Penn State RET in Interdisciplinary Materials

Teacher's Preparatory Guide

[Samantha Knepp]

Material Deformation – Finding Young's Modulus

Purpose To determine which wire would be best suited for use as suspending cables on a suspension bridge by analyzing a stress vs. strain curve.

Objectives 1) Introduce students to materials science and engineering 2) Physically understand Young's Modulus 3) Build skills in experimental design

Time required 3 double periods

Level High school (AP Physics 1)

National Science Education Standards [12]

- Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4)
- Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. (HS-ETS1-1)
- Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering (HS-ETS1-2)

Teacher Background Materials Science is a multidisciplinary field in science that is not well understood amongst members of the general population. Using topics gone over in AP Physics 1, students can be made more aware of what Material Science is, giving them more options to choose from when deciding what career path to take after high school.

Civil engineers are often tasked with things such as building bridges, roads, dams, drainage systems, and many other real-world problems. Within each of these problems lies the inherent nature of Materials Science. In this lab, we will particularly look at the problem of determining what material should be used when building the suspending cables on a suspension bridge. To analyze this question, we must consider the elastic properties of different materials. Nominally, in order to answer this question, we must find Young's Modulus for the various samples we are considering. Young's Modulus, E, is defined as

$$E = \frac{\sigma}{\varepsilon} = \frac{Stress}{Strain}$$

where

$Stress = \frac{F}{A} = \frac{Force}{Area}$ And $Strain = \frac{l_o}{\Delta l} = \frac{Initial\ Length}{Change\ in\ the\ Length}$

Note: Area is the cross-sectional area of the wire.

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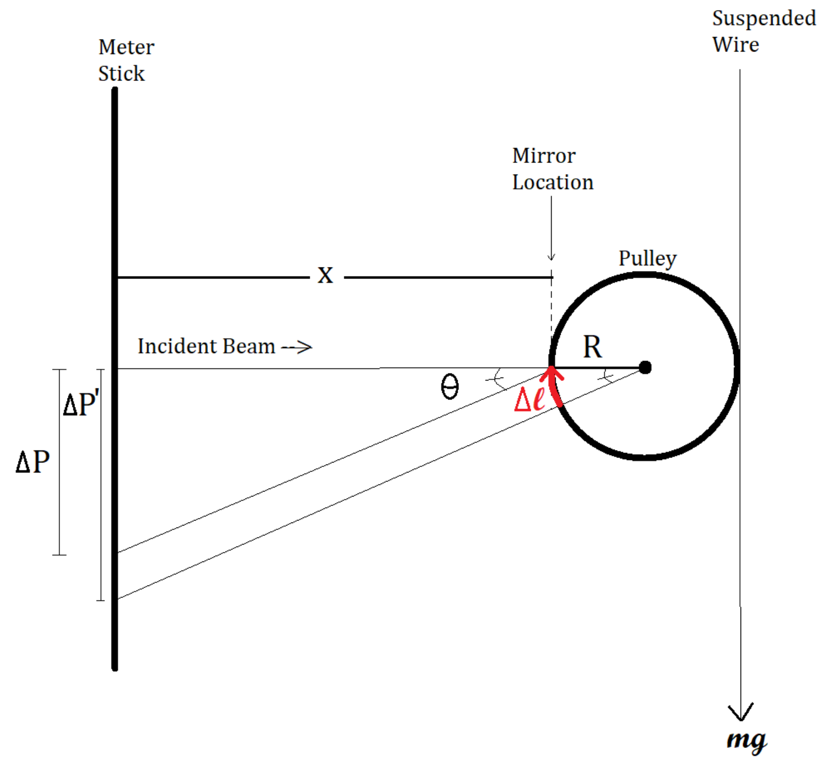
To find the stress in the wire is very straight forward: The force is determined by the force of gravity caused by the added mass to the end of the wire via the mass hanger. The area is determined using the diameter, which is measured using the micrometer and the equation for the area of a circle, $C=\pi r^2$ ($r=D/2$). Finding the strain is a little more complex, but still doable. It may be important to note that there are a couple assumptions in this analysis: 1) The suspended wire touches the pulley at a point location, and 2) there is no slip between the pulley and the suspended wire. Since our experimental design makes use of a laser and a mirror, we will have to compare these quantities with those that will be measured. To do so, consider the diagram to the right.



