of the part deforming under load. It was beneficial for an in-depth understanding the specific problem, but was limited to three problems due to the "labor intensive nature of developing multimedia material."[4]

Salehpour and Antoline take it one step further, creating not only a computer model and analysis but a physical part that is tested to failure. This further extends the benefit of visualization, but is also limited in the number of loading situations that can realistically be covered.

The proposed quick response drill is unique in that it provides a more shallow (simple graphics) and broad (many instances) method, so that students see a wide variety of loading conditions in a short period of time.

Proposed training method

A training method is proposed in which students are presented with simple block-diagram illustrations of a large variety of loading conditions in rapid succession. They are instructed to identify the type and direction of stress at a specified point that results from the applied load. Immediately afterward, the same illustrations are presented again along with the correct answers. A sample set of illustrations is shown below, in Figure 1. In Figure 2 is shown a form that the students may use to record their answers. Each illustration is displayed for 30 seconds, so the entire exercise takes about 10 minutes to complete. Discussion of correct answers takes about 5 to 10 minutes.

The form is designed for speed and ease of use. A column is provided for each of four different types of stress, $\tau_{torsion}, \tau_{shear}, \sigma_{axial}$ and $\sigma_{bending}$. For each illustration, the student decides what type of stress is present at point A, and in which direction it is acting. The direction is entered into the appropriate cell.

The design of the set of illustrations was guided by several objectives. First, the diagrams of the parts are simple and consistent. This allows the student to focus on the differences between the applied loads without distraction. Second, most illustrations are in pairs. The two illustrations in a pair have the same load, but ask for the stress in a different location. This encourages students to consider the shape of the stress distribution. Finally, loads are applies in all three principal directions, so that all scenarios are covered.

For example, illustration 1 shows a force acting vertically downward (-Y) at the end of a lever arm, and point A is located above the center of the shaft. Illustration 2 has the same applied load, but point A is located horizontally beside the center of the shaft. Point A in both illustrations sees a clockwise torsion shear stress, +Y in 1 and –Z in 2. The same load also causes a bending stress, +X in 1, but zero bending stress in 2 since point A is on the neutral axis.

Benefits of the Quick Response Drill

This training tool focuses on the beginning of a solid mechanics problem, when the student needs to engage in analysis (Bloom's level 4) to identify the types of stresses present. Often this step is more difficult than engaging in application (Bloom's level 3) to solve the equations. Thus, the drill helps the students prepare for exams, where it is not always obvious if the problem involves bending, torsion, axial, or a combination of stresses. It also helps the students prepare for the real world, where problems are rarely put into easily recognizable categories.

The proposed drill uses illustrations that are easily prepared using 3-D solid modeling software. Therefore, the cost to develop the drill is low. The author prepared the illustrations shown in Figure 1 within about 2 hours. The cost is also low in terms of class time. It can easily be done in less than half of a 50 minute class.

Since the cost per illustration is low, both in preparation and in class time, a wide variety of scenarios can be used. This broadens the students' exposure, and increases their confidence that they can handle any problem. Another benefit to the low preparation time is that this method can easily be adopted by faculty in many universities.

Students' Reaction to the Quick Response Drill

A study has not yet been done to objectively evaluate the effectiveness of this training tool. However, students' reaction has been positive. For example:

"The PowerPoint slides with different loading conditions helped to understand where stresses occur," was stated as one of the aspects of the course that was most beneficial.

"I thought that the exercise was extremely useful and helpful in understanding the concept because the problems were simple enough that the broad concept could be perfectly understood allowing us to then apply the concepts to the more complicated HW problems. "

"I found the exercise to be very beneficial. Often times it is difficult to visualize the effects particular loads may have on a structure - some loads being of a more abstract variety than others. This exercise provided fantastic examples of stress results of particular loading situations, and I will likely print the images out to use as reference."

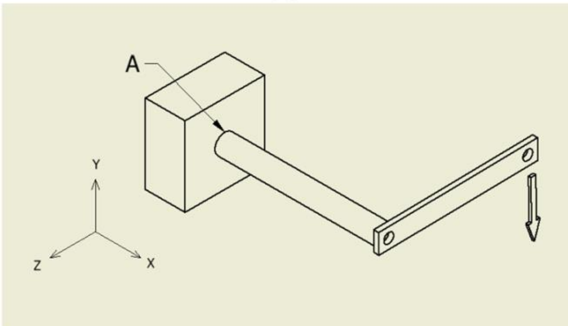
Another student suggested that it could be helpful to include a picture of the stress element in question. An example of this enhancement is shown in Figure 3.

