Mechanics of Materials Lab – Mechanics Section
Experiment #8: Deflection and Strength of Beams

Objectives

The object of this experiment is to allow students to demonstrate their knowledge of beam deflection theory through the completion of an experiment that:

1) Applies a load to a beam
2) Measures the deflection at selected locations
3) Sets up a protocol for comparison of measured values with theoretical values

Approach

Students will be introduced to a large-scale beam specimen, electronic transducers and data acquisition systems. The theory by which each of the mentioned devices operate will be discussed. Students will configure these devices and set up a laboratory experiment. Students should be mindful of why each experiment configuration was chosen.

Relevance of Experimental Design

When considering the effect of loads on structures it is often necessary to perform tests to remove uncertainty. To this end, it is important to design the test such that it demonstrates or verifies the theoretical predictions of the structural performance. Verification of beam theory via testing requires additional information such as the values of yield strength and modulus of elasticity.

To obtain the theoretical modulus and yield strength of the beam, students should consider the results of Experiment 5 (tension test of a specimen cut from the web of the same beam material). The obtained modulus and strength values should be used to estimate the theoretical deflection values for the beam deflection experiment. The tension test will utilize extensometers to obtain strain values used to calculate Young's Modulus for a displacement range less than 0.05 inches. After which the specimen will be tested to failure as in the Tension lab of this manual.

The experiment will be setup in three-point bending. The testing group may place the load anywhere between the two reaction supports with the understanding that a maximum of 22 kips is available to fail the beam in bending. A load applied at mid-span produces the highest bending moment; however, the testing group may choose an off-centered location provided it still exceeds the bending capacity of the beam specimen.

Two displacement transducers will also be made available which can be placed at any location beneath the beam as specified by the testing group. Comparison of the measured and predicted displacement from those locations can be made for any applied load.

When selecting a load testing apparatus, the maximum available jack stroke (6 inches) must be compared to the theoretical displacement required to fail the beam in bending. Therefore, the testing group must select the position of the load on the beam so that the 22kip maximum load with a 6in maximum deflection will suffice.

The testing group must also consider the manner in which the beam is to be loaded to failure. Two modes of testing are routinely performed: (1) load controlled or (2) displacement controlled. Load control means that the load will be applied at a constant rate (i.e. 1 kip/min) and the displacement is measured, whereas displacement control means that the load actuator (hydraulic ram) will advance at a prescribed displacement rate (i.e. 1 in/min) and the resulting load to cause that displacement is measured. Most loading devices are computer controlled wherein the computerized system will do all within the mechanical limits of the system to perform the requested loading. When the beam is being loaded in the elastic range, both load and displacement-controlled systems are essentially the same. The testing group should consider the ramifications of the two loading scenarios after the yield stress has been exceeded.

Finally, digital data collections systems are now inexpensive and readily available for laboratory and field testing alike. These systems are capable of sampling/recording at variable rates, the limits of which are defined by the internal electronics (and cost). The testing group should determine the minimum required sampling rate when compared to the loading or displacement rate to ensure that the requested sampling rate is both possible and provides a satisfactory representation of the entire loading event.

Report Type

Formal Report

Theoretical Background

According to the beam deflection theory, the deflection of a beam at any point due to a concentrated load applied at the center is determined by:

$$\delta_x = \frac{Px}{48EI}\left(3l^2 - 4x^2\right) \quad \text{for any position where } x < \frac{l}{2}$$

$$\delta_{\max} = \frac{Pl^3}{48EI} \text{ when x = l/2}$$

Where $\delta_{\mathbf{x}}$ is the deflection of the beam at a point (x) from the support, and $\delta_{\max}$ is the maximum deflection of the beam (located at the midpoint).

Where x = distance from nearest support where deflection will be determined (in)
l = total length of beam between supports (in)

P = force being applied to the beam (kips)
E = modulus of elasticity (ksi) obtained from the preliminary tension test
I = area moment of inertia (in^4)

Instructions

This experiment is performed in two sessions: a planning session and a testing session.

First Session (Planning the Experiment):

Before the students can test the beam there are several calculations which must be performed in order to select the appropriate testing device and experimental duration. Failure to calculate these values will result in students not being allowed to perform the experiment.

