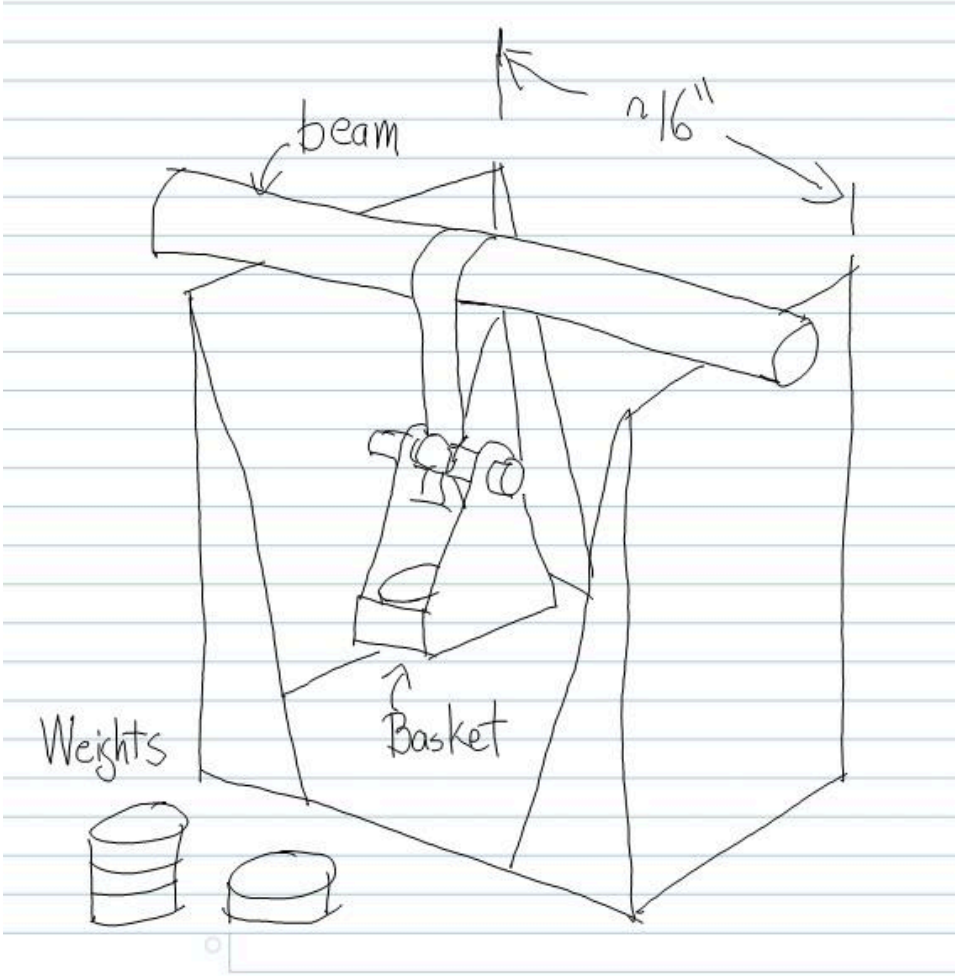
Activity: Structural Engineering with Newspaper Beams



Grade Level(s)	Timeframe
3-5, 6-8, 9-12	60-90 min

ABSTRACT

This lesson explores aspects of structural engineering and the iterative engineering design process by experimenting with different ways of making beams out of rolled newpaper and testing the resulting strength using a simplified 3-point bend test

Tested with Grade 5, but suitable for most any higher level by adding or removing complexity of the contruction methods and challenge criteria.

EQUIPMENT AND MATERIALS

- Newspaper
- Masking tape
- 3-point bend test setup made out of corrugated carboard box, 3/4" ribbon, cargo strap or lanyard, and other cardboard. (Make before the class.)
- Small weights (2-3 lb total) (for each apparatus)
- Glue sticks (optional)
- Precision scale (optional)
- Dowels or rods of various diameters, eg. 1/4” to 1-1/2”, 30in long (optional), shared between groups
- Empty aluminum can, block of wood the same height, and board to go between, that adult can stand on (optional)

GETTING READY

Introduction:

Students are briefly given a general introduction on structural engineering. Paper and cardboard is then introduced as a material that is interesting for engineers to work with because it has many advantages. Despite the perception of being weak, structural engineering principles can be applied to paper and cardboard to make interesting structures, including bridges and even buildings. To understand how to make strong structures, engineers first study the strength of the materials and components made using them by subjecting them to testing. A 3-point bend test is a common test that is used to

determine the strength of beams used in a structure. Students are told their challenge will be to make strong beams out of newspaper and masking tape (mainly to keep the paper from unraveling) where the strength will be evaluated using a bend test.

Theory/Engineering Principles:

As the most common shape of the newspaper beams to be made is a circular tube, general beam theory would predict the strength is governed by the moment of inertia of the cross-section (I = pi x R**3 x thickness). However, the beams to be made here will behave as thin wall shell structures where failure is largely dictated by local buckling, which is mainly empirically determined and the traditional strength equations do not apply, so no need to fuss about those beam equations if they are long forgotten. Rather, the resulting bend strength is largely determined by other physical properties to be investigated by testing.