The first student comment in this section was included in the course evaluation at the end of the semester. The course evaluation did not ask any questions related to the quick response drill. Therefore, this comment was unsolicited.

The other three comments were in response to a request for comment, and were e-mailed to the professor. These were the only written responses from a class of 25. Verbal responses and the level of engagement indicate that most students found the exercise to be beneficial. No negative verbal or written feedback was received.

Another way to assess the effectiveness of the quick response drill would be to test the hypothesis, "The quick response drill reduces the number of "clueless" answers on a quiz or exam." A "clueless" answer would be defined as one in which the student does not correctly identify the type or direction of stress. Errors in calculation or mis-applied equations would not register as "clueless." This assessment has not yet been done, but is being considered for the future. It would require about 20 minutes of class time for the "before" quiz. The "after" problem could be part of an exam, and therefore not require any additional class time.

1.



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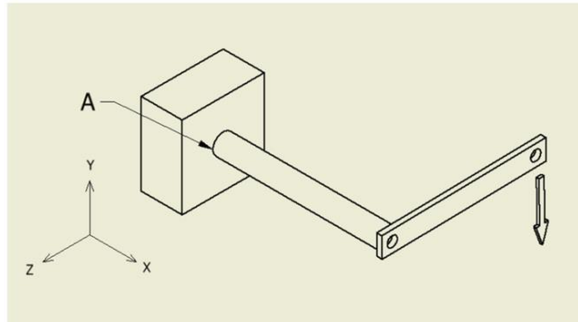

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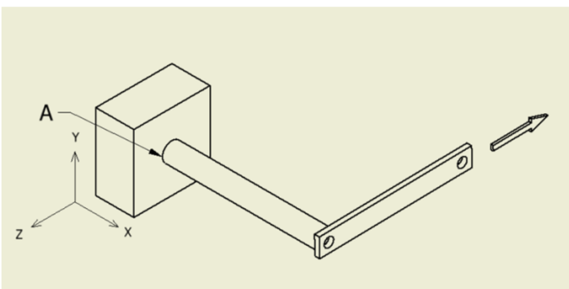

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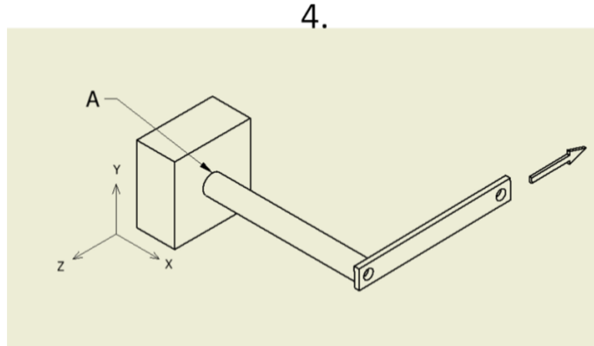

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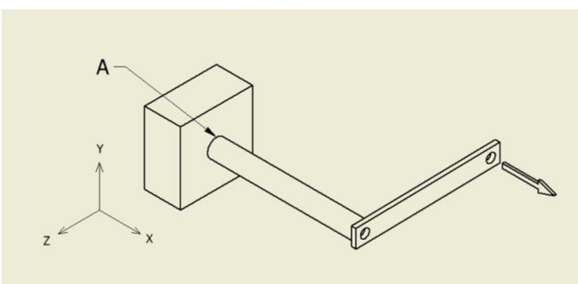

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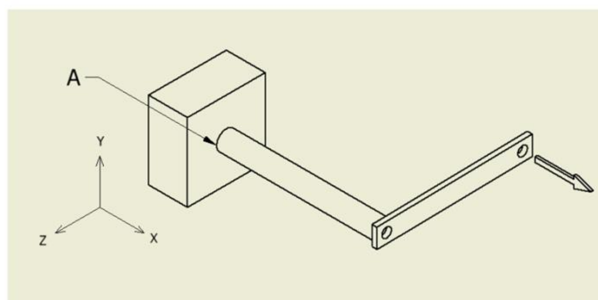

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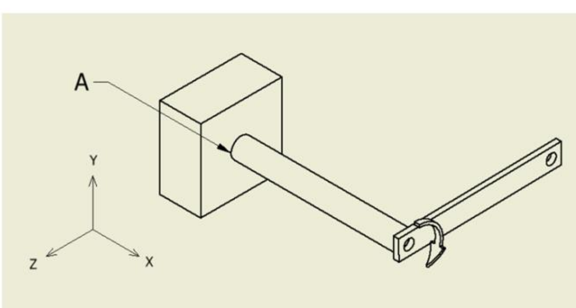

