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Best Practice: Creative Online Assessments and Laboratory Exercises for a Mechanics of Materials Course to Maintain Academic Integrity and Student Engagement

Dr. Anthony Battistini, Angelo State University

Dr. Anthony Battistini is an Associate Professor in the David L. Hirschfeld Department of Engineering at Angelo State University. He received his BSCE (2007) degree from Lehigh University and an MS (2009) and PhD (2014) degree from The University of Texas at Austin in structural engineering. "Dr. Batts", as his students call him, aspires to provide students with a quality and enjoyable experience in the classroom and seeks to make classrooms more culturally responsive. To get more ideas for demonstrations, how to introduce themes to your classes, or ways to include professional readiness skills, check out his YouTube Channel (search Dr. Anthony Battistini) and his other ASEE conference papers.

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Abstract

In recent years, online education has become more commonplace. From the student perspective, asynchronous online courses provide flexibility in learning, allowing students to work at a time convenient for them and at their own preferred pace from almost anywhere in the world. Similar benefits are availed to faculty, who for one reason or another, want to have flexibility in work time and location. From a departmental perspective, particularly for a regional rural university, online courses provide the ability to stay connected to their own students, for instance during a summer semester when engineering students are often working as interns in cities far from the main campus. Lastly, from an administrative perspective, online courses can be used to recruit additional students and transfer students to the program and can increase revenue to the university.

While online courses can have many benefits, many STEM instructors are apprehensive of their use, particularly in courses with labs where students are expected to have hands-on, meaningful interactions with engineering principles and to develop proficiency in experimental data acquisition and analysis. With the expanding availability of powerful AI tools, other instructors question the integrity of student learning in online courses.

The following paper documents creative online assessment strategies used by a civil engineering instructor to mitigate concerns on academic integrity in an engineering mechanics of materials course while increasing student engagement. For example, themed exam problems delivered in the online format have randomized variables for each individual student as compared to similar problems in the face-to-face version of the class using traditional in-class written exams. In addition, the instructor requires video submissions of exam problem solutions from each student to verify his or her identity as well as provide an assessment measure for comprehension.

The Mechanics of Materials course described includes a lab component, in which one of the lab assignments serves as the initial, formative data point for the program's ABET assessment for Student Outcome 6: an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. In many introductory lab courses, students perform prescribed laboratory exercises and do not participate in the development of the lab procedure or the experimental design. The paper documents the instructor's ideas on how to develop meaningful and organized labs that meet the development aspect of ABET SO 6, including examples used in the face-to-face and online versions of the course.

Lastly, the author provides student performance and feedback from the course. Quantitative data is used to compare grades earned in both modes of delivery. Qualitative feedback is provided, particularly regarding the use of the video submissions in the online format and the effectiveness of the online experiments.

Motivation

In recent years, many universities have leveraged the use of online courses to engage students and maintain contact with their students. Traditionally, many faculty have dismissed the use of online courses for engineering content, particularly courses with a lab component. However, during the COVID-19 pandemic, everyone was forced to administer their classes remotely, including courses with labs. The experience led the author to develop creative lab exercises for a Mechanics of Materials course to engage students in real life engineering experiments at their homes, while maintaining the requirements of ABET Student Outcome 6, for which the course serves as the initial formative data point for their ABET Continuous Improvement program. In addition, the instructor has addressed concerns for academic integrity through randomized exam problems and student video solutions to accompany their submitted calculations.

Assessments- Labs

ABET Student Outcome 6 states that students must demonstrate "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions." In particular, the outcome requires students to develop the experimentation plan- not just follow a set of provided instructions. For the face-to-face version of the course, the instructor has two experiments that help support ABET Outcome 6; the first is meant to give students experience in developing and executing an experimental plan on their own, while the second is used as the ABET data point to assess how well the students meet the outcome. The following summarizes the two experiments:

- Lab 02: Stress vs Strain Test
  - Face-to-face
    - Students are provided with a variety of materials (gym weights, tape, markers, clamps, rulers, calipers) to measure the deflection of a bungee cord, ultimately needing to convert the results into a stress vs strain curve for the material.
    - Students spend time to plan their experiment without instructor help based on Lab 01 which used a UTM to conduct the similar experiment as well as class lessons.
    - Students are expected to identify or realize on their own the stress vs strain curve for the elastic bungee cord will not be linearly elastic like the metals previously covered in the class.
  - Online
    - Students must find materials at their home (bungee cords, fishing line, climbing rope, rubber bands, workout bands, weights, buckets/bottles of water (for measuring force), tape, markers, clamps, rulers) to measure the deflection of an object of their choosing, ultimately needing to convert the results into a stress vs strain curve for the material.
    - Students work remotely, but in teams of 2-4, to plan their experiment without instructor help based on Lab 01 which displayed videos from a UTM to conduct a similar experiment with provided data sets as well as class lessons.

    - Students conduct the experiment at home- often choosing to compare different materials so that each student in a lab group can conduct a physical test.
    - Students can choose to conduct the labs together if they desire. Where possible, the instructor will try to match students who wish to meet together into a lab group based on a pre-semester student survey.
    - Students are expected to identify or realize on their own the stress vs strain curve for the elastic bungee cord will not be linearly elastic like the metals previously covered in the class.
- Lab 05: Comparison of Theoretical to Measured Bending Stress
  - Face-to-face
    - Students attach a strain gage to an aluminum ruler in Lab 03
    - Students are provided with a variety of materials (small weights, tape, markers, clamps, rulers, calipers, and strain gage module to display readings) to measure the actual stress in the ruler when loaded with weights.
      - Ideally, students will run a 4 point bending test to ensure more stable readings in the strain gage.
      - 3 point bending tests and cantilever tests have been used with success, with small variations/error in the experimental to theoretical results.
    - Students must also calculate the theoretical bending stress by determining My/I, and then compare results.
  - Online
    - Lab 04 from the face-to-face version is a concrete cylinder test. In the online version the students create concrete rectangular prisms in addition to a "cylinder" for testing, using concrete obtained from a typical hardware store (or provided by our lab if they are in the area to pick it up)
    - Students must use weight (a 5-gallon bucket with sand or water is suggested) as well as the concrete rectangular prism to run a 3 or 4 point bending test to cracking, similar to a modulus of rupture test.
    - Students use the measured moment to calculate the theoretical bending stress. This is then compared to the ACI suggested formula of $7.5\sqrt{f'c}$ formula for the modulus of rupture, using estimated values for their f'c for their concrete.

At first, the author was unsure how students would respond to the online experiments. However, anecdotal feedback from the students indicate the labs are one of the most exciting portions of the online class and that it really forced them to think through experimental design, especially with limited supplies at their homes.

The Lab 02 assignments are provided in Appendix A and the Lab 05 assignments in Appendix B.

Quantitative/Qualitative Feedback- Labs

To assess the effectiveness of the online labs, performance related to ABET Student Outcome 6 was examined over previous years for which the author was the instructor of record. As previously mentioned, the first formative data point for ABET Student Outcome 6 is obtained in the Mechanics of Materials course. For the face-to-face course, Lab 05 has been used for the data collection point. For the online course, Lab 02 or Lab 05 is used. The Lab 04A: Concrete Beam Construction for 3 Point Bending Test (which leads into Lab 05) presented in Appendix B was first added in Summer 2024; however, many students had difficulties with completing the lab due to confusion on the instructions. The instructor revised the directions and provided some online videos of him/her completing the experiment for Summer 2025, but a scheduling error led to the Lab being optional to prioritize other course work for the students.

Figure 1 presents the ABET Student Outcome 6 Data for the course.

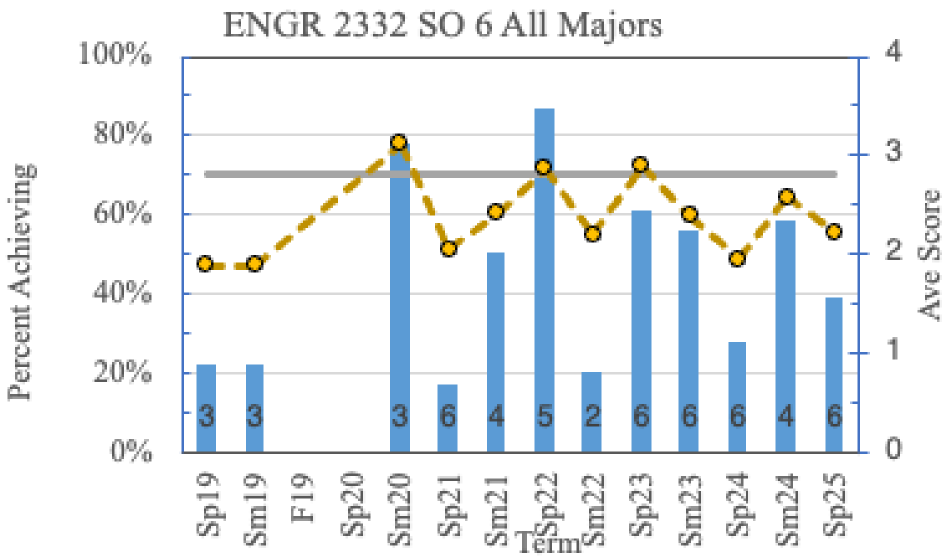


Figure 1: ENGR 2332 Student Outcome 6 Data

In general, you can see that the Summer semester offerings, which are in the online format, are currently trending upward in terms of performance, whereas the Spring semester offering, which are face-to-face have generally remained low, but are slightly improving. The high variability of the data motivates the instructor to develop a new, consistent lab that would be offered in the same manner in both online and face-to-face modalities to obtain more reliable data to analyze.

Assessments- Exams

As one of the primary tools used by faculty to assess student learning, traditional exams in the online environment introduce concerns for academic integrity as well as rigor. To address the latter, the author ensures the exam questions always align with the student learning outcomes for the course. It is the author's belief that as long as students can achieve these outcomes, it does not matter whether they do it in a high-stakes timed exam environment or a lower-stakes, untimed one.

In order to address academic integrity concerns, the author will use the students' campus ID number or assign numbers to student names to randomize variables within the exam. To facilitate grading, the author has developed spreadsheets to enter the variables and calculate the answers.

In addition, students must upload a video explaining their solution procedure, which helps the instructor verify the students' identity and confirm his/her understanding of the concepts.

Examples for Exam I and Exam II are provided in Appendix C and D accordingly. The corresponding author would be happy to share the spreadsheets and/or source files with interested faculty via email correspondence to help verify identity.

Quantitative/Qualitative Feedback- Exams

With regards to the exams, which are used as the primary measure of student learning in this course, one of the major concerns when comparing face-to-face and online modalities is whether or not a consistent, fair experience for the students is provided. To analyze whether or not grade outcomes are consistent, Exam I, Exam II, and Final Grade averages are compared across semesters for which the author was the instructor of record. Table 1 presents data for the course and Figures 2-4 present exam data.