1. Conduct a tensile test of a dog bone specimen cut from the web of the beam. Students will be required to set up the test however the instructor will run all tests.

2. Using the data obtained from the tensile test students must derive the Young's modulus and the yield strength of the beam,

3. Based on the moment of inertia of the section and the yield strength "F_y" of the material (obtained for tensile test) the students are required to determine the maximum load "P_{max}" the beam can support. This will be done by first calculating the maximum bending resistance using the formula

$$\sigma = \frac{M_{\max} c}{I}$$

   Where σ will be equal to the yield strength of the material, **c** = ½ the height of the section, and **I** is the Inertia.

   P_{max} will then be calculated using the formula

$$M_{\max} = \frac{P_{\max} L}{4}$$

4. After determining the maximum load which the section can withstand, the maximum theoretical deflection ($\delta_{\max}$) must then be calculated using the formula for deflection given in the theoretical background.

5. Lastly, the load or displacement rate for the test must be calculated such that failure occurs in 15 minutes (to maintain lab scheduling). Rates should be per minute

Summary: When entering the lab to perform the second session, students MUST be prepared and have the following: location of displacement gages, maximum anticipated load (P_{max}), maximum anticipated jack stroke (δ_{max}), load rate and displacement rate.

Second Session:

This session is conducted in the structure's lab (ENG021G). MTS Systems and an Optim MegaDAC 5414AC will be used for load application and data acquisition, respectively.

1. Test the load cell and displacement transducers as instructed by the operator. Make a note of the process discussed for testing and balancing (tare) devices using the MegaDAC system.

2. Level the hydraulic ram and load cell combination using provided level.

3. Position roller supports so that the apex of the two rollers provides a 4ft span. Secure each roller support.

4. Place the beam on the roller supports. Note: The load is applied vertically on to the horizontally aligned beam.

5. Center the beam with the loading platen. The beam web should run on the centerline of the load platen from each support.

6. Place the displacement transducers under the beam. Be sure the displacement gage plungers are slightly depressed and in contact with the underside of the beam.

7. Position the longer stroke transducer under the beam at the center of the loading location, (directly below the web). Position the second transducer under the beam directly below the web. **NOTE:** You must record a measurement for the position of the second displacement transducer.

8. The operator will now balance system which starts both the load and displacement values at zero. Make a note on how this affects recorded values.

9. The operator will start the test. Observe the load vs displacement plot on the display provided.

10. Upon test completion, record the name of your data file and collect your data.

After Class:

Formal Lab Report:

1. Formal Cover Letter

2. Introduction / Background (Importance of testing, Why are these type of experiments performed? (1-2 paragraphs, include references)

3. Test Setups
   a) Tensile test information (Why was the tensile test conducted, why was an extensometer used instead of just displacement?)
   b) Support, load and displacement gage location selection based on first session preparations.
   c) Deflection test information. (What type of data acquisition system was used, sampling rate, load or displacement rate? How was data collected?
   d) Free body diagram of the test setup.
   e) Test specimen setup and testing procedure.

4. Results
   a) Shear and bending moment diagrams for both theoretical and experimental max values (Graph on same graph for comparison.)
   b) Load vs. Displacement graphs with experimental and theoretical data (graph both displacement transducers, graph 1: experimental and theoretical for 2’’ transducer; graph 2: experimental and theoretical for 4’’ transducer)

5. Conclusion
   a) How long did it take the beam to reach yield? Did it reach yield in the allotted time? Please discuss! In addition, compare the theoretical displacement at yield to the theoretical displacement at the same yield load. Comment on the discrepancy, if any.
   b) Using engineering judgment compare the experimental modulus of elasticity to the theoretical modulus of elasticity, derived from the tensile test, and the theoretical modulus of elasticity in literature. Also, compare the experimental yield stress (from the yielding bending moment) to the theoretical yield stress estimated from the tensile test. State percent difference/error and explain the discrepancy, if any (i.e. sources of error, etc…)
   c) How does this experiment help us as engineers? (i.e. Understanding materials, etc…)

NOTES: (1) Everything stated above needs to be included in your report, however, these should not limit your report. TAKE THESE IDEAS AND SUGGESTIONS AND EXPAND ON THEM. (2) Please state all references, include a reference page. (3) Remember that, as always, everything needs to be computer generated, label units, and label graphs.