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LESSON PLAN: Deflection of Balsa Wood Bridges

Objectives:

SWDAT …

1. Experimentally determine the smallest *deflection to load ratio ($\Delta y/P$)* for a given length of four different beam designs of balsa wood.
2. Make a connection between the results for different beam designs and the equation that describes how deflection varies with the geometry of the beam.

Subject(s): Applied Physics, Principles of Engineering (POE) or similar class

Rationale:

Building balsa wood structures, especially bridges, is a common project for technology and physics classes; however, these projects are often based more on construction and testing and less on the *physical principles* necessary for good design. This lesson will address one aspect of bridge design – physics of deflection – and will allow students to investigate its nature, and subsequently to develop a solid foundation (literally and figuratively) for the eventual construction of the balsa wood bridges.

Prior Lessons:

- Brief introduction to torque & lever arms and their relationship to bridges
- Introduction to Young's modulus in relation to tension and compression

Assessments:

- **Primary** - formal lab report
- **Secondary** - questions for quizzes & tests
- Throughout the lesson informal Q & A will be employed

Further Notes:

This lesson will be taught over 3 periods: one for introduction and theory, the other two to do the lab and discuss results. The details of the lesson that follows are purposely kept to the basics, as it is at the teacher's discretion to modify or enhance as he or she sees fit.

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LESSON:

Day 1 - Introduction and Theory

- Start class with demonstration of a length of wood or metal placed across a two supports, and slowly add weight to the middle of the beam until the wood breaks or the metal bends beyond repair.

- Relate the demo to the bridges and what they are supposed to do and *not* do, especially the ones they will be building for their POE project.

- Ask students what factors may affect a bridges ability to support a static load
    - ➔ material, length, geometry or shape of beam, support it rests on, etc.

- Introduce the equation that relates how much a beam bends (deflection) to the above factors and define each part ➔ $\mathbf{\Delta y = P \cdot L^3 / E \cdot I}$ where $\Delta y \equiv$ deflection; $P \equiv$ load; $L \equiv$ length of beam; $E \equiv$ elastic modulus; $I \equiv$ moment of inertia (in 2-D).

- Highlight the cubic influence of length w/ numerical examples. Use materials table to show how elastic modulus of balsa wood favorably compares to other woods. Do sample problems if needed.

- Point out that for their bridge the length (L) will be constant as well as the building material. Since elastic modulus is based on the building material, **E** will also be constant. Thus the only design variable is **I** (moment of inertia) which depends on the geometry or shape of the beam.

- Introduce lab experiment to be done next class: students will test how deflection varies with 4 different geometries (I) for a given length of beam. The geometries are shown below.

    - ➔ The lengths will be ~ 30 cm. The wider beam (2b) can be a wider piece of balsa wood or 2 pieces glued together. The former is preferred so that effects of glue do not factor in.

- For homework students should develop a hypothesis as to which geometry will give the smallest deflection to load ratio, with a rationale.

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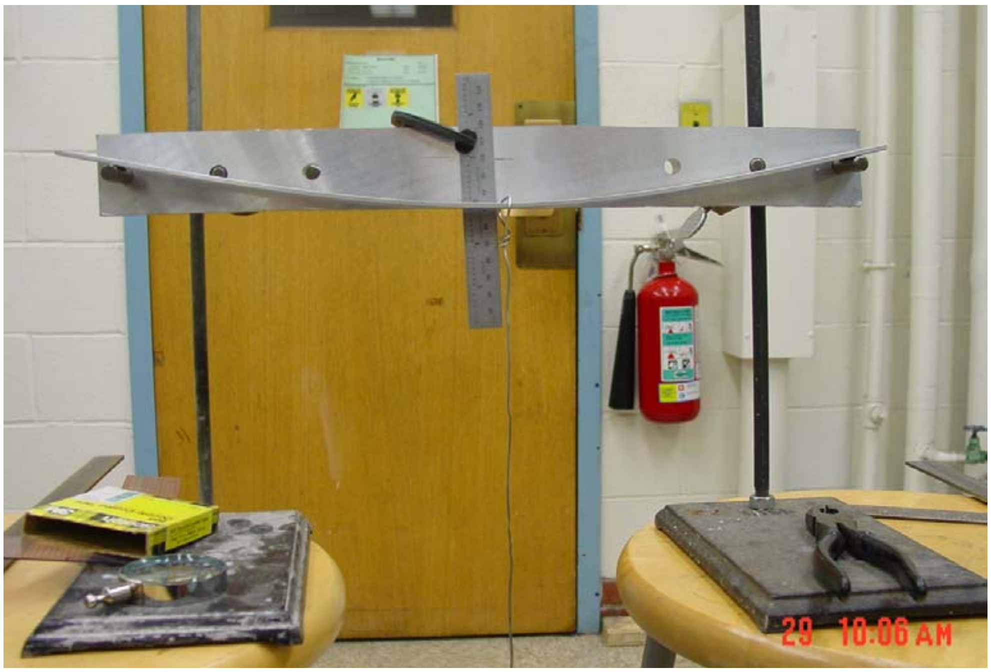
Day 2 – Experiment & Discussion