Table 1: ENGR 2332 Enrollment Data

ENGR 2332: Enrollment Data		
Semester	**Modality**	**Students**
Spring 2016	Face-to-face	47
Fall 2016	Face-to-face	50
Spring 2017	Face-to-face	43
Spring 2018	Face-to-face	20
Summer 2018	Face-to-face	9
Fall 2018	Face-to-face	3
Spring 2019	Face-to-face	13
Summer 2019	Face-to-face	12
Fall 2019	Face-to-face	7
Spring 2020	Face-to-face	12
Summer 2020	Online	9
Spring 2021	Face-to-face	19
Summer 2021	Online	13
Summer 2023	Online	15
Spring 2024	Face-to-face	20
Summer 2024	Online	11
Spring 2025	Face-to-face	22
Summer 2025	Online	12

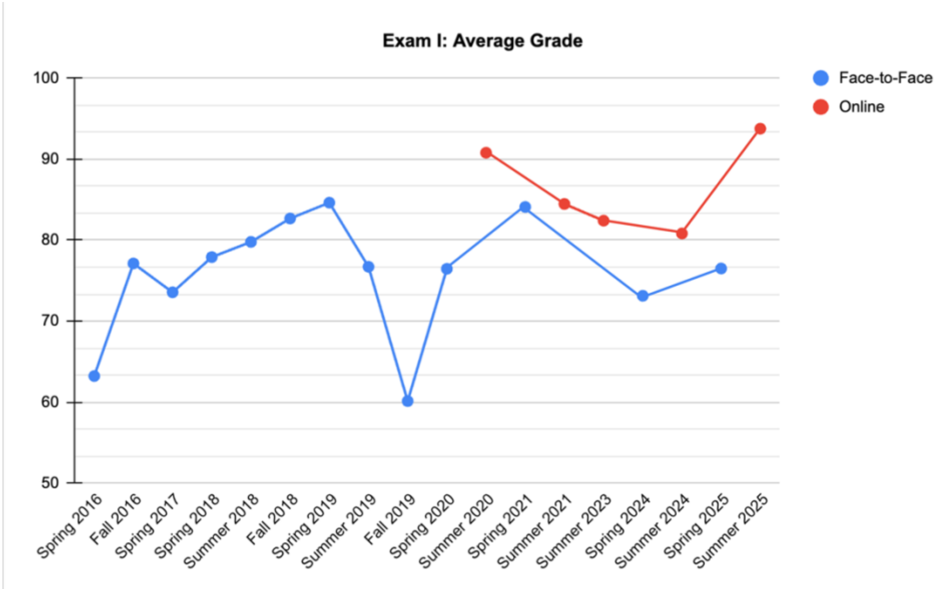


Figure 2: ENGR 2332 Exam I Data

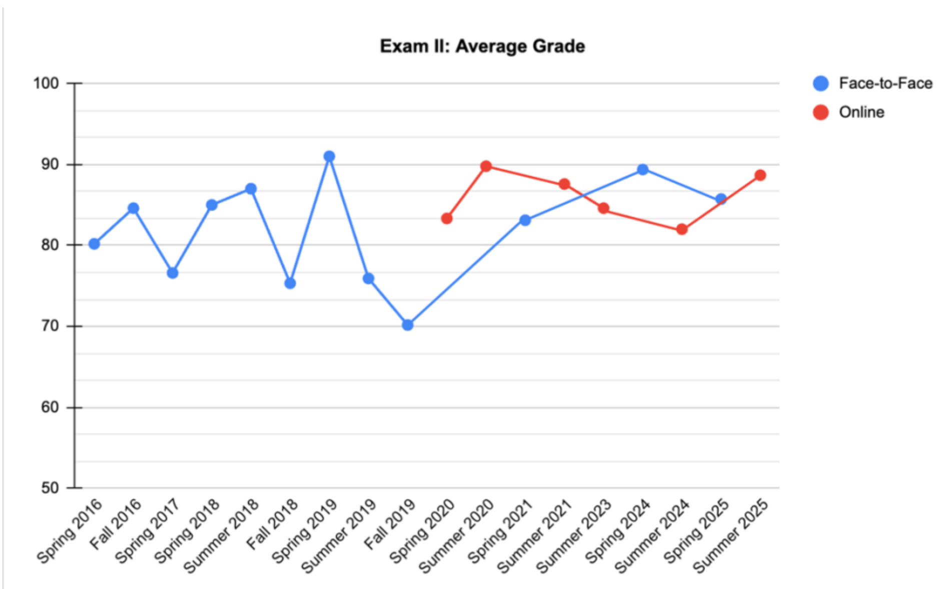


Figure 3: ENGR 2332 Exam II Data

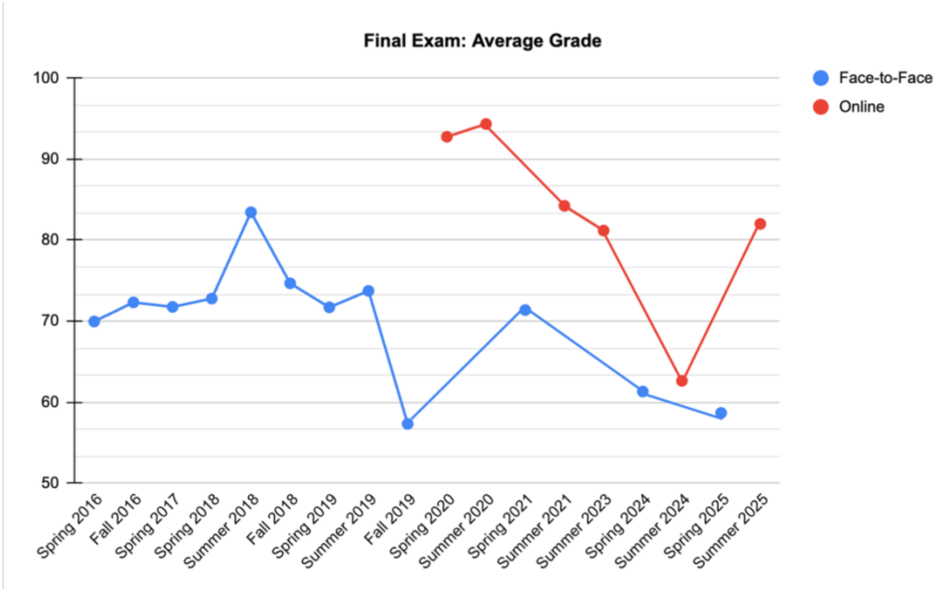


Figure 4: ENGR 2332 Final Exam Data

Based on the data shown, it is observed that students generally perform better on all exams in the online modality. While this was expected since the high-stakes, timed element of the exam is removed, it does bring up potential concerns to the instructor to continue to ensure students are abiding by the university's academic integrity policy. While there have been no identified, blatant copying of solutions, the instructor will continue to find ways to provide unique assessments.

From Figure 2, it is seen that for Exam I, students in the online course averaged 5-10 points higher than their face-to-face counterparts. It is interesting to note that students in Summer 2025 scored the highest on this exam, which was also the first time Exam I had randomized variables for each student.

From Figure 3, it is observed that since Spring 2020, students are generally performing equally on Exam II in both modalities. It is interesting to note that since Summer 2020, Exam II has contained randomized variables for both face-to-face and online courses, so this data is the most compelling to see that student achievement has been somewhat consistent, at least for the topics of the course covered (stress and strain transformation, shear and moment diagrams, bending stress).

Finally, Figure 4 shows Final Exam Data. To date, the final exam has not contained randomized variables. The assessment tool has now remained consistent for semesters since Spring 2024 with no final exam solutions disseminated to the students. However, in the online modality, students do have the opportunity to save their own completed exam. With Summer 2025 scoring very well on the exam, the instructor is concerned that perhaps a solution of the exam does exist, prompting him/her to update the Final Exam for Spring 2025.

Conclusions

While the online space poses difficult challenges for engineering courses, particularly labs and exams, the author believes that creativity can offer solutions. In particular, the online labs have resulted in creative examples from student groups.

The grade data presented shows that using variables in the exam assessments and video solutions can help to ensure academic integrity in the online space and maintain consistent exam performance.

Appendix A

Lab 02B: Deflection Experiment
In-Person Class

Overview

In Lab 02A, you were asked to develop an experimental plan to determine the force-deflection behavior for a bungee cord. Ultimately, we want to calculate the stress-strain behavior for this cord and perhaps make observations/calculations regarding its engineering properties.

Required PPE

- Safety Glasses
- Closed-Toe Shoes

Materials

The following materials are available at the back of the lab room for your shared use in this lab:

- Pencils, pens, markers
- Paper
- Tape
- Bungee Cords
- Weights
- Rulers
- Calipers
- Buckets

Safety and Restrictions

- The main safety issue for this lab is the bungee cord. If the weight suddenly slips from the cord or the cord breaks, it is possible for the cord and hook to snap and injure the student. In particular, the hook on bungee cords can severely damage the eye and/or cut the skin.
- When carrying and applying the weights, the possibility for injury due to the weights falling or being dropped is a concern. Please do not suspend the weights high above the ground or place your hands/feet below the weights.
- The intent of this experiment is to obtain data in the elastic region. As such, we will not be loading the bungee cords to failure. You are asked to only load the cords to a **maximum of 25 lbs**.

Lab Procedure

- Use the steps your team developed in Lab 02A to perform your experiment.

Lab Results/Report

- Record any necessary measurements from the experiment.
- Plot the force versus deflection curve for the bungee cord as measured in the lab.
- Plot the calculated stress versus strain curve for the material.
- Comment on its behavior in terms of the material being linear/nonlinear and elastic/plastic.
- Report the modulus of elasticity if possible. Discuss the usefulness of this property for metallic material as discussed in class compared to the bungee cord.
- The items above will be submitted in a lab report meeting the requirements posted to the Lab 02C Assignment, to be further discussed in class.

Lab 02B: Deflection Experiment
Online Version

Overview

In Lab 02A, you were asked to develop an experimental plan to determine the force-deflection behavior for a bungee cord. Ultimately, we want to calculate the stress-strain behavior for this cord and perhaps make observations/calculations regarding its engineering properties.

Required PPE

- Safety Glasses
- Closed-Toe Shoes

Materials

The materials available to you at your houses.

Safety and Restrictions

- The main safety issue for this lab is the bungee cord / rubber band / fishing line / weight bands etc.. If the weight suddenly slips from the specimen or the specimen breaks, it is possible for the specimen to snap and injure the student. In particular, the hook on bungee cords can severely damage the eye and/or cut the skin.
- When carrying and applying the weights, the possibility for injury due to the weights falling or being dropped is a concern. Please do not suspend the weights high above the ground or place your hands/feet below the weights.
- The intent of this experiment is to obtain data in the elastic region. As such, your team does not need to load the specimens to failure.

Lab Procedure

- Use the steps your team developed in Lab 02A to perform your experiment.
- Please record an overview of your experiment or post a video of a demonstration of the video in the Flip L2 topic. I have set the time for the video to 10 minutes maximum (max allowed by Flip) so be aware you will need to edit the video if you exceed this.

Lab Results/Report

- Record any necessary measurements from the experiment.
- Plot the force versus deflection curve for the bungee cord as measured in the lab.
- Plot the calculated stress versus strain curve for the material.
- Comment on its behavior in terms of the material being linear/nonlinear and elastic/plastic.
- Report the modulus of elasticity if possible. Discuss the usefulness of this property for metallic material as discussed in class compared to the bungee cord.
- The items above will be submitted in lab report form meeting the requirements to be discussed in Lab 02C.

Appendix B

Lab 05A,B: Bending Stress Laboratory

Overview

In this laboratory, teams will be using strain gages attached to an aluminum ruler to measure bending stresses (see Lab 03). The lab teams will then compare measured strains/stresses with theoretical bending stresses calculated using the engineering mechanics equations derived in class.

