EXPERIMENTAL PROJECT 2013-2014

The Elastic Properties of a Wooden Metre Ruler

When you have investigated elastic materials, that is materials that can be stretched or compressed and subsequently spring back to their original shape and size, you will probably have measured the extension of a steel spring. You may even have done an experiment on an elastic band, which is rather different to a spring. These are very important materials, but many materials do not appear in this convenient shape, especially composite materials such as wood and reinforced concrete. You rarely find a wooden spring or even think of wood as stretching like a metal. Yet wood is flexible. It bends and springs back to its original shape unless you bend it so much that you hear those very faint cracking sounds and realise that you have bent it too much. Wood is still used a great deal in the construction of buildings and some wonderful new architectural designs are made from wooden structures. Wood is not going to be replaced in the near future, so we do need to know about its elastic properties. We want a value that we can look up for a particular type of wood, so that when we have a beam that is of known length and width, we are able to work out how much it might bend when it supports a load. The constant which describes the elasticity of the wood (or spring or other stretchable material) is called Young's Modulus. It is often determined for steel by measuring the stretch of a long thin wire when weights are hung on the end. This is not so easy for wood; you can't get a piece of wood like a wire, and it is hard to hang weights on a strip of wood without them pulling the wood apart. When a spring or a wire is stretched with a small extension, the same force applied will compress it by the same amount (you may have to put in in a tube to keep it straight).

For a piece of wood we can clamp one end to a flat bench and hang weights off the other end which sticks out. The ruler sags down in an arrangement that is called a cantilever, as shown below in Figure 1. The top surface of the thin wooden ruler is stretched just a little bit, and the bottom surface of the wood is compressed just a little bit, and yet we see a quite measureable sag. So this is a clever way of amplifying the effect of the elastic properties of the wood. The same can be done for concrete, which is certainly very important as bridges are constructed from steel and concrete cantilevers, at least until the two ends of the bridge meet in the middle.

Many blocks of flats have cantilevered balconies which sag slightly, and will even bounce up and down if you jump up and down on them.

The Young's modulus is also an important quantity in other ways (which we will not investigate here). If a disc is spun very, very fast, then it can store kinetic energy. Such rotating discs (flywheels) can be found in the rear engine compartments of buses. The kinetic energy of the bus is converted into fast rotation of the disc as the bus slows down (to avoid wasting the energy by heating up the brakes) and then the energy from the flywheel is used to speed up the bus when it leaves the bus stop. These discs are best made of composite lightweight materials spun very fast, and Young's modulus is a significant factor when designing such flywheels.

We are not going to derive the formula for the cantilever here, but you can look it up and it is not too difficult to follow.

Apparatus

1. 2 or 3 wooden metre rulers (width $2a$ and thickness $2b$ – *note the factor 2; it appears here so that it does not appear in the formula later*) or wooden slats (Fibreglass rulers are liable to snap when overloaded, and will be more likely to do so in Experiment 2 after being heavily loaded in Experiment 1)
2. 1 or 2 G – clamps
3. A weight W, mass M, selected in the range 500 – 1000 g
4. A ruler and callipers/ micrometer for measurement of $2a$ and $2b$
5. Stop watch, or equivalent timing device
6. Graph paper

Safety

1. Closed footwear in case the weight drops onto your foot.
2. Safety goggles worn when the ruler is being loaded with heavier weights.

Experiment 1

Static Deformation

Clamp a wooden metre ruler to the bench so that it overhangs the edge of the bench, the G-clamp being at the edge of the bench, Figure 1 (screw the G clamp from under the bench so as not to grind the end of the screw into the ruler).

Attach the weight *W*, selected in the range 500 -1000 g, to the end of the metre ruler using gaffer tape or string or any alternative method. **Measure** sets of values of *L* and *D*, where *L* is the horizontal distance from the edge of the bench to the vertical through the centre of gravity of the weight, and *D* is the vertical displacement of the end of the ruler from its unweighted horizontal position. Restrict the measurements of *D* and *L* so that the elastic limit of metre ruler is not exceeded (it should spring back to its starting position).