- Students can work in groups of 3 or 4 for any number of experimental set ups

- **MATERIALS:**
  - ➔ A set of ring stands with horizontal support rods
  - ➔ Meter stick w/ mm rules or vernier caliper
  - ➔ Hanging wire (nichrome works well)
  - ➔ Container to hold load
  - ➔ Washers or pennies or slotted masses for the load
  - ➔ 4 different balsa wood beams

- The experimental set up is shown below. It is important that the load hang from a support at the middle of the beam so that the deflection equation is valid.



➔ Any support stands can be used, but there must be enough clearance height for the load to hang freely. It is best that the balsa beam rest on cylindrical supports so that the contact surface is minimal. If this is not practical use whatever works best.

➔ There are a number of ways to measure deflection. Using a meter stick is the most convenient, but may not give the most precise results. Fastening a millimeter ruler at the middle of the beam and measuring change in position will work, but is more difficult to set up. A vernier caliper could also be used by having a reference width before deflection and measure the change after deflection.

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- The general **PROCEDURE** is as follows:

    1. Take smallest balsa wood beam (¼"x ¼") and rest it freely on supports. Record its position relative to the millimeter ruler. This will be the zero point.
    2. Secure a piece of nichrome wire at its center and attach a cup at the other end such that it hangs freely. The mass of the cup & wire can be measured later
    3. Mass a few washers or pennies, place in the cup and measure the deflection. If there is no measurable deflection, add a few more.
    4. Repeat step 3 for four or five more loads. It is important that the load mass not be so much that the balsa beam cracks or breaks.
    5. Once a set of loads is measured, a different beam is set up and steps 2-4 are repeated.

- **ANALYSIS** of data

    1. On a common graph (P is on the x-axis), students should plot their four sets of data and expect a linear graph for each.
    2. Find the slope of ($\Delta y/P$) each line and make a table showing lowest to highest. Expected results: t-beam should have smallest ratio, followed by stacked beam (¼"x ½"), then wide beam (½"x ¼") & lastly ¼" x ¼" beam.

- **DISCUSSION** of results:

    The important connection to make is that for a given length and material, the shape of the beam makes a noticeable difference in the amount of deflection, and therefore ability to support a static load. The question is why?

    ➔ Different geometries give different moments of inertia (I), and the greater the moment of inertia, the less deflection.

    ➔ For a rectangular shaped beam of width, ***b,*** and height, ***h,*** the equation for moment of inertia is **$I = 1/12\ b \cdot h^3$**

    ➔ Clearly a "taller" beam has a much greater influence on **I** than width; therefore the t-beam and stacked beam give least deflection

    ➔ The t-beam (or I-beam) is more advantageous because they can cover the width of the "road bed" w/ less material than the stacked beams.

- Sum up the key points of the lab and lead students back to their ultimate goal of building a balsa wood bridge that can support the greatest static load. Though there is much more to the bridge design than a simple beam span, they now have a sound foundation for beginning phases of the design.

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