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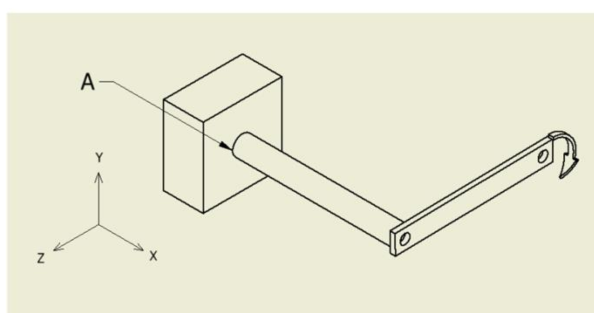

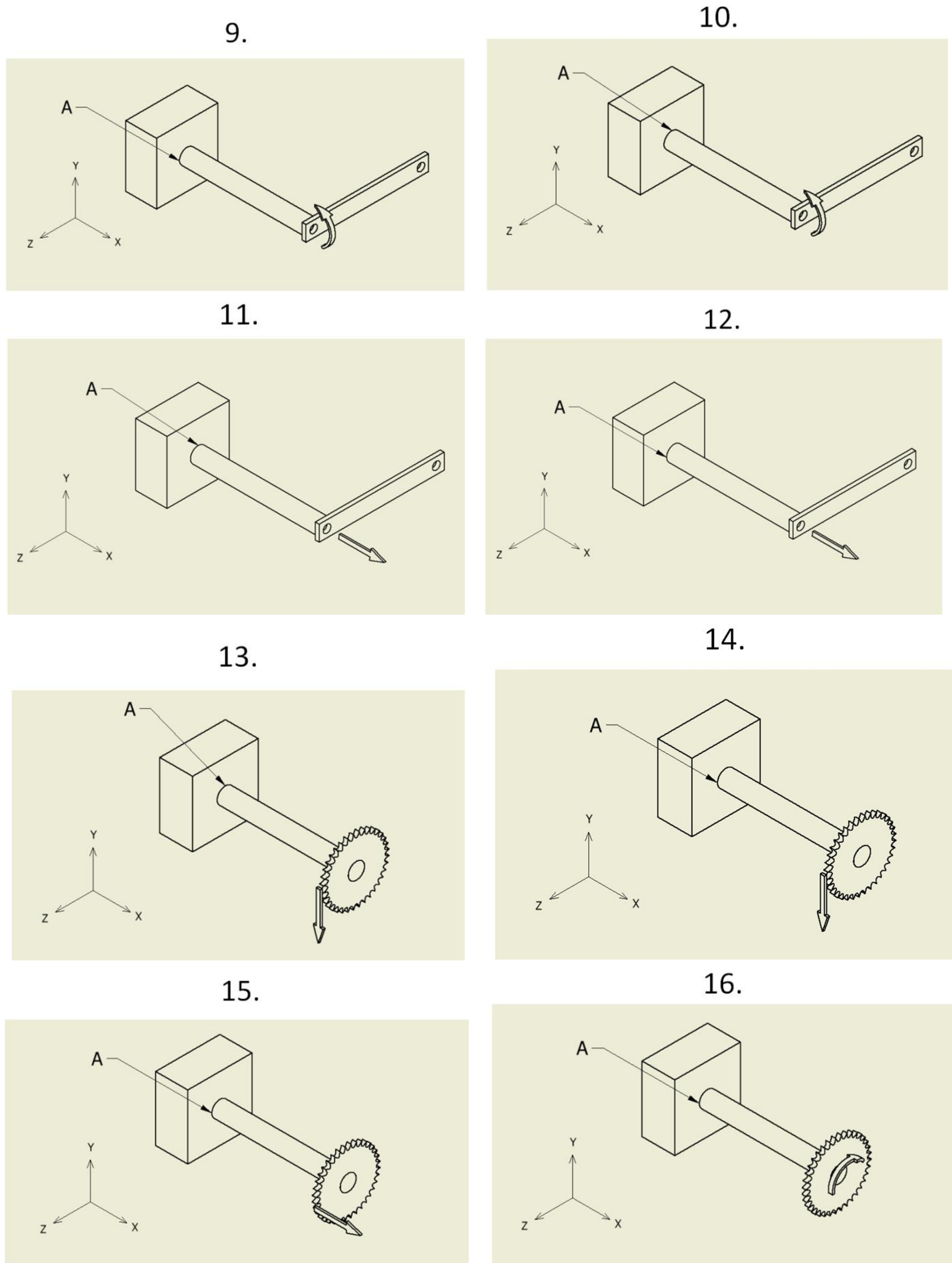

Figure 1. Illustrations of Loading Conditions

Indicate the direction of any stresses at point A (+X, -Y, +Z, etc)

slide	$\tau_{torsion}$	τ_{shear}	σ_{axial}	$\sigma_{bending}$
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				