A brief overview of the lab is here: https://youtu.be/KQXlpKaI0dk

Required PPE

- Closed-toe Shoes

Materials Available- Requests for additional materials can be made

- Strain Gage
- Aluminum Ruler
- Strain Gage Module (measures/displays strain)
- Weights
- Pencils/Pens/Markers
- Level
- C-clamp
- String

Safety and Restrictions

- The main safety issue for this lab is injury occurring from the use of the die grinder and grinding discs, if your group needs to replace the strain gage previously applied in Lab 03. See Lab 03 for details and safety protocol.
- The other hazard may be dropping of the weights as you measure the bending stresses.

Lab 05A Procedure

- In your lab groups, decide how you will use the materials above to compare measured stresses in the aluminum ruler to calculated stresses.
  - How will you want to arrange the weights on your ruler to measure the bending strain?
  - Do you want to put one weight at midspan or develop a constant moment region with two identical weights?
  - How will you support the ruler? What are the boundary conditions?
  - How will you compare the measured bending strain to the theoretical bending stress?
  - How many different arrangements of weights will you consider to confirm the accuracy of the results?
  - What other measurements will need to be taken?

Lab 05B Procedure

- If your strain gage does not work, reattach a new gage following the procedures of Lab 03.
- Work with the instructor to get your strain gage properly connected to the module.
- Document the steps you followed to measure the strain.
- List any limitations or sources of error that occur during the experiment that could lead to errors in strain measurement. Follow up with possible errors introduced in Lab 03.

<u>Lab Technical Memo [100 pts]</u>

- Write a technical memo (2-4 pages) summarizing your experiment, loading positions, possible errors, results, and conclusions. In your results and conclusions, be sure to compare your measured strains to strains predicted from engineering mechanics. Attach any relevant calculations and shear/moment diagrams.

- Provide any appropriate information, pictures, figures, or calculations you feel are necessary to completely explain your experimental procedure, the data collected, and subsequent conclusions based on your data.

- In your technical memo, include the following headings:

  Introduction
  - Describe the purpose of the experiment.
  - Identify the key variables to be studied.

  Materials
  - List the materials used in the experiment.

  Experimental Methods
  - List the steps the lab group used to complete the experiment.
  - Document a detailed data collection plan.

  Results
  - Present the major data obtained from the experiment. Use figures and tables to assist in a clear presentation of the data.
  - Calculate measured bending stresses in the ruler and compare to theoretical predictions for all load cases considered. Include sample calculations here or in an Appendix.

  Conclusions
  - Draw conclusions based on your experimental data. Do the measured and theoretical calculations agree? If not, why might they be different?
  - Were there any limitations or observed problems in your experiment that affected your results?
  - How would you improve your experimental methods if you were to repeat the experiment?

ENGR 2332: Lab 04A Assignment
Concrete Beam Construction for 3 Point Bending Test

Learning Objectives

- Construct a miniature concrete beam specimen for experimental testing
- Design an experiment to measure the effects of different variables in the concrete materials used
- Explain and simulate standard procedures for concrete cylinder strength specimens

History

Concrete is one of the most widely used construction materials in the world. Contrary to the belief that the Egyptians were the first to use concrete, the history of it begins with a lime concrete floor that was discovered at Yiftah El in Galilee, Israel and dates back to 7000 B.C. However, the Egyptians were the first to use it on a large scale, including the construction of the Great Pyramid of Cheops (at Giza) around 2500 BC (Kosmatka et al. 2002).

Early applications of concrete basically involved the rehydration of calcium sulfate (gypsum) or calcium carbonate (limestone). Both substances can be ground into a fine powder and heated; upon the addition of a small amount of water, the paste will re-set into a hardened material. However, since gypsum is soluble in water, and the reaction between lime and water requires evaporation to harden, the major downside to the use of these cements is that they require a dry curing environment (Pessiki 2005).

The ancient Romans and Greeks improved upon these methods by adding silica, found naturally in volcanic ash, to the lime. When mixed with water, these compounds create calcium silicate hydrate, a gel capable of hardening in hydraulic environments (Pessiki 2005). In addition, these cements were much stronger than previous ones, allowing the construction of large structures such as the Colosseum. These cements became the forerunner to modern-day Portland cement.

Concrete

The basic formula for concrete is:

$$\text{Concrete} \quad = \quad \text{Cement} \quad + \quad \text{Aggregate} \quad + \quad \text{Water}$$

In this laboratory, we will be creating a sample concrete cylinder and a rectangular beam using various proportions of the above components. Depending on the mix you obtain, it will probably contain ground Portland cement, course aggregate (stone/rock), and fine aggregate (sand) to which you will be adding water to create the concrete. Your mixes may also include other admixtures or additives- whatever is easy to find will work fine for this experiment. Typically, concrete cylinders are made in accordance with ASTM C31: Standard Practice for Making and Curing Concrete Test Specimens in the Field (posted to Blackboard) and the concrete beam specimens are made in accordance with ASTM C78: Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). The steps included in this laboratory are meant to mimic these specifications, but will differ because of modifications so you can construct them at home with limited supplies.

Slump

One variable affecting the strength of the concrete is the amount of water added to the mix, measured as the water-to-cement ratio, w/c. One way to visualize the affect of this ratio on the workability of the concrete is to measure the slump. Slump is a test procedure outlined in ASTM C143: Standard Test Method for Slump of Hydraulic-Cement Concrete (posted to Blackboard). To measure slump in this home experiment, you will fill the "slump cone" using a modified procedure. You will then remove the cone and (as quick as possible) measure how far the concrete cone has "slumped" down.

Concrete Cylinder Compression Test

Since the strength of a batch of concrete will vary depending on the type of cement used, the aggregates used, the water to cement ratio, and other admixtures/additives used in the mix, engineers must verify that the concrete obtained in any given project meets the minimum strength requirements of the design. To determine the compressive strength of the concrete, cylindrical test specimens are created with each batch of concrete, allowed to cure at similar environmental conditions, and then are tested in compression until rupture. When engineers specify the strength, it is assumed this is the standard strength at 28 days from construction. Therefore, we will make our specimens and hopefully have 28 days to let them cure before we test. However, if you are late in construction of your samples, please wait at least 10 days before testing and make a note of the curing time in your experiment.

Concrete 3 Point Bending Test

In this test, engineers are able to determine the unreinforced tensile strength of the concrete. Based on a number of documented tests, there is a relationship between the tensile strength obtained in this experiment and the compressive strength of the concrete. Since the class is online and may not have access to the amount of compression force needed to break our sample cylinders, the main objective of the experiment is to create these beams. We will learn more about bending stress in beams in Lessons 15 and 16, and will then be able to determine the approximate strength of the concrete.

Variables

Each group will be expected to construct at least one rectangular beam specimen and one sample cylinder for each member of the group. Like in Lab 02, I want each group to design their own experiment, choosing different variables to test. If you are nearby and can use the same batch of concrete, then you can add different things to the mix to test the difference. If you are located separately, maybe the main variable will be the type of concrete you acquire, or if anyone is up for making more than one beam specimen, you can try some of the variables listed below.

Superplasticizer

To increase the workability of the concrete, many people will add water to the mix. However, this leads to a loss in concrete compressive strength, which may be unacceptable for a given project. One alternative is the use of additives or admixtures which alter the chemistry of the concrete. Plasticizers, or superplasticizers, are formulated so the concrete will become more flowable without changing the strength properties or arrangement of aggregate in the mix. We have some plasticizer at the lab, but you probably do not have it around your house, but maybe you do!

Sugar

It is somewhat urban legend that concrete truck drivers keep a bag of sugar in the truck in case they get stuck in traffic. It is said, that sugar will delay the set time of the concrete, and chemically speaking, it is true. From what I read, the sugar will not affect the final strength. If your team wants to test this variable, try doing some research and come up with an experimental plan to test this hypothesis!

Salt

In addition to sugar, my concrete professor in college said that salt has the opposite effect, so in his words, "If you really don't like your neighbor, either add a bag of salt or a bag of sugar to the concrete as they place their new pool." It seems documented that salt water (like ocean water) will accelerate the set time of concrete. You can also try this variable out if you would like!

Fibers

Concrete is inherently good in compression but not in tension. Besides steel rebar, another way to add tensile strength is to add fiberglass fibers, stainless steel fibers, or carbon fibers to the concrete to increase the tension strength. Other ideas that have been proposed are shredded plastics or aluminum from recyclables. If you have an idea, feel free to add fibers of some sort to the batch to test it out. As this specimen will be largely unreinforced, the affect of the fiber should be able to be tested.

<u>Test Supplies</u>

- 15 lbs Total of Concrete (ready-mix concrete, or you can buy pure cement and follow this ratio by weight)
  - 19% Cement
  - 48% Course Aggregate (medium to large stone)
  - 33% Fine Aggregate (sand)
  - Water (based on water to cement ratio; lbs water = (w/c ratio)*(lbs cement); w/c ratio $\geq$ 0.35)
    - Example: w/c = 0.40 (i.e. use 0.40*(12 lbs cement) = 4.8 lbs water)
  - Variables
- 1 box of cheap Saran wrap / plastic wrap
  - We will be using the box as the mold for the beam and lining it with plastic wrap; so just be prepared that you will end with a roll of wrap with no box.
- 2 Solo cup or similar plastic cup
- Cooking oil (optional)
- 1 Old pencil or stick
- 1 Ruler
- Scissors or knife
- Old mixing bucket, wheel barrow, or dirt yard
- Mixing shovel

<u>Test Procedures</u>

** Take pictures for your lab reports! **

Slump Test (ASTM C143)
To the best of your ability, follow this procedure for the slump test, substituting the following terms:

- slump cone = solo cup
- rod = pencil/stick

- Create a "slump cone" by cutting the bottom of the cup out; then turn so the larger end of the cone is on the ground or a covered surface
- When the concrete is homogenously mixed, fill slump cone 1/3 full (by volume). Be sure to securely hold the slump cone to the ground while filling.
- Rod the layer 25 times using 5/8" diameter rod
- Fill the slump cone to 2/3 full (about 6-1/8" deep)
- Rod second layer 25 times, allowing rod to penetrate first layer approximately 1". Be careful to not allow the rod to strike the bottom.
- Fill slump cone to heaping full.
- Rod 25 times, allowing rod to penetrate second layer approximately 1". If concrete drops below surface of cone, add additional concrete as necessary.
- Strike off the excess concrete using a rolling, screeding motion of the rod.
- In one movement taking 5 +/- 2 seconds, remove the slump cone, invert the cone, and set next to the concrete.

- Position the rod across the top of the inverted cone and measure the amount the concrete drops below this point. This is the slump.
- According to the specification, the entire process should take place in less than 2.5 minutes.
- Repeat this test three times for your concrete.

Concrete Beams (ASTM C78)

- Line the rectangular box of the plastic wrap with plastic wrap. Optionally apply or spray a very thin layer of form oil (cooking oil) to the wrap to allow easy release.
- Once you have measured the slump three times, place the concrete into the rectangular form.
- Use the rod to consolidate the concrete to release trapped air. I would try to place the beam in at least three layers.
- You may also use formwork vibrators to help with consolidation. In real life, these are mechanical vibrators attached to the exterior of metal forms and run along the length of the beam. In our lab, you can just gently shake/vibrate the whole beam or use the pencil to tap the outsides of the form.
- Once the beam is full, drag the pencil across the top of the beam to screed off excess concrete. If the concrete is not up to the top, add more than repeat screeding motion.
- Using a marker, label the box of the specimen with the course number, your lab group name, and today's date.

