Bending Load & Calibration Module

Objectives

After completing this module, students shall be able to:

1) Conduct laboratory work to validate beam bending stress equations.
2) Develop an understanding of how stress and strain in different materials are affected by bending with:
   a) force-loads
   b) displacement-loads
3) Calibrate an instrumented beam for the purpose of measuring force.

Background: Strain Gages

There are several different types of strain gauges used for measuring strain. For this experiment we will be using etched foil strain gauges. In an etched foil strain gauge, a very thin piece of metal is etched and placed on a plastic film carrier. This is known as a bonded-foil strain gauge. This assembly is then carefully glued onto the test specimen whose strain is to be measured. As the metal foil in the strain gauge is stretched or compressed along with the test specimen, its electrical resistance changes. Depending on the metal used, very large strains of up to 50,000 με ($50X10^{-6}$ in/in) may be measured.

The so-called "gage factor" is a calibration factor that relates strain to a change in resistance. The gage factor must be know (it is provided by the gage manufacturer) and the value must be entered into the *strain indicator*. The course instructor will demonstrate this. The *strain indicator* is the little "black" box (or blue) that contains circuitry for converting resistance change into a strain reading.

Even large strains will result in only a very small change in the strain gage's resistance; therefore, a Wheatstone bridge is used to measure the resistance change. Wheatstone bridges are electrical circuits that produce a measureable voltage change based on very small changes in resistance. See Figure 1.

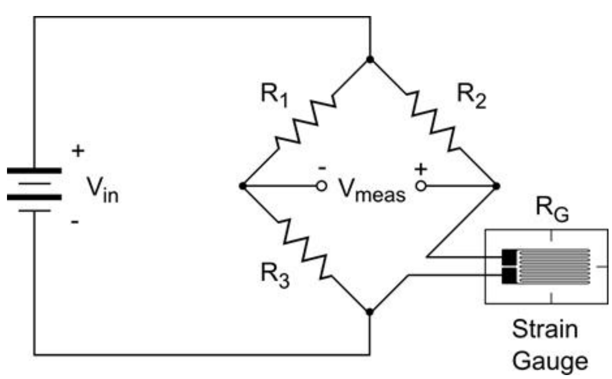

Figure 1 – Wheatstone bridge circuit for measuring strain ("quarter bridge")

Background: Bending Stress

Stress exists in two basic forms: shear stress and normal stress. Shear stress is what causes dislocation slip (aka “plastic deformation”); however, even in very simple uniaxial loading which produces normal stress ($\sigma = F/A$) along the axis of the bar, that loading also results in shear stress along other orientations (maximum shear occurring at 45 degrees from the axis). If there is normal stress in a part, there will always be shear stresses as well (with one single exception called hydrostatic loading). For this module, we’ll only be considering normal stress, but keep in mind, there are shear stresses present in the beam.

For a beam, bending stress is the principal stress (the “main” normal stress). It is the normal stress in the direction of the beam’s axis and it is given by:

$$\sigma = M*y / I \quad (1)$$

Where M is the bending moment, y is the distance from the neutral axis (the center of the beam) and I is a geometric parameter known as the area moment of inertia. For the top of a rectangular cross-section cantilever beam (as is used in this module) the stress in equation 1 can be re-expressed as:

$$\sigma = 6*P*L / (b*h^2) \quad (2)$$

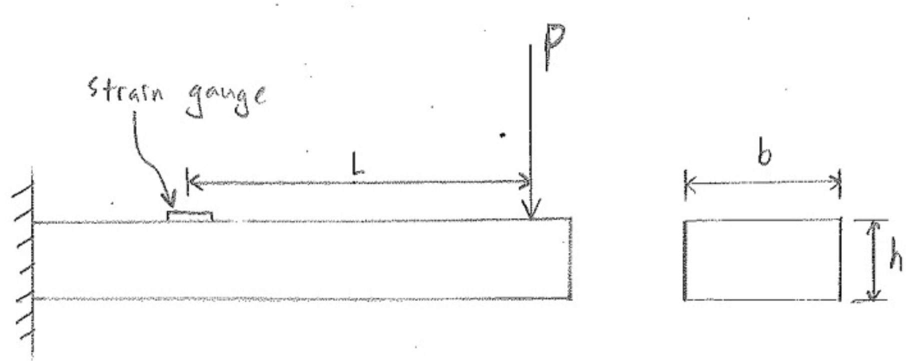

Figure 2 – A cantilever beam

As shown in Figure 2, P is the applied force, L is the distance from the load-point to the strain gage, b is the width of the beam and h is the height (thickness) of the beam. Bending stress (σ) is a normal stress acting in the direction of the beam axis.

The orientation of a strain gauge is extremely important. Strains and stresses vary depending upon direction. At any given point on a structure the strain in one direction will be different from the strain in another direction. To determine the bending stress, the strain gage must be aligned with the beam’s axis.
Equations 1 and 2 are derived from mechanics of materials and provide a theoretically based equation to determine stress based on an applied load. By

measuring the strain in the direction (ε) of the beam's axis, the stress can be determined by *experimental* measurements:

$$\sigma = E * \varepsilon \qquad (3)$$

Young's modulus (E) is also known as the modulus of elasticity. It is a material property that describes the stiffness of the material. For equation 3 to be valid, the following two conditions must be met:

a) the material must be linear elastic
b) the normal stresses in the two orthogonal directions must be zero

Most metals and alloys are linear elastic (as long as the stress does not cause yielding). For bending, the stresses perpendicular to the beam's axis are zero on the free surface of the beam (free surface = top and bottom surfaces not in contact with anything). So both conditions should be satisfied in this lab; therefore, equation 3 should be valid.

Materials and Supplies

- Instrumented beam test apparatus as shown in Figure 3.
- Calipers
- Set of masses: 50g, 100g, two 200g, and 500g
- P3 strain indicator

Procedure (to be conducted during lab)

In this lab we will be testing beams made of two different materials (aluminum alloy and steel). The test setup is shown in Figure 3.

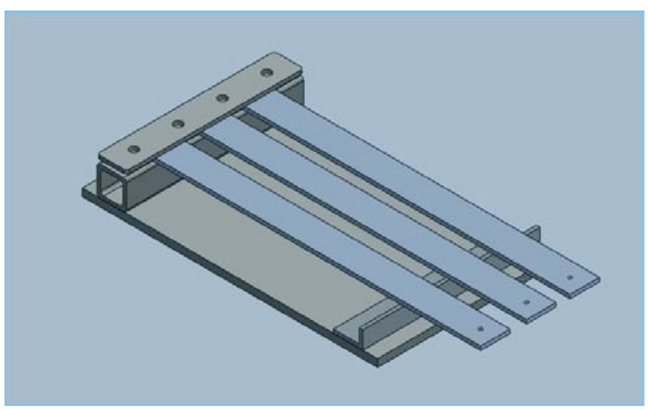

Figure 3 – Bending load test apparatus

1) Measure and record all values in Table 1.
2) Connect the strain gauges on the bending load test apparatus to a strain indicator (if not already done).
3) Place loads shown in Table 2 at the small hole on the end of the beams. Measure and record the corresponding strains in Table 2. Keep an eye on the beam's stop – do not apply greater loads once contact has been made with the

stop. Start with the aluminum beam and once completed, repeat with the steel beam.

4) Determine to within +/- 50g the maximum load that can be applied to each beam before “bottoming out” (touching the stop). Record this in Table 3.
5) Using Table 2’s data, how much strain would you expect from each beam if a 0.25kg load was applied? How much strain would you expect from each beam if a 0.80kg load was applied? After calculating these, apply the 0.25kg (and 0.80kg) loads and measure strain and record in Table 4.

Post-lab questions/analysis/conclusions (after completing the lab work). The following are detailed questions to be answered. Your answers should be in graphical form with paragraphs discussing the results.