Figure 2. Form for entering stresses caused by loads

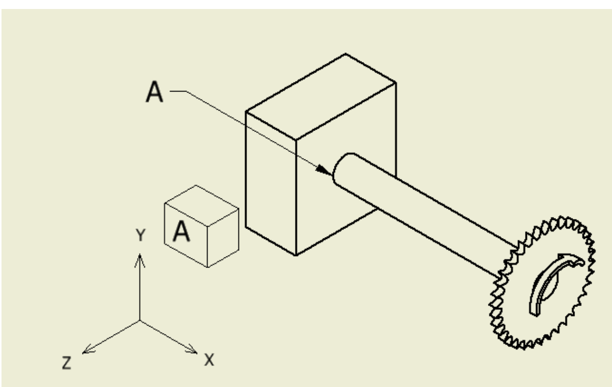

Figure 3. Illustration 16 enhanced with a picture of the stress element.

Potential enhancement and expansion

A further enhancement of the exercise would be to correlate the type and direction of stress directly with the standard notation of σ_x, τ_{xy}, etc. This can be accomplished by adding coordinate labels to the stress element, as shown in Figure 4 below. The form students use to enter stresses appropriate to the loading conditions could be modified as shown in Figure 5.

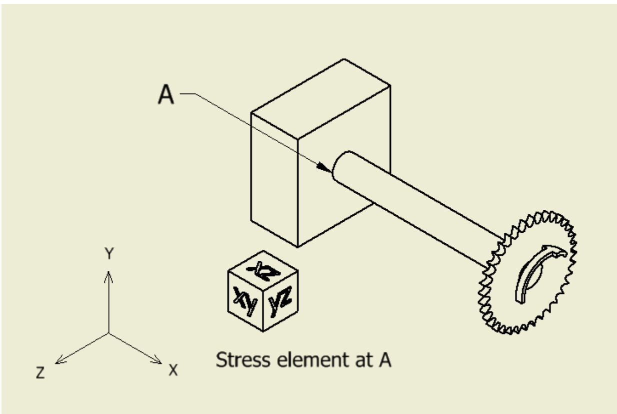

Figure 4. Illustration 16 enhanced with a stress element labeled according to coordinates.

Indicate the direction of any stresses at point A (+X, -Y, +Z, etc)

slide	τ_{xy}	τ_{yz}	τ_{xz}	σ_x	σ_y	σ_z
1						
2						
3						

Figure 5. Form for entering stresses caused by loads, in coordinate format.

The quick-response drill could also be adapted to other topics in solid mechanics. For example, illustrations of Mohr's circle could be shown, and students instructed to indicate the direction and type of stresses using the form of Figure 5. A sample illustration is shown in Figure 6. This exercise would reinforce the concept of correlating planes on the stress element with points on Mohr's circle.

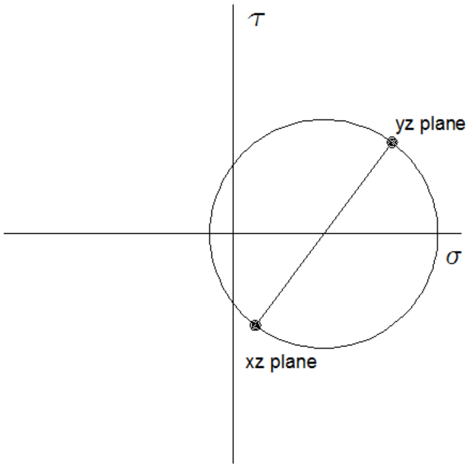

Figure 6. Sample illustration for Mohr's circle quick-response drill.

Summary

The proposed quick-response drill is a low-cost, effective means of training students in the higher-order analysis needed to solve problems in Solid Mechanics. It prepares students for exams and real-life situations in which it is not clear what equations are relevant. Its low cost recommends its adoption by many universities.

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