Concrete Cylinders (ASTM C78)

- Once you have measured the slump three times, select the appropriate plastic cylindrical molds from the side table.
- Using a marker, label the specimen with the course number, your lab group name, and today's date.
- For 4"x8" cylinders, fill the mold in two equal layers. For 6"x12" cylinders, fill the mold in three equal layers.
- After each layer, rod the mixture 25 times to consolidate the concrete, being careful to only allow the rod to penetrate the layer beneath it by 1" (like was done in the slump test; use the smaller diameter rod for the 4"x8" cylinders). Then tap the outside of the mold 10-15 times with a rubber mallet or open palm to make sure any voids along the outside of the mold are filled in.
- Once complete, use the rod to screed off any excess concrete.
- Use a trowel to finish the top of the cylinder making it as smooth as possible. You may also use a little water to help get a smooth top.
- Carefully transport the cylinders to the moist curing room. Make sure tops are still smooth and cap them.
- Repeat as necessary. Use excess concrete to complete additional 4"x8" cylinders.

Wait 28 days to reach full strength for testing!

<u>Lab Report Requirements- Part 1 of 2 [100 pts]</u>

- **Title Page**- provide a title for the experiment and list the lab team members
- **Abstract**- describe the overall purpose of the experiment and the major results obtained
- **Table of Contents**- list of page numbers where each section can be found
- **List of Figures** (if any)- list of page numbers where each figure can be found
- **List of Tables** (if any)- list of page numbers where each table can be found
- **List of Symbols**- list of any variables or acronyms used throughout report
- **Introduction**- describe the purpose of the experiment, why it is important, and any hypotheses on what might happen; specifically hypothesize about the strengths of the cylinders made by each team

- **Background**- take a look at some of the specification materials for both the slump tests and the cylinder strength tests; include information about concrete, its components, and where you might obtain these materials for construction
- **Materials**- list all materials used in the experiment (preferably in a bulleted list)
- **Experimental Methods**- list the steps taken in the experiment (a numbered or bulleted list would be appropriate); you may reuse the bullets above along with any other information you feel is relevant
- **Safety Plan**- list the measures used to prevent injury and improvements that could be made, if any
- **Results**- present the major results from the experiment; specifically show pictures of your slump test and provide a table with the values for the three slump tests performed
- **Conclusions**- none needed at this moment
- **Limitations/Future Work**- discuss any errors that might have occurred during your experiment and how to prevent them in future experiments; discuss future experiments or research that should be done
- **Works Cited**- cite all sources

Works Cited

Kosmatka, Steven H. et al. (2002). Design and Control of Concrete Mixtures, 14th Ed., Portland Cement Association, United States.

Pessiki, Stephen. Fall 2005 Civil Engineering Materials Class Notes. Lehigh University.

Appendix C

Name: ______________________________

ENGR 2332

Exam I

Squid Games: The Secret Games

오징어 게임

https://ast.wikipedia.org/wiki/Squid_Game#/media/Ficheru:Squid_Game_2021_vector_logo.svg

Directions

- Read each problem carefully
- Be sure to solve all the parts to each problem
- For full credit, draw complete free body diagrams where appropriate
- Write complete equilibrium equations
- **Make sure to include units and directions/sign conventions (if applicable) for all answers**
- Clearly box, circle, or identify answers
- <u>Perform your own work! You may NOT discuss the exam with any other person</u>, including others that are not currently taking the course. Any questions you may have should be directed to the instructor only.
- You may use the following to solve the exam: pencil/pen/markers, calculator, straight edge, compass, any notes from class, other online resources from Blackboard or other, or any other non-human source.

Your Contestant Number:

Choose a number between 001 and 456: ___ ___ ___

(12 pts) Question 1	________
(8 pts) Question 2	________
(4 pts) Question 3	________
(20 pts) Problem 1	________
(20 pts) Problem 2	________
(20 pts) Problem 3	________
(20 pts) Problem 4	________
(100 pts) Total	________

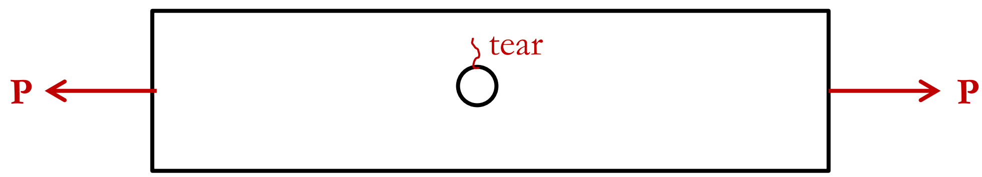
Story: You find yourself walking home from class one day, when a well-dressed businesswoman approaches you to find out if you have what it takes to get an engineering degree. You think so and answer 'Yes', but she asks you to prove it. She then asks a series of questions.

Given: The following short answer questions or short calculations.

Find: Provide the correct answers.

QUESTION 1: VOCABULARY [12 PTS]

________________ 1. The woman hands you a piece of paper and you both pull on it for a second. A small tear in the paper develops as shown. She asks why. This is an example of this phenomenon. [2 pts]



________________ 2. You fold the paper and throw it to the ground. Suddenly she slaps you in the face. She asks you if you can relate the longitudinal strain on your cheek to the lateral strain using this engineering property. [2 pts]

________________ 3. As your cheek stings and heats up, she asks you about $\boldsymbol{\alpha}$, this property of the skin that would relate strain to temperature. [2 pts]

________________ 4. Next, she places a small stone tablet on the ground you have to try to knock over with a rock. She asks you if you think the tablet will be this adjective, which describes a material characterized by stress-strain behavior that shows limited deformation prior to fracture. [2 pts]

________________ 5. You are able to hit the tablet with the rock. After the force of impact, the tablet returns to its original shape. She asks you to describe this type of behavior, where the material returns to its original shape after unloading. [2 pts]

________________ 6. Lastly, she asks if you know anything about torsion. You reply 'Yes'. As part of your description, you tell her about this property of the cross sectional area (not material), which provides a measure of a cross section's ability to resist twist. [2 pts]

QUESTION 2: MATERIALS [8 PTS]

For each question, choose one of the following answers:

- ASTM A36
- ASTM A572 Gr. 50
- ASTM A514 Gr. 100
- No difference

________________ 1. This steel grade has the highest yield stress. [2 pts]

________________ 2. This steel grade has the highest modulus of elasticity. [2 pts]

________________ 3. This steel grade likely has the best ductility. [2 pts]

________________ 4. This steel grade has almost no noticeable yield plateau. [2 pts]

QUESTION 3: MEMORY [2 PTS + BONUS]

1. Identify your favorite class theme so far this semester. What engineering concept(s) were taught related to that theme? [2 pts]

2. 'Someone' sacrificed themselves in the class to help us learn about stress and strain. What was/is his name? [1 pt]

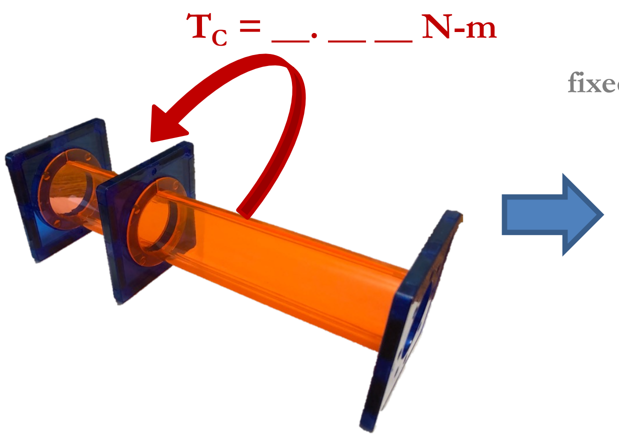
3. Of the following names, which one is a music artist whose music has been played in this class [1 pt]:

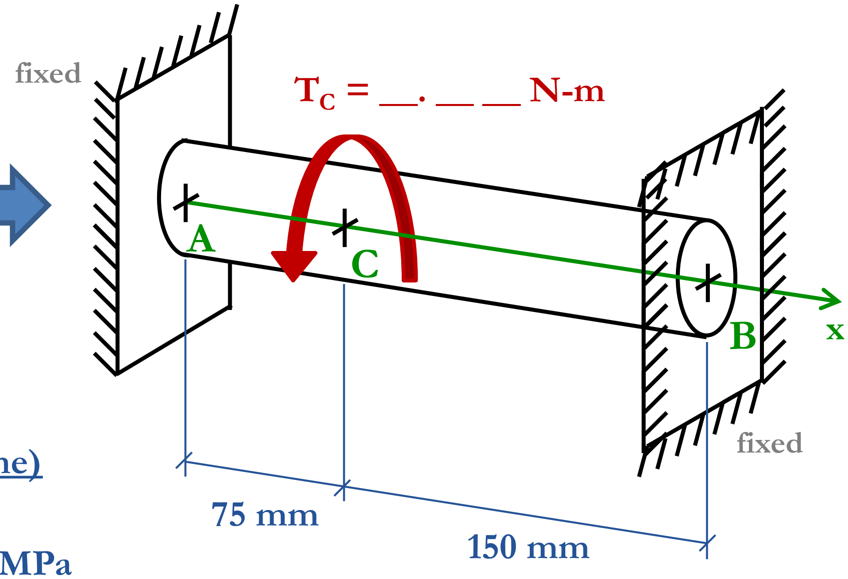
   Cornell Iral Haynes Jr
   Marshall Bruce Mathers III
   Chester Bennington
   Joe Jonas
   Tyler Joseph

머리 또는 꼬리 *[Heads or Tails]*, 구슬 *[Marbles]*

Story: After successfully answering the stranger's questions, you don't remember anything else. Maybe you got in a car with some fog? Anyways, you awake to find yourself in what looks like a regular classroom. You must play a game of heads or tails with your partner. After completing the game of heads or tails, you are escorted to a desk where you are asked to solve the following problem about loads on a marble run game. Why kid's games?

