UNIFIED ENGINEERING
Systems Problem 3
3/11/04

**Objectives**
After completing this systems problem, you should be able to:

Apply Bernoulli Euler beam theory to compute deflections and strains in a beam

Carry out a simple experiment using apparatus such as dial gauges and strain gauges

**Due Date**
March 18, 12 PM. The lab will be conducted in team of 2-3 people, arranged according to your schedules, but the pre-lab and post-lab write-ups are individual assignments – each student should hand in his or her own pre-lab and post-lab. Make certain that you have all the relevant information and data before you leave the laboratory. The usual collaboration policy applies.

**Introduction**
In lecture we have discussed the derivation of the expressions for the stresses and deformations of simple beams. These expressions are based on a set of modeling assumptions, including the Euler-Bernoulli hypothesis. This lab is designed to provide you with an opportunity to verify that simple beam theory provides a good prediction of the deformation and stresses in a beam and hence to explore the underlying assumptions. The laboratory consists of three related experiments, each of which probes one of the predictions of beam theory. The laboratory exercise will take place in the Civil and Environmental Undergraduate Structures Teaching Laboratory.

**Apparatus**
The apparatus consists of a mild steel beam, approximately 36" long, with a cross-section of 0.375" deep by 1.25" wide. The beam is supported on rollers at its ends and is loaded centrally by hanging weights from a chain suspended from a yoke clamped to the beam. The provided weights are approximately 6 lbs. Each, exact weights are marked. Strain gauges are attached on the top and bottom surfaces of the beam. Strain gauge monitors are available to monitor the strain gauges. The strain gauges are monitored individually in a quarter bridge circuit. A dial gauge is available to monitor the displacement at a fixed point along the beam. Assume that the steel of which the beam is made has a Young's modulus of 200 GPa ±5 GPa

**Pre-lab exercise**
Calculate or otherwise obtain an expression for the deflection of a beam simply supported at its ends and point-loaded at its center as a function of the beam dimensions, material properties, and applied load. Obtain expressions for the **strains** on the top and bottom surfaces of the beam as a function of the beam dimensions, material properties, applied load and axial position along the beam. Have these expressions available in the lab so that you can quickly compare theory with experiment. Given the dimensions listed above, calculate the applied load that will result in a stress of 150 MPa

in the beam, assuming that the span is the entire length of the beam.  This load should not be exceeded in conducting the lab.

**Experiments**
Three separate experiments will be conducted using the same apparatus.  Vernier calipers and meter rules are available to allow you to measure the beam dimensions and distances between the supports and loading points.  Do not forget to take this data for each experiment below.  Also take the time to inspect the fixture, loading apparatus, and instrumentation to evaluate any sources of error.  The lab work should take no more than 60 minutes, and a well-organized group may take substantially less time.

**Note:** You will need to adjust the apparatus between experiments, make sure that the support points are secure and properly aligned before applying load.

**Note:**  It is highly recommended that you perform at least some preliminary calculations while you perform each experiment.  This will allow you to identify any gross errors in the way you have conducted the experiment, for instance if the displacement or strain readings are faulty, or if you have incorrectly measured a dimension.   See also the directions for balancing and calibrating the strain gauge monitors at the end of this set of lab instructions.

1. **Verification of load-displacement and load-strain relationships.**
   Place the beam on its supports so that the strain gauges are on the upper and lower surfaces.  Apply load centrally to the beam and measure the resulting center point displacement using the dial gauge.  Also measure the strains on the top and bottom surfaces using the strain gauges.  Note, to avoid damaging the strain gauges they will need to be positioned slightly offset from the loading point.  This offset should be accounted for in calculating the strains via beam theory (how do the strains vary along the length of a simply supported beam?).  Similarly, if the dial gauge cannot be placed directly at the point of load application, and this offset will need to be accounted for.  Make measurements at 5-7 load levels during loading and 3-5 load levels during unloading. Tabulate and plot the displacement and strain data as a function of load.