As the wire stretches, it will cause the pully to rotate. In turn (pun intended), the mirror will rotate and the location of the reflected laser beam will move up the ruler. Since the wire is in contact with the pulley, and we assume no slipping, we can say that the change in the length of the wire is equal to the arc length of the pulley of radius R, through the angle θ. But, we need to connect this to measured values. To do so we consider the similar triangles as drawn above and realize that the lengths of corresponding sides and angles must be proportional. So, since the arclength is defined as

$$s = R\theta$$

And

$$tan\theta = \frac{\Delta P'}{x + R} = \frac{\Delta P}{x}$$

We get that

$$\Delta\ell = Rtan^{-1}\left(\frac{\Delta P}{x}\right)$$

Where R, ΔP, and x are all measured values.

Using the calculated values, a stress vs strain graph should be constructed and the average or a line of best fit will yield Young's Modulus. It is suggested that students use a spreadsheet to complete some/all calculations and graphs. Note that the values found should only be within the elastic region as detailed in the "Safety Information" section below.

Since the materials used in this lab will be materials which have known values for Young's modulus, it is an easy exercise to compute experimental error.

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Materials

- Meter stick
- 2 Ring stands
- 2 Ring stand clamps
- Mountable laser
- Chuck bearing or mountable pulley
- Mass holder
- 200 gram masses (for on mass holder)
- 1-2 inch circular plane mirror
- Micrometer/caliper
- 2 types of wire (brass/copper/etc)
- clamp to hold onto the wire
- tape
- Pencil
- Calculator
- Lab notebook
- Computer

Advance Preparation:
Any type of wire can be used, but ones that are more ductile may yield better results. Most materials will need to be purchased from a school science supplier such as PASCO, NASCO, Vernier, etc. Materials used for this lab should be separated into piles for each lab group, but they should not be constructed.

Safety Information:
While putting any material under stress, you introduce the possibility of material failure. In the case of wires, caution must be used as to not exceed the plastic limit and cause fracture. Because we are looking at Young's modulus, we want to ensure that our data is confined to the material's elastic region, so the material's fracture limit should inherently be avoided by giving students a maximum mass that will only cause deformation of the elastic region. To ensure that giving these limits do not give away the answer to the experiment, give the students a maximum mass value that will ensure that neither material will plastically deform. Additionally, students should be sure to wear closed toe shoes, pants that completely cover the legs, and a pair of safety goggles at all times. Students should be instructed to not point the laser at anyone at any point during this lab.

Teaching Strategies:

This lab should be conducted in groups of 3-4. Students need to be informed of how much weight is the maximum allowed to avoid fracture. Students should be properly trained on how to use a laser and a micrometer.

One of the main purposes of this lab is to give students the opportunity to determine how to construct an experiment with given supplies. This skill is one often utilized on the AP Exams. If will likely be necessary to give students hints throughout the entire lab.

Resources:

- This website shows the correct experimental set up of the apparatus. It also gives a separate way to analyze the situation than what I have shown above. http://hoffnerphysics.weebly.com/youngs-modulus.html
- This link is a video of how one might use excel to construct a graph of stress vs. strain. Note: we have only allowed students to cause deformation in the elastic region. https://www.youtube.com/watch?v=H_08pyYJIDg

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Directions for the activities with timelines:
Day 1: Background Research – Determine what information needs to be gathered.
Day 1: Make a plan - Considering only the materials provided, make a plan, including a sketch, of how your apparatus should be constructed.
Day 2: Construct your apparatus – Be sure to make sure everything works as intended before beginning to take data. Teachers may want to require students to have the teacher approve their device before beginning the data collection. Teacher should give students the data collection sheet after their apparatus has been approved.
Day 2: Collect data – Using the student worksheet, students should collect the required data.
Day 3: Analyze Data, make conclusions, and begin working on lab report.
Homework: Lab report due in 1 week from conclusion of Lab measurements.

