Laboratory 3  
**Topic: Beam Bending and Strain Transformation**

**Objectives**

1. To demonstrate the use of strain gages and associated instrumentation in experimental stress analysis.
2. To measure stresses in beams and compare them to the calculated moment and shear force acting on the cross-section of the beam.

**Introduction**

Beams are structural elements used to carry loads transverse to their length. They carry loads by bending. They are used in many engineering designs such as buildings, cars, airplanes, and bridges. In this laboratory exercise you will measure the bending strains in two 6061 aluminum I-beams using strain gages. You will then use this information to calculate the stresses that correspond to the measured strains.

In your calculations, take the elastic material properties of aluminum to be: $E = 10 \times 10^6$ psi and $\nu = 0.3$.

The experiments will be performed on standard S3x1.99 aluminum I-beams (Fig. 1). The cross-sectional properties of the beams are determined by industry standards, and can be found in tables provided by manufacturers and other standards organizations. The dimensions of the aluminum beam are the same as those of the S3x5.7 steel beam.

You will study two cases in this exercise, three-point bending (Fig. 2a) and four-point bending (also called pure bending) (Fig. 2b). As you can see, these names are very descriptive of the way the beams are loaded. It is assumed that you know how to find the shear force and bending moment in a beam. The discussion here is restricted to linear elastic materials. Beams, like other structural members, resist loads by deforming, which gives rise to strains and stresses in the material.

![Figure 1: Cross-section of the I-beam used in the laboratory.](image1)

![Figure 2: (a) Three-point bending (b) Four-point bending](image2)
Instrumentation

Both beams to be tested have been instrumented with strain gages. The placement of the gages on the beams is the same in both beams. Two uniaxial strain gages on one flange, one uniaxial strain gage and one 45° strain rosette on the other flange, and another 45° strain rosette at the center of the web of the beam (see section 8.10 of your text for a description of strain rosettes). In the three-point bending test, the strain gages are located at 1/4 of the span while in the four-point bending test they are located at mid-span (Fig. 2). The gage factors are:

- Uniaxial gages, 2.15
- Rosettes
  - Inclined gages, 2.125
  - Center gage, 2.155

The instrumentation used to measure strain will be the same in each set-up. In each test, you will be using a power supply/bridge unit. They display strain directly in units of microstrain (assuming you input the correct strain gage and operate them carefully).

Procedure

The steps to perform the experiment are listed below. If you have questions, ask your TA. One group will start with the three-point bending test while the other will start with the four-point test and then exchange set-ups.

**Four-point bending test**

1. The strain indicator is used to measure strain; it performs the calculation from the voltage automatically.
2. Record which gage is connected to each channel.
3. Make sure that the beam is totally unloaded by observing that it is not making contact with the upper semi-circular loading points.
4. Align the beam with the loading points.
5. Make channels 1 to 4 on boxes 1 and 2 active
   a. Press the “Chan” button
   b. For each channel
      1. Use the up/down arrow key to select the desired channel.
      2. Press right arrow key until “active” is displayed.
   c. Press “MENU” button
6. Make channel 1 on box 3 active using the above procedure. Disable channels 2-4.
7. Set all active channels to quarter bridge  
   a. Press “bridge” button  
   b. For each channel  
      1. Use the up/down arrow key to select desired channel.  
      2. Press right arrow key until “quarter” is displayed.  
   c. Press “MENU” button  
8. Set gage factor for all channels  
   a. Press “k” button  
   b. For each channel  
      1. Set channel number using right arrow  
      2. Use down arrow to highlight “gage factor”  
      3. Press right arrow to select digit  
      4. Press up/down arrow to set digit  
      5. Press right arrow to move to next digit  
      6. Press left arrow to move cursor into first column  
   c. Press “MENU” button  
10. Zero the output of the load cell.  
11. Now, slowly move the lower crosshead up until contact is made and the load starts  
    changing. Continue moving the crosshead up at a rate of 0.050 in/min. Stop when the  
    load reaches approximately 1000 lbf. Press the stop button when the desired load is  
    reached. DO NOT load the beam above 2200 lbf.  
12. Record the load and the strain output for each channel.  
13. Repeat steps 11 and 12 for increments of approximately 100 lbs up to a maximum  
    load of 2000 lbs. DO NOT load the beam above 2200 lbf.  
14. Release the load in the beam by moving the lower crosshead down.  
15. Once again, read the output of each channel to make sure that the zero strain  
    reference has not changed. If it has changed by more than 10 microstrain, you need  
    to repeat the measurement for that channel.  
16. Draw a sketch of the location of the strain gages on the beam. Identify the strain  
    gages by the color of the small piece of tape next to them. The lead wires have also  
    been color coded for convenience (see Appendix 1). Pay attention to the orientation  
    of the rosettes. Note that for the rosettes, the black and red wires are attached to the  
    inclined gages while the white wires are attached to the center gage.
Three-point bending test

1. The strain indicator is used to measure strain; it performs the calculation from the voltage automatically.

2. Record which gage is connected to each channel.

3. Make sure that the beam is totally unloaded by observing that it is not making contact with the upper semi-circular loading point.

4. Align the beam with the loading points. The black mark near one end of the beam must be on top of one of the loading points.