Given: **Enter your three-digit contestant number in the blanks for T_C**





ABS (acrylonitrile butadiene styrene) Plastic Properties

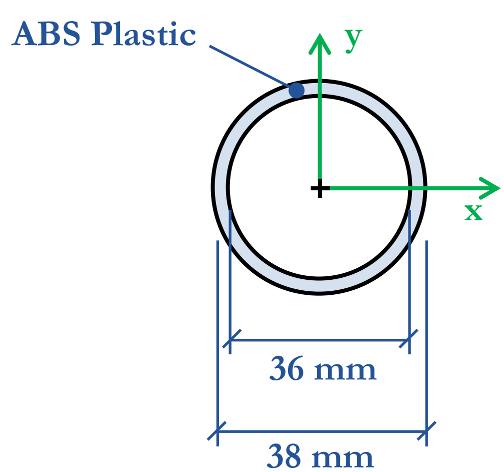
Max Allowable Axial Stress = 28 MPa

Max Allowable Shear Stress = 0.4 MPa

E_{ABS} = 2 GPa

G_{ABS} = 0.77 GPa

Cross Section AC, CB



Find:

(a) Draw an axial torque diagram for drive shaft ABC. [4 pts]

(b) Determine the maximum shear stress acting on the marble run tube wall ACB. [8 pts]

(c) Calculate the angle of twist at point C and indicate its direction. [4 pts]

(d) Upload a 2 minute or less video to your assigned Google Drive folder explaining your solution procedure to this problem. [4 pts]

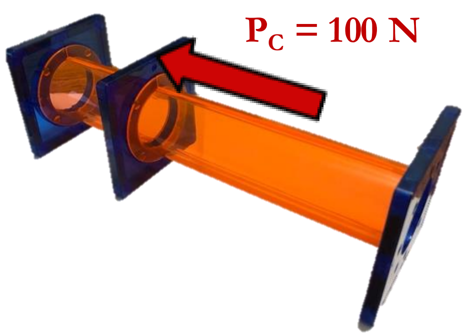
Solution:

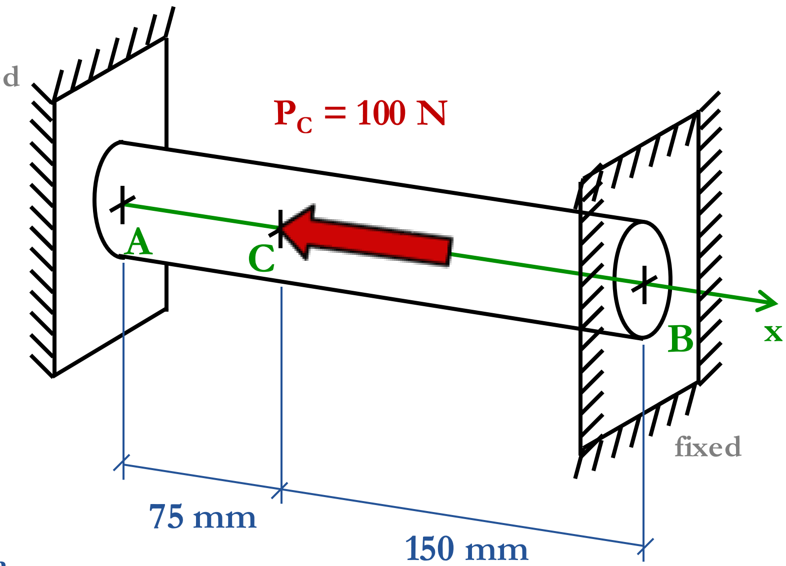
Solution (continued):

머리 또는 꼬리 *[HEADS OR TAILS]*, 구슬 *[MARBLES]*

Story: After successfully answering the stranger's questions, you don't remember anything else. Maybe you got in a car with some fog? Anyways, you awake to find yourself in what looks like a regular classroom. You must play a game of heads or tails with your partner. After completing the game of heads or tails, you are escorted to a desk where you are asked to solve the following problem about loads on a marble run game. Why kid's games?

Given:





ABS (acrylonitrile butadiene styrene) Plastic Properties

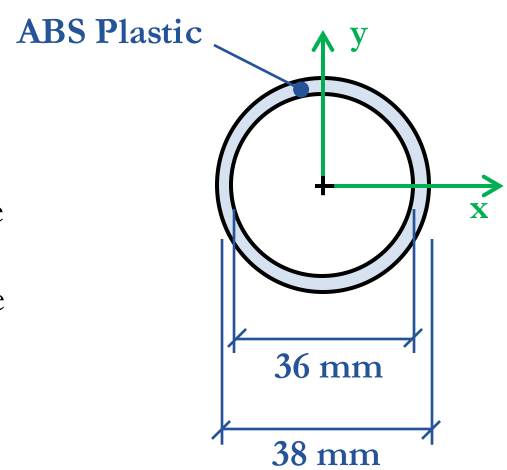
Max Allowable Axial Stress = 28 MPa

Max Allowable Shear Stress = 0.4 MPa

E_{ABS} = 2 GPa

G_{ABS} = 0.77 GPa

Cross Section AC, CB



Find:

(a) Draw an axial force diagram for drive shaft ABC. [5 pts]

(b) Determine the maximum axial stress acting on the marble run tube wall ACB. [10 pts]

(c) Calculate the axial displacement at point C and indicate its direction. [5 pts]

Solution:

Solution (continued):

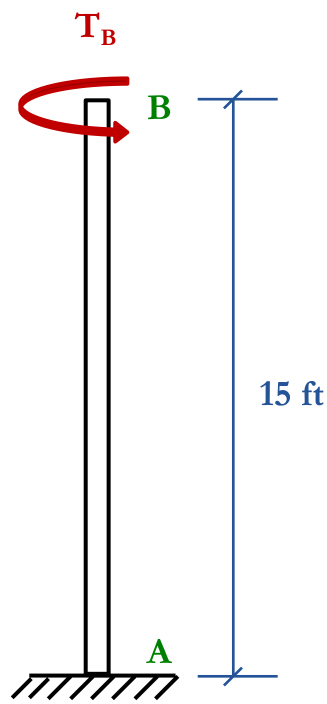
무궁화 꽃이 피었습니다 *[Red Light, Green Light]*

Story: After successfully completing the last problem, you are directed to an outside arena with a crazy looking doll. The doll's head rotates suddenly on its axis, producing the load shown on the shaft supporting her neck. You here some distant bangs, but you can't be bothered in the middle of an exam.

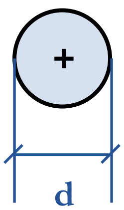
Netflix Show Video Clip: Squid Games, Season 2

Given: **Enter your three-digit contestant number in the blanks for P. This value is your number plus 5000.**

The 5 __ __ __ ft-lb/s motor rotates the dolls head π radians in 0.25 sec, creating a torque as shown on the steel rod supporting her neck.



Steel Rod Cross Section



$d = 1.5$ in

$E_{steel} = 29{,}000$ ksi

$G_{steel} = 11{,}500$ ksi

Find: (a) Calculate the torque applied to the shaft at B. [4 pts]

$$P = T\omega$$

$P = 5$ __ __ __ ft-lb/s $\qquad \omega = (\pi \text{ rad})/(0.25 \text{ s})$

(b) Draw a torque diagram for the steel rod. [4 pts]

(c) Determine the maximum shear stress in the rod. [4 pts]

(d) Calculate the angle of twist (in degrees) of the rod at point B relative to A. [4 pts]

(e) Upload a 2 minute or less video to your assigned Google Drive folder explaining your solution procedure to this problem. [4 pts]

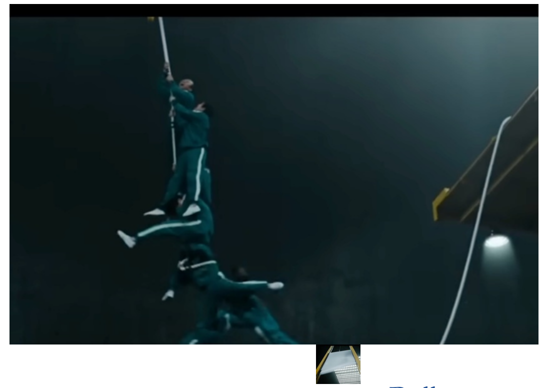
Solution:

Solution (continued):

PROBLEM 3 [20 PTS]

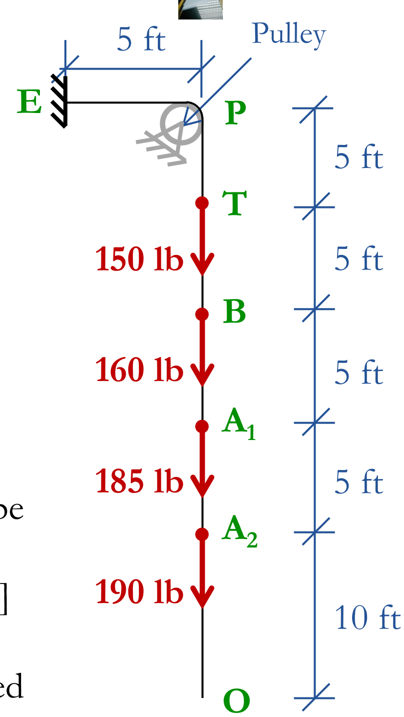
줄다리기 *[Tug-of-War]*

Story: For the next event, you are escorted to a room overlooking what seems to be a tug-of-war rope spanning between two suspended platforms. The next round of players enter the game. The game commences until one team is pulled from the platform as shown with loads given. Surely, they'll be ok, however you must answer this question or be eliminated… whatever that means.

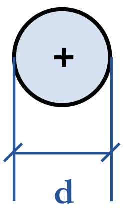


Netflix Show Video Clip: Squid Games, Season 1

Given: The rope shown with the loads given. Loads act at the tail of the arrows, namely at points T, B, A_1, and A_2.



Rope Cross Section



$d = 0.5$ in

$E_{nylon\_rope} = 100$ ksi

Find:

(a) Draw an axial force diagram for the 35 ft long rope segment $EPTBA_1A_2O$. [4 pts]

(b) Determine the maximum axial stress in the rope. [4 pts]

(c) Calculate the total axial deflection at point O. [8 pts]

(d) Upload a 2 minute or less video to your assigned Google Drive folder explaining your solution procedure to this problem. [4 pts]

Solution:

Solution (continued):

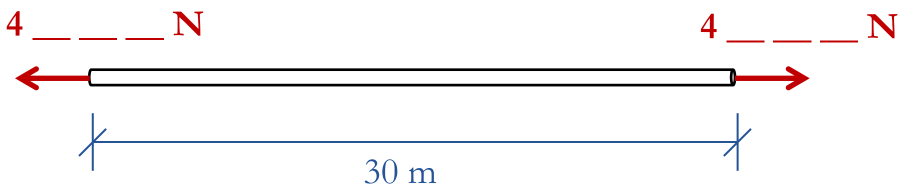
PROBLEM 4 [20 PTS]

줄다리기 [Tug-of-War- Part 2]

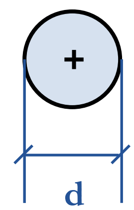
Story: You finish your calculations and look back up. Another two teams are setup to start the game. They seem equally matched.

Given: **Enter your three-digit contestant number in the blanks for P. This value is your number plus 4000.**

When the game begins, both teams exert an opposing force on the nylon rope of 4 __ __ __ N.