2. **Verification of role of cross-sectional properties.**
   Rotate the beam through 90° so that the strain gauges are on the side faces, and the depth of the beam is now the long cross-sectional dimension. Repeat experiment 1, recording load, displacement, and strain at a sufficient number of data points to produce a curve. Tabulate and plot the displacement and strain data as a function of load.

**3.    Verification of span-displacement relationship**.
Reorient the beam so that the strain gauges are on the top and bottom of the beam.

(a)    Reduce the span to approximately 75% of the original and repeat experiment 1, tabulating displacement and strain data.

(b)    Reduce the span to 50% of the original and repeat the measurements.

**Post-lab write-up**
The post-lab write-up should be an individual effort. In particular, the graphing of data and its interpretation should be done separately.  The lab write-up should take no more than 2 hours.

1.    Using graph paper or a computer graphing application, produce neat, labeled, and titled versions of the data that was taken in the experiments 1) through 3) described above. Estimate the errors associated with taking the data and include appropriate error bars with your data points.

2.    From the slope of the graphs compare the experimental data with the predictions of beam theory for how:
(a) Deflection varies with applied load for a fixed span
(b) Strain varies with applied load for a fixed span

(c) Beam stiffness $\left(\dfrac{P}{\delta}\right)$ varies with second moment of area, I

(d) Beam stiffness $\left(\dfrac{P}{\delta}\right)$ varies with span

3.    Comment on the accuracy of the predictions made by beam theory in describing the experimental data. If the experimental data does not conform to beam theory, suggest possible explanations.

4.    Please comment on whether this laboratory helped you understand lecture material and also on ways in which the lab could be improved.

**Safety and Care of Equipment**
There are no major safety issues associated with this lab.  Do take care not to drop the weights on your fingers!  The strain gauge wiring, and particularly the solder joints are prone to damage so treat them gently.   Similarly, the dial gauges have sensitive springs inside and so can be easily damaged if treated roughly.

There are hazardous chemicals stored in the lab, in the cupboards and in the fume hood. You should have no reason to go near these areas.  On a related note, we are very lucky to be allowed to use this lab by the Civil and Environmental Engineering Department.  To ensure that we are welcomed back in future years, please make sure that the lab is as tidy when you leave, as it was when you arrived.

**Notes on Strain Gauge Conditioners**

You have met strain gauge conditioners in performing the truss lab and elasticity lab last term. This is just a reminder of the mechanics of using them to measure strain. Remember that within the boxes is a Wheatstone bridge circuit that is used to provide a sensitive measurement of the change in resistance with strain. In order to provide a straightforward reading of strain, the gain on the amplifier will be set such that the voltage display has units of $\mu\varepsilon\left(\text{X}10^{-6}\right)$. This is achieved by an internal resistor of known resistance that is switched into the bridge circuit in parallel with the strain gauge in order to simulate a change in resistance of the gauge, and hence a certain strain level. You should only have to perform steps 3 and 4 in using the apparatus.

**Note:** There is a dial that allows you to switch between the two strain channels. Check which channel corresponds to the tension, and which to the compression side of the beam.

1.  With the excitation switch "on", adjust the "bridge excitation" with a screw driver to 6V on the voltmeter clock gauge. Do **NOT** do this without consulting a TA or instructor.

2.  With the excitation switch "off" zero the digital display with the "Amp balance" screw with a screw driver. Do **NOT** do this without consulting a TA or instructor.

3.  With the excitation switch "on", zero the digital display with the black "balance" pot.

4.  With the excitation switch "on", turn the "Cal" switch to A(tension), or B(compression).

5.  Adjust the "gain" pot so that the digital display reads 1000. This simulates 1000 $\mu\varepsilon$ i.e. giving a strain readout in $\mu\varepsilon$ .

6.  Note that you may have to iterate between steps 3 and 4 to achieve a balanced and calibrated strain channel. If the calibration and balance seem to be along way from the expected values, ask an instructor to take a look.

Have Fun!