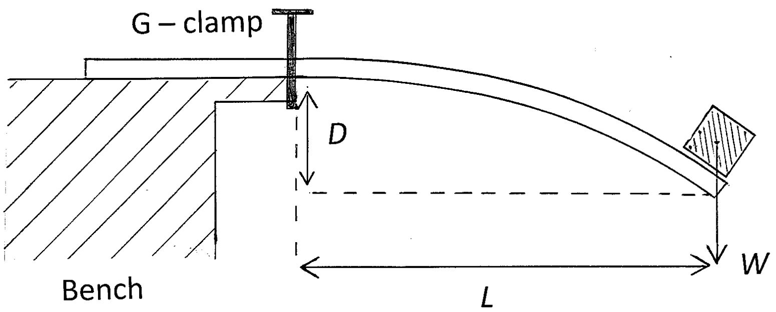

Figure 1

Plot a graph of *D* against L^3 for a range of values of *D* and *L,* and obtain the best straight line fit.

If we assume the relation

$$D = \frac{WL^3}{3IE}$$

where $I = \frac{4}{3}ab^3$ and *E* is the Young's modulus for the wooden ruler, **obtain a value for *E***.

Experiment 2

Dynamical Properties

Using the same arrangements as for Experiment 1, **measure,** for a range of values of *L*, the period for small oscillations, *T*, of the weight (one oscillation is the time taken for the weight to go up and down)

Assume that $T = kL^{\alpha}$ where k and α are constants.

Plot a suitable graph to determine the values of k and α. *(There are three distinct graphs you might consider plotting and you may want to plot more than one of them*).

Experimental Report

This report should contain:

(i) A description of the experiments
(ii) Tables of measurements
(iii) Precautions taken
(iv) Errors and accuracy estimates
(v) A photograph of the experimental arrangement
(vi) Calculations
(vii) Results, units and accuracy

Report Guidelines

You should give a full but concise description of the experimental procedure (you do not need to repeat the instructions given here). Highlight any particular ideas you had to make the results more reliable, with results, tables, units, uncertainties, graphs, diagrams and images. This is elaborated below.

- This set of instructions gives the practical details of the setup so you do not need to describe them. You must write about any additional points, the particular apparatus that you used (type of wooden ruler), precautions you took and good ideas you had about making the results more precise, what were the difficult measurements to make and why. Do not write an essay but just a short comment about each good idea.

- You should **describe briefly in words** how you checked that you did not exceed the elastic limit. Otherwise the ruler will start to behave differently half way through the experiment. Perhaps check with a heavier load early on. This is so that you get to understand how the apparatus behaves before you start taking readings.

- Take a **good range** of data, and **plot the graphs before you put the apparatus away**. You may find that you do not want an even spread of results, but that you need more at some particular values of x and rather fewer at other values of x. You do not have to take all of the readings in the right order. They will sort themselves out on the graph.

- Results tables should have the **original data** including any **repeated measurements**, with the **units** at the top of the column along with the **correct symbol** for the quantity. A column for the **average** can then be worked out. You might include a column with an **estimate of the uncertainty** on your average value?

- If you feel that the results are not right, then don't scribble them out or delete them; keep them and just point out what might be wrong with them or why you have no confidence in them. The purpose is to show that you have **investigated the apparatus** and given it a good try out so that you can convince the reader that you **know what you are talking about**. Things can go wrong and you need to show how you can overcome setbacks. If you delete everything that does not seem right to you, the reader might see a nice final table of results, but he does not know how much investigative effort you have put in to get that set of results. The reader might indeed wonder whether they are that good. Do **not** write an essay, just a few bullet point comments.

- Graphs should have labelled axes, units on the axes, a whole sheet of graph paper, some gridlines if done in Excel so that the reader can get values off the graph, a scatter graph with a line of best fit (trendline in Excel) – definitely do not "join the points". Display the equation for the trendline on the graph. **Comment on the graph** i.e. look at it and state what you can see about the shape of the graph, the scattering of the points, does it go anywhere near the origin, is it a straight line or a curve (or is it hard to tell), is the data close enough to the line of best fit to agree with the uncertainties you wrote down in your table of results?

- The **conclusion** is the table of results that you fill in, but you should also make at least a **comment** about whether you yourself think that the results are believable or not, and why.

End