Rope Cross Section



$d = 12.7$ mm

$E_{nylon\_rope} = 700$ MPa

$\nu_{nylon\_rope} = 0.40$

Find:

(a) On the plot shown, qualitatively draw the stress versus strain behavior for a typical alloy steel, similar to an ASTM A572 Gr. 50. Be sure to include magnitudes for F_y and E. The percent elongation at fracture for this grade of steel is about 20-30%. [4 pts]

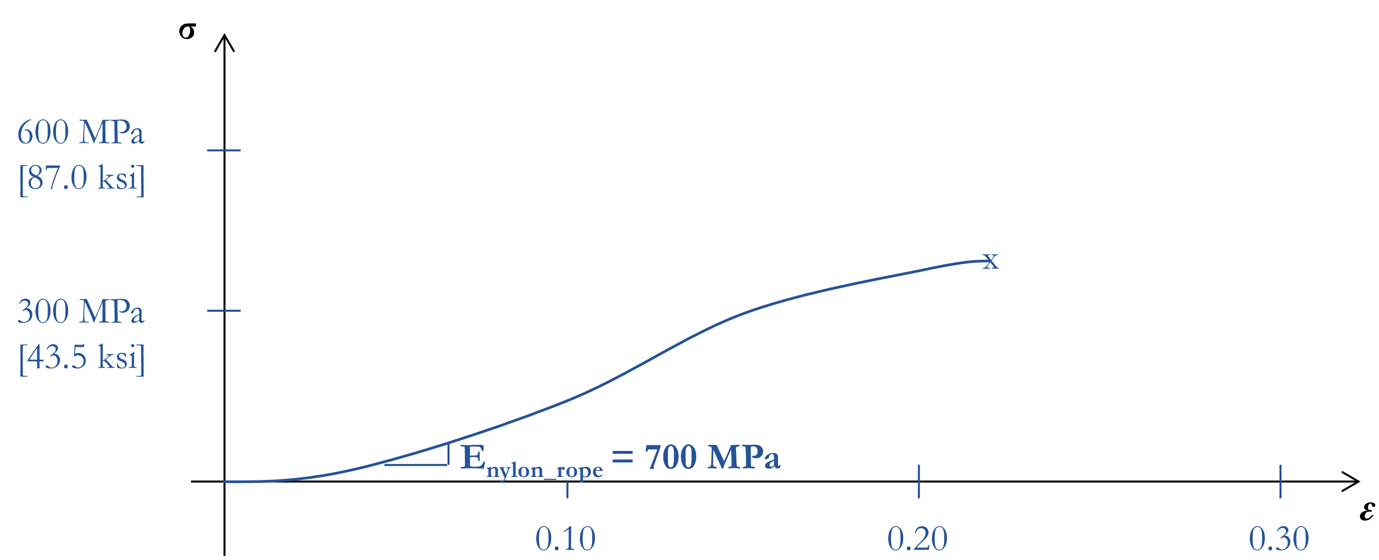
(b) Label the four regions of the steel stress vs strain curve. [4 pts]

(c) Assuming linear elastic behavior, calculate the axial elongation of the rope under the 4 __ __ __ N force. [3 pts]

(d) Calculate the reduced cross sectional dimensions of the rope under the 4__ __ __ N loading? [5 pts]

(e) Upload a 2 minute or less video to your assigned Google Drive folder explaining your solution procedure to this problem. [4 pts]

Solution:



Solution (continued):

Story: After successfully answering all those questions, you feel great about your engineering knowledge. You go back to the lounge area to relax and you look forward to seeing how your other classmates did. You hear a distant cash register trilling.

Material Properties, Stress, Strain

$$\sigma = \frac{P}{A_o} \qquad \varepsilon = \frac{\Delta L}{L_o} \qquad \%\text{ elongation} = \frac{\Delta L}{L_o} \times 100\% = \frac{L_f - L_o}{L_o} \times 100\%$$

$$\%\text{ reduction } A = \frac{|A_f - A_o|}{A_o} \times 100\%$$

$$\nu = \frac{-\varepsilon_{lateral}}{\varepsilon_{longitudinal}} \qquad G = \frac{\tau}{\gamma} = \frac{E}{2(1+\nu)}$$

$\sigma = E\varepsilon$ (in linear elastic range)

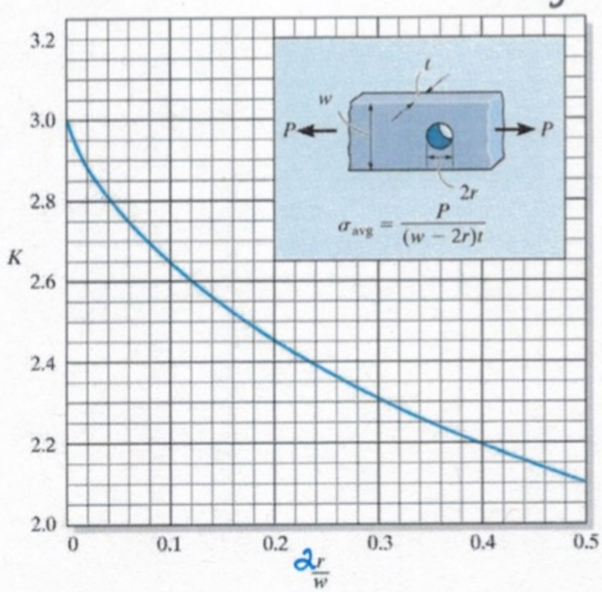
Axial Deflection

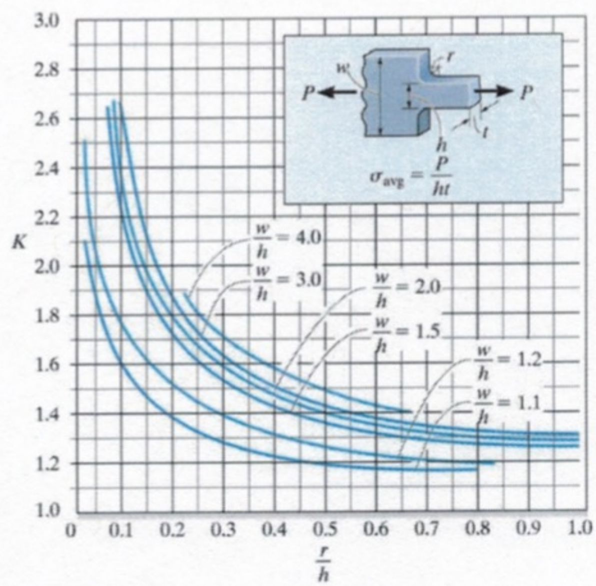
$$\delta = \frac{PL}{AE}$$

Temperature Effects: $\delta_{temp} = \alpha L \Delta T$

Stress Concentrations

$$K = \frac{\sigma_{max}}{\sigma_{avg}}$$





Torsion

$$\tau = \frac{T\rho}{J} \qquad J = \int_A \rho^2\, dA = \frac{\pi}{2}\left(r_o^4 - r_i^4\right)$$

$$\tau_{max} = \frac{Tc}{J} \qquad \phi = \frac{TL}{JG}$$

Power and Gears

$$\frac{T_A}{r_A} = \frac{T_B}{r_B}$$

$$P = T\omega = (2\pi f)T$$

Appendix D

Name: ______________________________

ENGR 2332 - Exam II

Squid Games: The Secret Games- 2

오징어 게임 2

Directions

- Read each problem carefully
- Be sure to solve all the parts to each problem
- For full credit, draw complete free body diagrams where appropriate
- Write complete equilibrium equations
- Make sure to include units and directions/sign conventions (if applicable) for all answers
- Clearly box, circle, or identify answers
- Perform your own work! You may NOT discuss the exam with any other person, including others that are not currently taking the course. Any questions you may have should be directed to the instructor only.
- You may use any non-human source to assist you with the exam (class notes, homework solutions, computer).
- **You may not use AI (artificial intelligence) to solve the exam problems directly.** You can ask AI for help on how to solve the problems, but you cannot upload a picture of the exam problem or type the problem directly to have it do the work for you. If using AI or other online resources, please cite their use.

Academic Integrity Statement

By signing my name below, I attest that I have not discussed the exam with any other students currently enrolled in the class. Additionally, I have not asked any other person for assistance in completing this exam. I have also not used AI to directly solve any of the problems. If I did use AI, or other online resources, I have clearly cited their use. The work submitted is completely my own.

X______________________________

(20 pts) Problem 1	________
(30 pts) Problem 2	________
(30 pts) Problem 3	________
(20 pts) Option #___	________
(100 pts) Total	________

ENGR 2332 - Exam II

Squid Games: The Secret Games- 2

Participant Numbers

01 – Bailey
02 – Lucas
03 – Gray
04 – Raegan
05 – Fern
06 – John
07 – Trey
08 – Fernando
09 – Beatriz
10 – Willie
11 – Tyson
12 – Zachary
13 – Roman
14 – Calvin

In Problems 1 and 2 of this exam, you will need to select the numbers for yourself and other classmates. Feel free to choose any of your classmates/numbers above, but please only use each once. Basically, the numbers you use in Problems 1 and 2 should be somewhat random and will most likely be different for each person's exam.

https://squid-game.fandom.com/wiki/Mingle?file=Mingle_Game_Image.png

섞다 *[MINGLE GAME– ROUND 1]*

Story: Weeks after escaping Exam I, you somehow find yourself voluntarily back for another round of Squid Games in Exam II. Crazy that this could be happening to you again?!

For the next game, you find yourself in a room with the other participants. The music playing is catchy. Then the music stops and you must run to a room with four of your classmates. Inside, you are faced with the following problem.

Given:

You must be able to analyze the state of strain on an in-service gas line (plane strain). Three strain gages are used and the following strains are given at the point of interest. Referring to page 2 of the exam, choose yourself and four other classmates. Please complete the blank lines using the assigned numbers of the participants.

https://www.chicagotribune.com/2020/12/22/peoples-gas-is-spending-billions-to-replace-miles-of-aging-pipe-below-chicago-by-2040-but-will-natural-gas-be-obsolete-before-its-complete/

ε_a = – __ __ x 10^{-5}
[Use your assigned number; this value is negative]

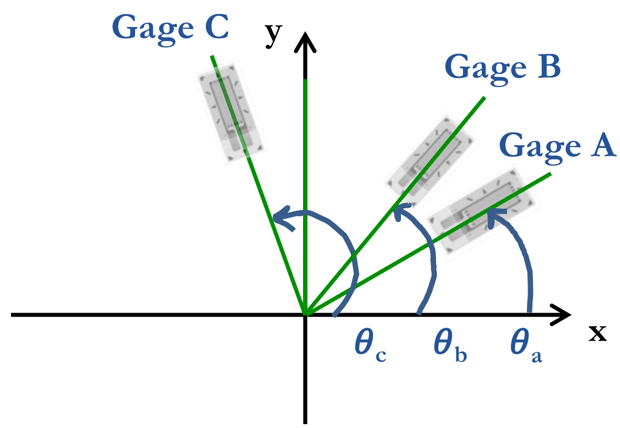
θ_a = __ __ °
[Use a classmate's #; should be an angle between 1° and 14°]

ε_b = – __ __ x 10^{-5}
[Use a classmate's #; this value is negative]

θ_b = 60°

ε_c = __ __ x 10^{-5}
[Use a classmate's #; this value is positive]

θ_c = 1 __ __ °
[Use a classmate's #; should be a number between 101° and 114°]



Find:
(a) Explain why a gas line (like the one shown in the picture) is an example of plane strain. [3 pts]
(b) Determine the in-plane strains: ε_x , ε_y , γ_{xy} [8 pts]
(c) Identify the in-plane principal strains: ε_1 , ε_2 [4 pts]
(d) Identify the maximum in-plane shear strain: γ_{max} [2 pts]
(e) Submit a short video to your assigned Google Drive folder explaining your solution procedure. [3 pts]

Note: Part (b) will require solving multiple equations simultaneously. If you choose to use an equation solver (calculator, computer program, or website like Wolfram Alpha) to assist with the math, please indicate which resource you use. I do not need to see the math steps, but I do need you to write the appropriate equations you will use to solve this.