Cleanup : Students will disassemble their apparatus and put like pieces together in piles.

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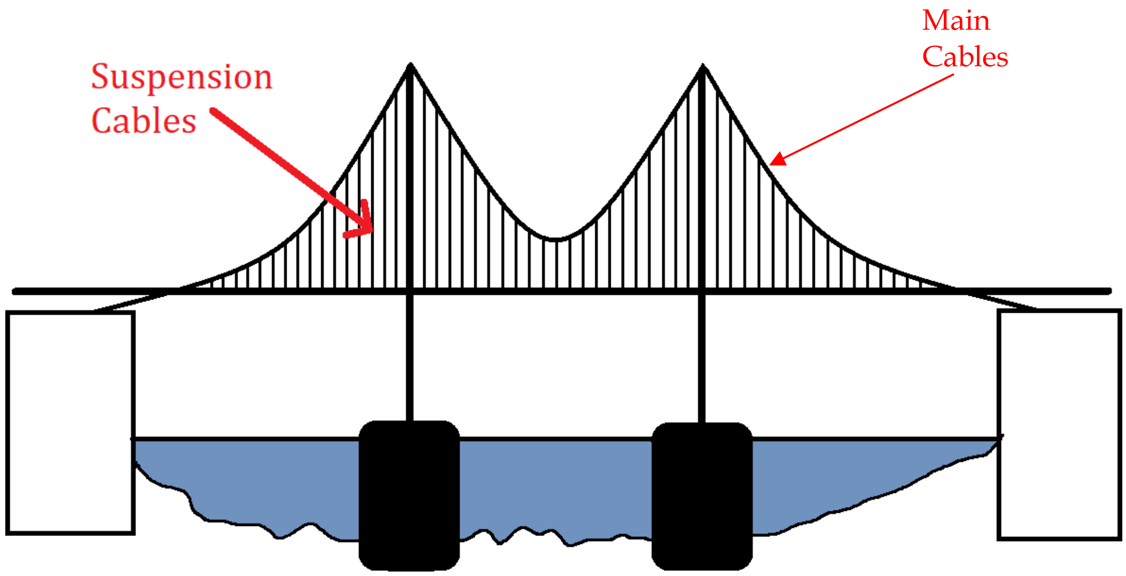
Example Student Worksheet

Material Deformations (with Answers in Red)

Introduction

A local civil engineer in the state bridge department needs to build a suspension bridge. They have considered all things except which type of wire material should be used for the bridge suspension cables (see figure below). You have to choose between two samples of which would be best to use.



In order to decide which sample is best for the task at hand, you must come up with a way to test the samples given two unknown types of wire cable.

This experiment will help you with your scientific reasoning skills in addition to your experimental design skills.

Materials [list]

- Meter stick
- 2 Ring stands
- 2 Ring stand clamps
- Mountable laser
- Chuck bearing or mountable pulley
- Mass holder
- 200 gram masses (for on mass holder)
- 1-2 inch circular plane mirror
- Micrometer/caliper
- 2 types of unknown wire
- clamp to hold onto the wire
- tape
- Pencil
- Calculator
- Lab notebook
- Computer

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Procedure

1. You will begin by considering the problem at hand and coming up with a way to mathematically solve the problem. What physical quantity is it that you are trying to find and how will you find it? Write down your thought process in your lab notebook and be sure to draw at least one sketch. If you get stuck, ask for help!

2. Once you think you know what quantities you need to find, make a plan of how your will construct an apparatus to do so using the materials listed on the first page. Be sure to include a sketch in your lab notebook and label all important quantities.

3. Explain to your teacher what it is that you think you need to do to solve the problem. Once given approval from the teacher, you may begin constructing your apparatus.