5. Make channels 1 to 4 on boxes 1 and 2 active
   a. Press the “Chan” button
   b. For each channel
      1. Use the up/down arrow key to select the desired channel.
      2. Press right arrow key until “active” is displayed.
   c. Press “MENU” button

6. Make channel 1 on box 3 active using the above procedure. Disable channels 2-4.

7. Set all active channels to quarter bridge
   a. Press “bridge” button
   b. For each channel
      1. Use the up/down arrow key to select desired channel.
      2. Press right arrow key until “quarter” is displayed.
   c. Press “MENU” button

8. Set gage factor for all channels
   a. Press “k” button
   b. For each channel
      1. Set channel number using right arrow
      2. Use down arrow to highlight “gage factor”
      3. Press right arrow to select digit
      4. Press up/down arrow to set digit
      5. Press right arrow to move to next digit
      6. Press left arrow to move cursor into first column
   c. Press “MENU” button


10. Zero the output of the load cell.
11. Now, slowly move the lower cross-head up until the load starts changing. Continue moving the cross-head up at 0.050 in/min until the load is 500 lbs. Press the stop button when the desired load is reached. Do not load the beam above 1200 lbs.

12. Record the load and the strain output for each channel.

13. Repeat steps 9 and 10 for increments of approximately 50 lbf until you reach a load of approximately 1000 lbf. Do not load the beam above 1200 lbf.

14. Release the load in the beam by moving the lower cross-head down.

15. Once again, read the output of each channel to make sure that the zero strain reference has not changed. If it has changed by more than 10 microstrain, you need to repeat the measurement for that channel.

16. Draw a sketch of the location of the strain gages on the beam. Identify the strain gages by the color of the small piece of tape next to them. The lead wires have also been color coded for convenience (See Appendix 1). Pay attention to the orientation of the rosettes. Note that for the rosettes, the black and red wires are attached to the inclined gages while the white wires are attached to the center gage.

Report Guidelines (Note: Review Section 8.10 in the text ahead of time for information on strain rosettes, pages 565-567 (2nd ed.) or 582-584 (3rd ed.) and Eqns. 8.50 to 8.54)

An Excel spreadsheet or Matlab code to assist in making calculations, tables and graphs is strongly recommended.

For each beam:

1. Draw the shear force and bending moment diagrams for each bending case as a function of the applied load P. Clearly label the values of shear force and bending moment at the gage location.

2. Calculate the shear force and bending moment, at the proper gage locations, for each load you applied in each beam.

3. Record the strains measured by the single, linear gages.

4. Derive equations to convert the strains in the rosettes to strains in your directions of interest. Calculate the strains, \( \varepsilon_x \), \( \varepsilon_y \), and \( \gamma_{xy} \), in the web, and \( \varepsilon_x \), \( \varepsilon_z \), and \( \gamma_{xz} \) in the flange using the rosette data.

5. Calculate the stresses – i.e. \( \sigma_x \), \( \sigma_y \) and \( \tau_{xy} \) or \( \sigma_x \), \( \sigma_z \), and \( \tau_{xz} \) from the measured strains from both the rosettes and the linear strain gages.

6. Plot \( \sigma_x \) in the top flange, bottom flange, and in the web (calculated in step 4) as a function of bending moment (from step 1) for each load in both beams. What is the theoretical relationship between moment and stress? Show the theoretical relationship on the same plot as the experimental data for each location.
7. In your discussion, note how the stresses along the axis of the beam (in the $x$ direction) in the top and bottom flanges and in the web differ. Based on this data, and the fact that the **resultant axial force** on the beam is zero, suggest a possible relationship between the stresses at equal distances above and below the center of the beam (keep it simple!). What parameters other than the applied moment and the distance from the center of the beam might affect the stress?

   *We will review the answers to these questions in class later in the semester. Do not be concerned with getting the correct answers at this point. Just give reasonable answers and back them up based on what you know from the class (or other classes) so far.*

8. Plot the shear stresses, $\tau_{xy}$ in the web and $\tau_{xz}$ in the flanges (calculated in step 4) as a function of the shear force (calculated in step 1). (If the shear force that was calculated is constant, you may plot the shear stress $\tau_{xy}$ as a function of the shear force at another location, as long as this is clearly stated in the figure caption.) How is the shear stress in the web and flange of the beam related to the applied shear force? What parameters other than the applied shear force might affect the shear stress in the beam?

**Note:**

Tables may be placed in an appendix. They will not count as part of the seven page limit.
APPENDIX 1: Color Code for Strain Gage Channels

<table>
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<tr>
<th>4 POINT</th>
<th>Box-Channel</th>
<th>Color</th>
<th>Sub-Color</th>
<th>Type</th>
<th>Gage Factor</th>
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<tr>
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<td>BLUE</td>
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<td></td>
<td>Uni-axial</td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>RED</td>
<td></td>
<td></td>
<td>Uni-axial</td>
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</tr>
<tr>
<td>1-3</td>
<td>YELLOW</td>
<td>BLACK</td>
<td></td>
<td>INCLINE</td>
<td></td>
</tr>
<tr>
<td>1-4</td>
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<td>RED</td>
<td></td>
<td>INCLINE</td>
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Appendix 2: Image of a 45° rosette strain gage
Questions (to be answered before you begin the lab)

1. Fill in "Gage Factor" column in Appendix 1. Bring Appendix 1 to lab.

2. Briefly, using words only (no equations), explain how a strain rosette works.

3. What load (in lbf) must not be exceeded on the 4-point bending test?

4. What load (in lbf) must not be exceeded on the 3-point bending test?

5. Draw the shear and moment diagrams for the 3-pt and 4-pt loading conditions in terms of the load P.
Appendix 3

Equipment

- ATS Testing Machine
- Personal Computer Data Acquisition Hardware/Software
- Strain Gages
- Strain Indicator