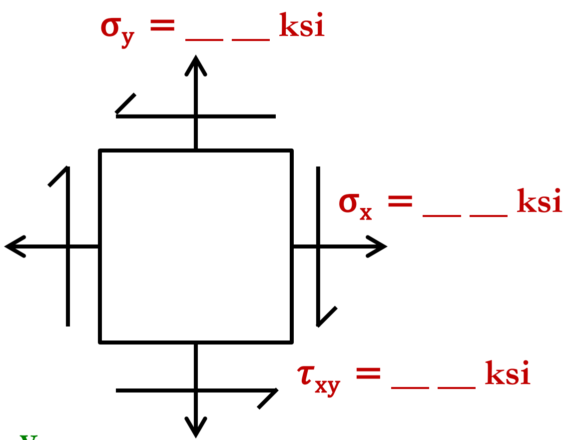
Solution:

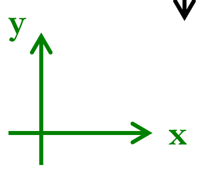
Solution:

PROBLEM 2 [30 PTS]

석다 *[MINGLE GAME– ROUND 2]*

Given: After Round 2, you find yourself in a room with two different students from the class. In order to not be eliminated, you must complete the following Mohr's Circles for plane stress and conduct a check for failure. Each of the stresses σ_x, σ_y, and τ_{xy} correspond to your assigned numbers. The stress in the z-direction is 0 ksi.





Note: $\sigma_z = 0$ **ksi**

$F_y = 50$ **ksi**

Find:

(a) For this problem, values for σ_x, σ_y, and τ_{xy} should be between 1 ksi and 14 ksi. Please note the orientation of the stresses should match the arrows shown. Using your assigned number and the numbers of two of your classmates, fill in the blanks for the stresses in the figure on the left.

(b) Draw Mohr's Circles for the 3D state of stress shown for this element (the "three circles"). Label key values including [10 pts]:
- coordinate axes / units
- principal stresses
- absolute maximum shear stress

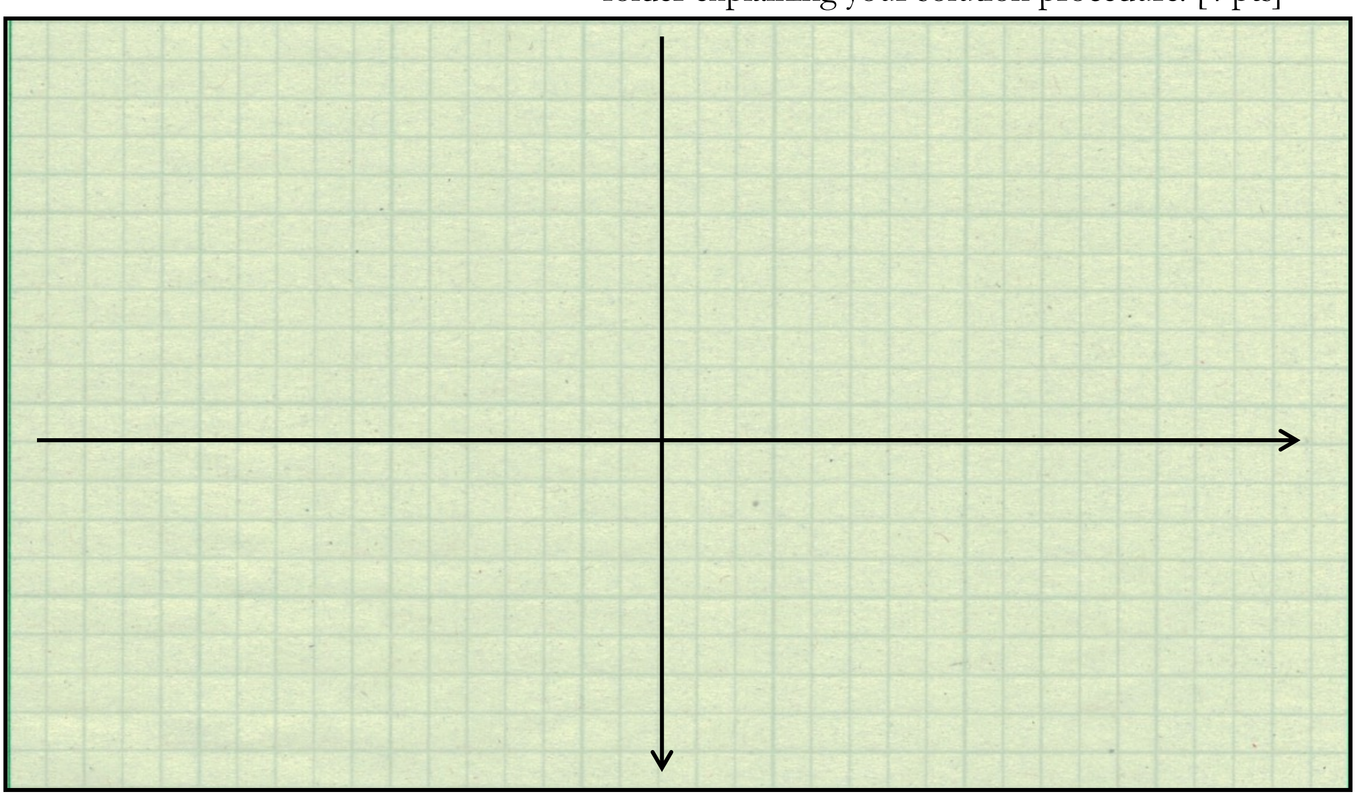
(c) Determine the principal stresses for the element. [5 pts]

(d) Determine the absolute maximum shear stress. [3 pts]

(e) If the steel has a yield stress of 50 ksi and the desired factor of safety is 1.50, use Tresca's criterion to determine if the material can meet the desired design condition with respect to yielding. [8 pts]

(f) Submit a short video to your assigned Google Drive folder explaining your solution procedure. [4 pts]

Mohr's Circles:



Solution (cont):

징검다리 *[Stepping Stone Bridge]*

Story: As you wonder about the fate of the other contestants, you are taken to the office of the front man and asked to develop the specifications for a new game.

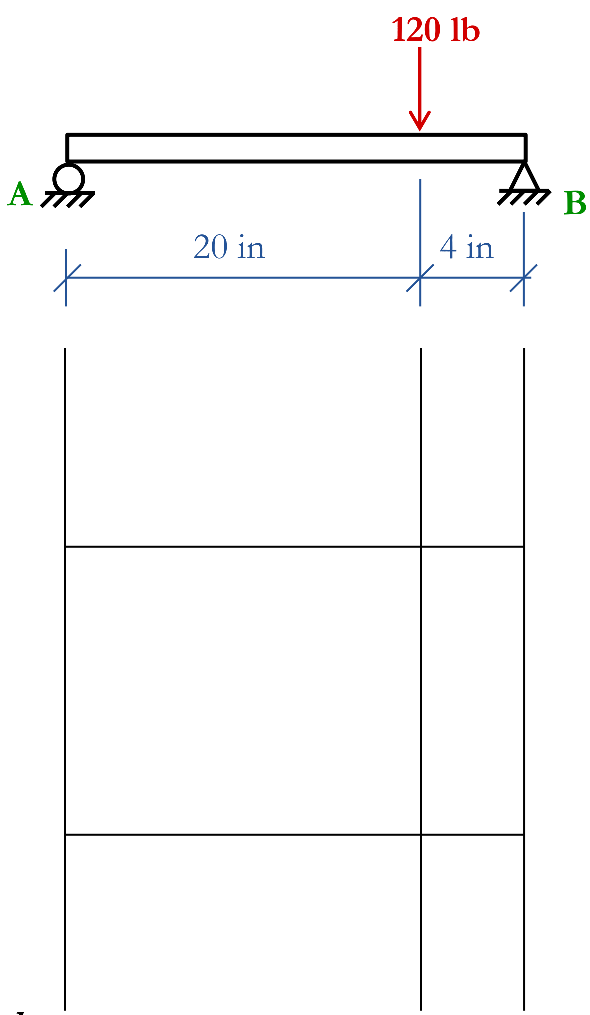
Given: You are given two loading scenarios below. For each case, you will need to determine the thickness of the square panes of glass needed to achieve the desired results.

Glass "Stepping Stone" Cross Section

Scenario 1: One Person on Plain Glass

$E_{glass} = 10{,}150{,}000$ psi

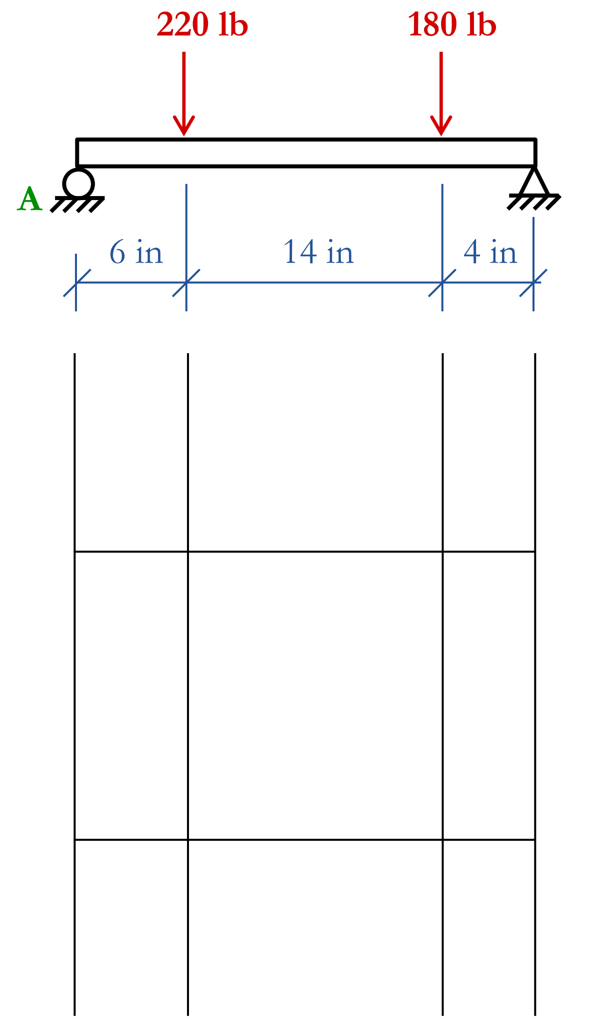
$\sigma_{max\_tension} = 6000$ psi



Scenario 2: Two People on Tempered Glass

$E_{glass} = 10{,}150{,}000$ psi

$\sigma_{max\_tension} = 24{,}000$ psi



Find:

(a) Draw the shear and moment diagrams for the two scenarios with load shown. [8 pts]

(b) Identify the maximum moment each scenario must withstand. [2 pts]

(c) Determine the location of the neutral axis and sketch it above on the cross section indicating its location by distance (in terms of the thickness t). [2 pts]

(d) Calculate the moment of inertia (in terms of t) about the neutral axis for the glass stone. [3 pts]

(e) Using the bending stress formula (My/I), calculate the maximum bending stress each scenario will experience (in terms of t). [5 pts]

(f) Using the max tension stress values provide, calculate the minimum thickness of the glass needed to support the loads in each scenario. [8 pt]

(g) Select one thickness of glass that will fail for Scenario 1 but will not fail for Scenario 2. [2 pts]

Solution:

In the second portion of the Mechanics of Materials course, we studied stresses in 2D. We performed stress transformations in order to determine the principal stresses/max shear stress to predict if failure was likely to occur. We then went on to look at a specific 2D case- beams in bending. While beams exist in the 3D world, we typically load them in such a way that produces 2D stresses. We calculated bending stresses in Lessons 15 and 16, and in Lessons 18 and 19, we will examine bending deflections and transverse shear stress.

