Exercise 5: Plastic Deformation

Name(s): ______________________________

Uni(s): ______________________________

Plastic Deformation

Now that we have learned about the elastic response of materials by investigating the Young's modulus, we will look instead at how materials plastically deform. Specifically, we will try to determine the yield stress σ_y of plain steel by using the following relationship we developed between the strain of the string and the frequency at which it vibrates, given below:

$$\boxed{\nu_{min} = \frac{1}{2L}\sqrt{\frac{E\epsilon}{\rho}}} \tag{1}$$

The yield stress of a material is very important because most materials deform plastically in a predictable manner before failure, so the characterization of how a material plastically deforms is integral to preventing materials from failing in engineering applications.

1. Much like last week, we will be changing the strain on the string by changing using the tuning pegs. As before, record the fundamental frequency you see in the spectrum analyzer as a function of strain ϵ. However, this time, record data points (again, probably in 1/4 turn increments) **until the string breaks**.

   Also, be sure that your spectrum analyzer (such as AudioXplorer `http://www.arizona-software.ch/audioxplorer/` for Macs or Spectrum Lab `http://www.qsl.net/dl4yhf/spectra1.html` for Windows) is set to record frequencies with a resolution of at most 2 Hz. This will likely mean setting your FFT sample length to at least 4096 samples. Remember that longer samples and better frequency resolution results in better data!

2. As before, make a plot of ν^2 as a function of ϵ by squaring both sides of equation (1), giving us

$$\nu^2 = \left(\frac{E}{4L^2\rho}\right)\epsilon \tag{2}$$

3. Now, check your graph to make sure that the graph is not perfectly linear. Remember that plastic deformation is indicated on the graph by a non-linear relationship between stress and strain. If your data looks perfectly linear, look again at the frequency resolution of your data and consider taking new data.

4. Once you've checked to make sure your data isn't linear, convert your y-axis values of ν^2 into values for stress σ. You should use the relationship given in equation (2) as well as the definition that, in the linear regime,

$$\sigma = E\epsilon \tag{3}$$

   Again, be very careful with the units in this calculation!

5. Make a plot of your values of stress σ, on the y-axis as a function of strain ϵ, on the x-axis. This graph is known as a *stress-strain plot* and is a fundamental tool for analyzing the deformation of materials.

6. Next, generate a line that follows represents $\sigma = E\epsilon$, using the value of E you calculated in last week's exercise. This line should match up relatively well with the elastic region of your stress versus strain plot.

7. Often, since the material deforms plastically a small amount as soon as a stress is applied, we calculate σ_y after accounting for a **0.2% strain offset**. Create a new line that also shows $\sigma = E\epsilon$ (with the same slope E) but is shifted by 0.2% to the right (along the x-axis).

8. Given the 0.2% offset, the yield stress σ_y is defined as the stress where the offset line intersects with the stress-strain plot. Use your new offset line to determine σ_y from your graph (either visually or numerically). Express your answer in terms of MPa.
   Q: What value for σ_y do you calculate? ___________
   Q: A good estimate for the Young's modulus of steel is $250MPa$. How well does your result compare?