4. Once your apparatus is constructed, you may begin taking data. To help with this process, you may use the tables provided on the back of this sheet, but remember to transfer all data to your lab notebook.

5. Enter your data into a spreadsheet and begin making calculations to find stress, strain, and Young's modulus. Note: it may be necessary to create a graph to find Young's modulus.

6. Complete an error analysis of your results.

7. Complete a formal Lab Report as outlined in the Lab Notebook/write-up Rubric.

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Record Your Observations:

You may organize your data here, but be sure to include this information in your lab notebook.

Measurements:

Initial Wire 1 Length (m)	
Initial Wire 2 Length (m)	
Distance from mirror to meter stick (m)	
Diameter of wire 1 (m)	
Diameter of wire 2 (m)	
Radius of pulley (m)	
Initial beam position (m)	

Wire 1: **Wire 2:**

Hanging Mass (kg)	**Reflected beam position (m)**		**Hanging Mass (kg)**	**Reflected beam position (m)**

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Enhancing understanding Cover this section *after* the activity. Since this activity was largely based on having students practice their skills in experimental design, this would be a great time to have them reflect on the experience.

Possible discussion questions:

- What about this lab did you find most difficult?
- How did you feel about using the spreadsheet? Do you feel like it went well or do you feel like you need more practice?
- What do you think would happen to the wire if you would have continued to add mass to it? How would this idea relate to your graph?
- Is your result 100% conclusive? Explain
- If you were to continue testing this wire for use as a suspending cable, what parameters/conditions would you test?

Many civil engineers do not conduct experiments like this one. They are given types of materials with the values of these quantities already known. However, there are always new materials being made and tested to try to find even more robust materials and to test already developed materials in different ways, such as looking at how materials deform in different environments. This is the work of Material Scientists.

Going Further: Students who have a good grasp of the content of the lab can be further challenged with these questions:

Would you want to use this material for the Main Cables as well? We do not know if this would be a good material for the main cables because there are also shear forces acting on the main cables and our experimental results tell us nothing about shear elasticity.

Assessment and rubrics:

Lab notebook and write-up rubric attached

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Lab notebook (25 points):

Your lab notebook is a place you write down EVERYTHING about your experiment. The goal is that if someone else were to look at your lab notebook, they would be able to follow the instructions given and replicate the same experimental results that you achieved. Below, you will find some general requirements for your lab notebook. Your lab notebook should follow these guidelines:

1. Neat/legible and written in pen (1pt)
2. Title and purpose clearly stated (2 pts)
3. Procedure described clearly and succinctly, including errors and the steps taken to correct them and any tips for success (5pts)
4. Diagram of apparatus set up included with any important specifications. (5 pts)
5. Data is neatly written in table format. (3 pts)
6. Descriptive comments of any qualitative observations. (2 pts)
7. Computations (data analysis) performed neatly showing intermediate steps (4 pts)
8. Errors crossed out with a single line and explained (2 pts)
9. All pages dated at the top (1pt)

Lab write-up (50 pts):

After completing your trials, you will need to share your results with others. This is done by completing a formal lab write up. The following information should be included in your write up.

General (5 pts)
- figures contain captions
- Past tense used
- Double spaced.

Abstract (5 pts)
- Summarizes paper
- Gives conclusion.

Introduction (5 pts)
- Contains relevant background information (what does the reader need to know in order to understand the data analysis?)

Procedures/materials (3 pts)
- explains experiment in paragraph form
- includes diagram of experimental set-up
- Does NOT list materials, but gives them throughout

Prescribed analysis (10 pts)
- Explanation of data manipulations (what did you do with the data to find the results?)
- Includes error analysis
- Includes equations used w/ variables defined
- Includes relevant diagrams (FBDs)

Results and their Discussion (15 pts)
- All relevant findings are explained
- Contains support/evidence for findings
- Contains a discussion of uncertainty

Conclusion (2 pts)
- Summarizes findings/relates to purpose
- Gives possible relations to the real world/possible future studies

Appendix (5 pts)
- All graphs are complete and easily read
- All relevant data is in table format

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