As part of this course, I want you to feel somewhat in control of your learning in this class. Therefore, I am providing a few options on how to finish this exam.

Please circle/indicate only one of options (i) or (ii) that you will do to complete the exam.

(i) Problem 1 involves strain transformation. By applying the strain transformation equation at three gages, a system of three linear independent equations can be solved to find ε_x, ε_y, and γ_{xy}. Once obtained, the principal strains and max shear strain can be solved.

Using Microsoft Excel, Google Sheets, or MATLAB, create a worksheet that allows you to input the strain gage readings and strain gage angles and automatically calculates the in-plane strains ε_x, ε_y, and γ_{xy} AND the principal strains ε_1, ε_2 and max shear strain γ_{max} . [see example shown]

Submissions:

- Excel worksheet, Google Sheet, or MATLAB .m file code
- .pdf of three test cases for input and output

Scoring:

___

(5 pts) input/output has poor formatting; answers are incorrect

(10 pts) input/output has some structured formatting; answer is correct for only one test case

(15 pts) input/output is formatted; answer is correct for three test cases; program does not work for instructor test cases

(20 pts) input/output is very nicely formatted; answer is correct for three test cases; program works for instructor test cases

Example of Dr. Batts Excel spreadsheet used to check your answers from Problem 1.

	Gage Reading		Gage Angle (Degrees)
Gage A	100	x 10^-6	0
Gage B	-200	x 10^-6	65
Gage C	-300	x 10^-6	105

			Coefficient Matrix						
A	0.0001	=	1	0	0	ε_x			
B	-0.0002	=	0.178606195	0.8213938	0.3830222	ε_y			
C	-0.0003	=	0.066987298	0.9330127	-0.25	γ_xy			
			Inverse Matrix						
			1	0	0	ε_x	=	100	x 10^-6
			-0.12494676	0.4442762	0.6806706	ε_y	=	-305.551087	x 10^-6
			-0.19835847	1.6580613	-1.4597028	γ_xy	=	86.4627388	x 10^-6
						ε_1	=	104.557214	x 10^-6
						ε_2	=	-310.108301	x 10^-6
						γ_max	=	414.665515	x 10^-6

(ii) Similar to Problem 1, Problem 2 involves stress transformation and using the principal stresses/max shear stress to check failure. These equations can be easily coded into a spreadsheet or computer program to output the desired answers.

Using Microsoft Excel or MATLAB, create a worksheet that allows you to input the in-plane stresses σ_x, σ_y, and τ_{xy} , the material yield stress F_y , and the desired factor of safety. The program should output the principal stresses, the max absolute shear stress, and should check if the results satisfy both Tresca and von Mises criteria. [see example shown]

Submissions:

- Excel worksheet, Google Sheet, or MATLAB .m file code
- .pdf of three test cases for input and output

Scoring:

____

(5 pts) input/output has poor formatting; answers are incorrect

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(20 pts) input/output is very nicely formatted; answer is correct for three test cases; program works for instructor test cases

Bonus:

____ (3 pts) worksheet plots Mohr's Circles for 3D states of stress (the "three circles")

Example of Dr. Batts Excel spreadsheet used to check your answers from Problem 2.

Stress Input			
σ_x	=	20	ksi
σ_y	=	-4	ksi
τ_xy	=	5	ksi
F_y	=	70	ksi
F.S.	=	1.5	

Prinicpal Stresses			
σ_1	=	21.0000	ksi
σ_2	=	0	ksi
σ_3	=	-5.0000	ksi

Max Shear Stress			
τ_max_abs	=	13.0000	ksi

Tresca Yield Criteria			
13.00	≤	23.33	OK

von Mises Yield Criteria			
571	≤	2177.78	OK
23.896	≤	46.67	OK

Mohr's Circle		
Center at:	8	,0
Radius =	13	ksi

Material Properties, Stress, Strain

$$\sigma = \frac{P}{A_o} \qquad \varepsilon = \frac{\Delta L}{L_o} \qquad \%\,\text{elongation} = \frac{\Delta L}{L_o} \times 100\% = \frac{L_f - L_o}{L_o} \times 100\%$$

$$\%\,\text{reduction } A = \frac{|A_f - A_o|}{A_o} \times 100\%$$

$$\nu = \frac{-\varepsilon_{lateral}}{\varepsilon_{longitudinal}} \qquad G = \frac{\tau}{\gamma} = \frac{E}{2(1+\nu)}$$

$$\sigma = E\varepsilon \text{ (in linear elastic range)}$$

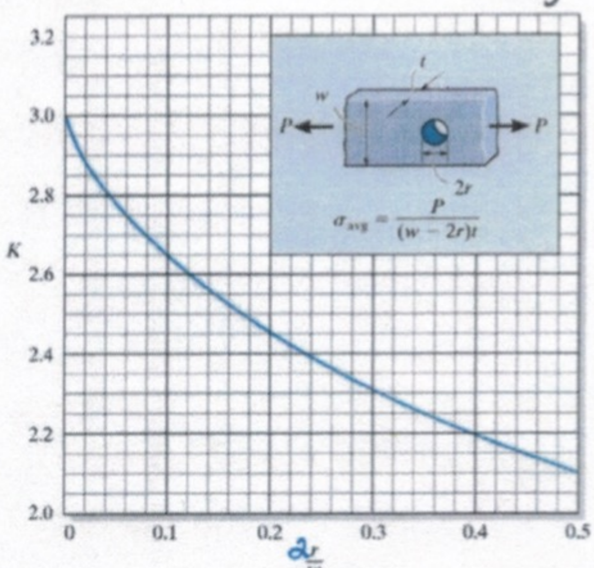
Axial Deflection

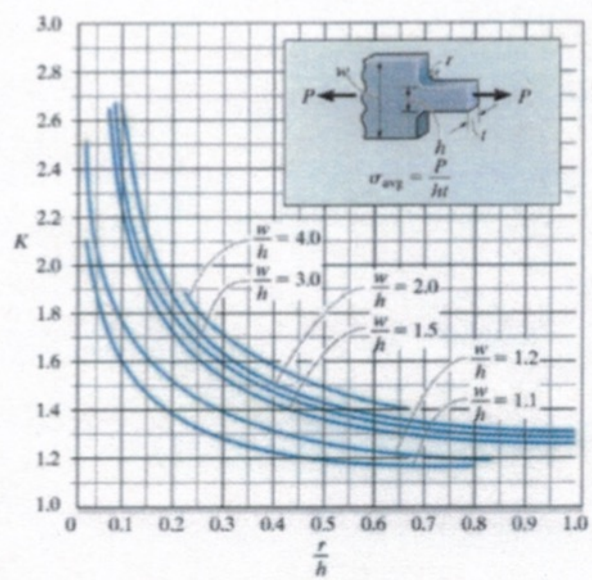
$$\delta = \frac{PL}{AE}$$

Temperature Effects : $\delta_{temp} = \alpha L \Delta T$

Stress Concentrations

$$K = \frac{\sigma_{max}}{\sigma_{avg}}$$





Torsion

$$\tau = \frac{T\rho}{J} \qquad J = \int_A \rho^2\, dA = \frac{\pi}{2}\left(r_o^4 - r_i^4\right)$$

$$\tau_{max} = \frac{Tc}{J} \qquad \phi = \frac{TL}{JG}$$

Stress Transformation Equations

$$\sigma_{x'} = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2} cos2\theta + \tau_{xy} sin2\theta$$

$$\sigma_{y'} = \frac{\sigma_x + \sigma_y}{2} - \frac{\sigma_x - \sigma_y}{2} cos2\theta - \tau_{xy} sin2\theta$$

$$\tau_{x'y'} = -\frac{\sigma_x - \sigma_y}{2} sin2\theta + \tau_{xy} cos2\theta$$

Principal Stresses

$$tan2\theta_p = \frac{\tau_{xy}}{\frac{(\sigma_x - \sigma_y)}{2}}$$

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2}$$

Max In-Plane Shear Stress

$$tan2\theta_s = -\frac{\frac{(\sigma_x - \sigma_y)}{2}}{\tau_{xy}}$$

$$\tau_{max,in-plane} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2}$$

Absolute Maximum Shear Stress

$$\tau_{max,abs} = \frac{\sigma_1 - \sigma_3}{2} \quad where \quad \sigma_3 \le \sigma_2 \le \sigma_1$$

Tresca's Criterion

Failure when:

$$\left|\frac{\sigma_1 - \sigma_3}{2}\right| \ge \left(\frac{\sigma_Y/F.S.}{2}\right)$$

von Mises's Criterion

Failure when:

$$\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2] \ge \left(\frac{\sigma_Y}{F.S.}\right)^2$$

Moment of Inertia

$$I_{N.A.} = \Sigma(I_{C.G.} + d^2 A)_{each\ segment}$$

$$I_{C.G.} = \frac{1}{12} bh^3 \ for\ rectangles$$

Strain Transformation Equations

$$\varepsilon_{x'} = \frac{\varepsilon_x + \varepsilon_y}{2} + \frac{\varepsilon_x - \varepsilon_y}{2} cos2\theta + \frac{\gamma_{xy}}{2} sin2\theta$$

$$\varepsilon_{y'} = \frac{\varepsilon_x + \varepsilon_y}{2} - \frac{\varepsilon_x - \varepsilon_y}{2} cos2\theta - \frac{\gamma_{xy}}{2} sin2\theta$$

$$\frac{\gamma_{x'y'}}{2} = -\frac{\varepsilon_x - \varepsilon_y}{2} sin2\theta + \frac{\gamma_{xy}}{2} cos2\theta$$

Principal Strains

$$tan2\theta_p = \frac{\gamma_{xy}}{(\varepsilon_x - \varepsilon_y)}$$

$$\varepsilon_{1,2} = \frac{\varepsilon_x + \varepsilon_y}{2} \pm \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

Max In-Plane Shear Strain

$$tan2\theta_s = -\frac{(\varepsilon_x - \varepsilon_y)}{\gamma_{xy}}$$

$$\frac{\gamma_{max}}{2} = \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

Strain in Each Gage of Strain Rosette

$$\varepsilon_i = \varepsilon_x cos^2\theta_i + \varepsilon_y sin^2\theta_i + \gamma_{xy} sin\theta_i cos\theta_i$$

Generalized Hooke's Law

$$\varepsilon_x = \frac{1}{E}[\sigma_x - \nu(\sigma_y + \sigma_z)] \qquad \gamma_{xy} = \frac{1}{G}\tau_{xy}$$

$$\varepsilon_y = \frac{1}{E}[\sigma_y - \nu(\sigma_z + \sigma_x)] \qquad \gamma_{yz} = \frac{1}{G}\tau_{yz}$$

$$\varepsilon_z = \frac{1}{E}[\sigma_z - \nu(\sigma_x + \sigma_y)] \qquad \gamma_{zx} = \frac{1}{G}\tau_{zx}$$

Bending Stresses

$$\sigma = \frac{My}{I}$$

Centroid

$$\bar{y} = \frac{\Sigma \bar{y} A}{\Sigma A}$$