Optional Related Demonstration:

A great demonstration of the importance of avoiding kinks at some point in the lesson is to do the collapsing aluminum can demonstration: An empty, pristine, aluminum drink can can support approximately 130 to 180 lbs if loaded uniformly. However any dents or damage to the walls greatly reduces this load capacity. My weight being above the collapse threshold, I do this demonstration by placing a board over top of an empty can at one end, and a block of wood of similar height on the other, and then I stand roughly in the middle of the board. The can should bear the applied weight if it has no dents. The side of the can is then taped with a stick. A rather instantaneous complete collapse of the can should then happen once the can goes into unstable buckling. Practicing this prior to the lesson is recommended, as it requires a bit of dexterity and balance, at least for me, to not prematurely collapse the can.

Experimental Setup:

The 3-three point bend test setup for this lesson can be rather simple. A box can be modified or constructed as in the diagram provided to create two walls with an approximate 16 inch span, and similar height. A small “v” is cut in the top of the supporting walls to help center the beam being tested. Center loading of the beam is achieved using a ribbon (I used an old lanyard) tied to a basket type holder that receives the weights. A ribbon approximately 0.75 in wide is prefered over something thin like a string, as the latter

will cause the tube to fail too quickly (it initiates a kink). For the weights I suggest using a plurality of evenly sized metal based objects, like large washers, bigger size nails or bolts, pennies perhaps, etc. I used metal plates salvaged from some old vertical blinds. It could take up to 2-3 lb. of weights, but the EiR should should do some tests prior to the lesson to make sure there is enough to break the different beams that might be tested in the apparatus constructed. The students run the test by incrementally (and gently) adding weights to the basket until failure occurs, which typically is a sudden and dramatic collapse of the beam, and then recording the number of weights added at failure.

Activity:

After explaining the test procedure to the students (which can include demonstrating one of the tests suggested below) the students are then instructed to make their own beams, and then when they are ready, to test them. They are told to start with a design they think will be strong, and that they will have the chance to further test different ideas or variables (as in the list below) to improve their design. Students can work individually or in pairs. Rods or dowels of various diameters can be used to help in rolling the paper tightly and without kinks, as these are important to making strong beams. Note the rods should be long enough (30 in. or so) to have an end stick out so they can be easily pulled out once the roll is made, as shorter rods tend to get stuck in the roll and are hard to get out. To some extent, these tools can be shared by the students so it should take just a few of each for the lesson.

Some ideas for testing that can be demonstrated or suggested to the students are:

- Does it make a difference to roll the paper starting at a corner and rolling diagonally, versus rolling the paper starting along a straight edge and rolling parallel? Rolling diagonally will result in a greater number of layers in the middle of the beam, putting more strength where the bending moment is largest (examples of this can be found in actual beam applications). Observed in my lessons, a beam made by rolling diagonally will have twice the strength relative to a beam rolled parallel.

- What is the effect of the diameter of the beam? In theory strength increases as R**3, but thickness decreases with 1/R assuming the same size paper is used. For the diameters studied in my lessons, there was little change in strength with diameter when using a single sheet of newspaper. While the strength should go up with diameter, this is negated by the propensity for buckling which also increases with the thinner walls.

- Does strength increase with increasing diameter if the thickness is kept constant?

- How much does doubling/tripling paper thickness increase strength? Is it a linear amount?

- Will stuffing shredded paper within the tube help increase strength? This can have an internal stiffening effect that can help mitigate buckling. Did the failure or buckling occur where perhaps there was a void in the stuffing?

- What is the result of nesting two or more small diameter tubes inside a larger tube? This too can act as an internal stiffener, and perhaps more weight efficient than stuffed paper?

- What about adding a “collar” to the middle section of the beam?

- How might different sizes of paper be layered prior to rolling to create thicker layering in areas that need most reinforcement.

- Will applying a glue stick to the paper prior to rolling increase strength?

- If two beams are tested in tandem, is there a difference in testing them in a superposed position versus side by side. What if the beams are glued together using a glue stick and the tests are repeated?

Other thoughts/tips:

In my experience with grade 5 students, they were quite excited just to test different tubes that they made using a wide variety of ideas without the lesson having imposed any design or material limitations, although different rules can be imposed to make it more challenging. By encouraging students to do iterative tests, and the EiR helping the students interpret the test results and question them on what they might try next, this

lesson works well in showing the students the engineering method of developing an idea or design, testing it, analyzing the result, developing a new idea on how to make it better, and then testing again. In particular, the quick turnaround with which successive beams can be made in this lesson should work especially well where time constraints of a lesson, or the attention span of the students, is a limiting factor.

For more advanced levels, I can see increasing the challenge level by focusing less on the iterative process but rather creating a competition to achieve the best specific strength, where the strength to weight ratio of the beams is determined by weighing the beams. Conversely, the challenge can be to find the design that achieves the highest load for a fixed amount of paper. This can also be extended to include going from constructing simple beams to constructing truss structures. There are lots of ways to change this lesson.