1) From the strain measurements in Tables 2 and 3, calculate the corresponding stresses using both equation 2 and equation 3. Enter values into the tables. NOTE: Equation 2 is the theoretical stress value base on a given force and Equation 3 is the experimentally determined stress level based on strain measurements and Young’s modulus.
2) Using data in Table 2, create graphs showing the bending stresses as calculated from equations 2 and 3; both as a function of applied force (not mass, you need to determine the force). Discuss the results – are the calculated values based on loading (equation 2) equivalent to the experimentally determined values based on strain measurements (equation 3)?
3) Using data in Table 2, create graphs showing the bending strain and the bending stress from equation 3 as a function of applied force. Are stress and strain linear with applied force? Does bending stress depend upon Young’s modulus and/or force? Does bending strain depend upon Young’s modulus and/or force?
4) Using data in Table 3, create graphs showing the strain and calculated stress (equation 3) as a function of Young’s modulus (each graph will have only two data points). For a given deflection, is stress a function of Young’s modulus? Is strain? For a given deflection, is strain a function of Young’s modulus?
5) These beams can be used as load cells (a device used to measure force). Determine the calibration factor for both beams. Do this by using the data in Table 2 and plotting the force as a function of strain (for both beams) and fit a linear trend-line to the data. The slope of the line (units of N/$\mu\varepsilon$) is the calibration factor (it allows you to determine the applied force for a given strain reading).
6) Airplane wings are cantilever beams. The following images are of a Boeing 777. The first image was taken in Boeing’s Everett, Washington hanger during deflection/strength testing (just prior to failure). The other image shows that during flight, the wing tips deflect approximately 10 feet compared to ‘neutral’ loading, and the wing can withstand up to about 26 feet of deflection before failure (confirmed by testing). The 777 wings are made from aluminum alloys. If all other factors were identical, except the wings were to be made from steel, how much deflection would you expect during flight? If the steel had equal strength to the aluminum, how much deflection would the steel be able to withstand before failure? Note that all aluminum alloys have Young’s modulus of about 70 GPa and most steels have a Young’s modulus of 210 GPa.

You can watch the wing test at (or google “777 wing test - youtube”):
https://www.youtube.com/watch?v=Ai2HmvAXcU0

ORIGINAL DATA SHEET

Lab title: Bending Stress ______Date conducted:____________Location__________

I actively participated in the collection of this data. The information contained here has not been falsified and to the best of my knowledge correctly records the data obtained in lab.

Print name:______________________Signature:___________________________

Table 1 – Beam characteristics

Material	**Young's modulus, E**	**Width, b (mm)**	**Thickness, h (mm)**	**Length, L* (mm)**
Aluminum (6061-T6)	70 GPa			
Steel (AISI 1015)	210 GPa			

*Length is the distance from the load application to the center of the strain gage.

Table 2 – Recorded strains for a given load

6061-T6				**AISI/SAE 1015**			
Mass (kg)**	**ε (με)**	**Stress, eq 2 (Mpa)**	**Stress, eq 3 (MPa)**	**Mass (kg)****	**ε (με)**	**Stress, eq 2 (MPa)**	**Stress, eq 3 (MPa)**
0				0			
0.1				0.1			
0.2				0.2			
0.3				0.3			
0.4				0.4			
0.5				0.5			
0.6				0.6			
0.7				0.7			
1.0				1.0			

**keep an eye on the beam and the stop. Once contact with the stop is made, discontinue putting additional weight on the beam.

Table 3 – maximum mass (+/- 50g) before bottoming out on the stop

Material	**Mass (kg)**	**ε (με)**	**Stress, eq 2**	**Stress, eq 3**
6061 T6 aluminum				
AISI 1015 steel				

Table 4 – strain corresponding to 0.25kg and 0.80 loads.

Material	**Load (kg)**	**Calculated strain (με)**	**Measured strain (με)**	**Load (kg)**	**Calculated strain (με)**	**Measured strain (με)**
6061-T6	0.25			0.80		
AISI 1015	0.25			0.80		