Structural Analysis of *Typha Latifolia*

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Abstract - The *Typha latifolia*, commonly known as the cattail plant, possess certain material properties that allow them to withstand a large amount of bending without the stem becoming fractured or damaged. The plant has a variety of uses. Research has been done on its ability to filter toxins, to be used as insulation, and its buoyancy capabilities, but structural research of the plant have not been previously recorded. This study focuses on the elasticity of the stem. The study of the plant structure is conducted by the application of knowledge primarily found from mechanics of materials. The three point bending theory was applied to determine the modulus of elasticity. The cattail stalks are subjected to a series of three point bending tests to obtain the material properties. The three point bend test is a proven method in obtaining material properties for many materials.

Keywords: Three point bending, Young's modulus, Cattail, Typha latifolia

BACKGROUND

The *Typha latifolia* stalks are typically about 9ft in height and often grow near bodies of water. Due to their ability to withstand significant wind forces, they are able to provide shelter and protection for animals. It is predicted that the elasticity and the cross sectional geometry of the stalk play key roles to the plant's unique set of structural capabilities. The application of techniques found from mechanics of materials assist in providing a relationship between the collected data found from testing and the theoretical formulas used to determine the material properties. Such studies on the plant are not formally recorded. Some important factors to consider during the following experiment are the complex nature of the biology of the plant, as well as the non-uniform elasticity, and cross sectional area along the entire stalk. These features require separate testing to be done at several sections of the stalk.

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THEORY

Materials are understood to be linear if they present a linear stress-strain relationship. All materials present a linear relationship given a low enough stress or strain. The Young's modulus *(E)* represents the relationship in the elastic range and measures the stiffness of the given material. The elastic range is defined as the material's recoverability after the removal of the external force, such as wind. The cattail plant exhibits a large amount of deflection and is able to recover back to its original position. In a three point bend test, the maximum deflection will occur where the load is applied. Using the deflection formula [1], *E* is determined as follows:

$$\delta = y_{max} = \frac{FL^3}{48EI} \qquad (1)$$

Where δ is the deflection, also known as the maximum y value in this case (y_{max}), *F* is the applied load, *L* is the distance between the supports, and *I* is the second moment of cross sectional area. The cross section of the plant is considered to be a hollow ellipse [2], which requires additional evaluation:

$$I = \frac{1}{64}\pi(BD^3 - bd^3) \qquad (2)$$

Where *B* is the outer major diameter, outer *D* is the minor diameter, *b* is the inner major diameter, and *d* is the inner minor diameter. Combining equations (1) and (2) and solving for *E* produces:

$$E = \frac{4FL^3}{3\delta\pi(BD^3 - bd^3)} \qquad (3)$$

Young's modulus is also defined as the slope of the elastic region in a stress versus strain curve:

$$E = \frac{\Delta\sigma}{\Delta e} \qquad (4)$$

Where σ is the stress and *e* is the strain. Materials are considered elastic to a certain *yield* point. Applying stress higher than the yield point, which is considered as the yield strength of a material, creates permanent deformation in a material where equations (3) and (4) are no longer valid. Figure 1 displays a typical load versus deflection curve, which is used in theoretical calculations to find the strain versus strain curve. As noted in the figure below, the linear portion is the elastic region and the portion past the yield point (*Y*) is the plastic region. The yield point can be found using the 0.2% offset method by drawing a line parallel to the linear line at 0.002 strain value.

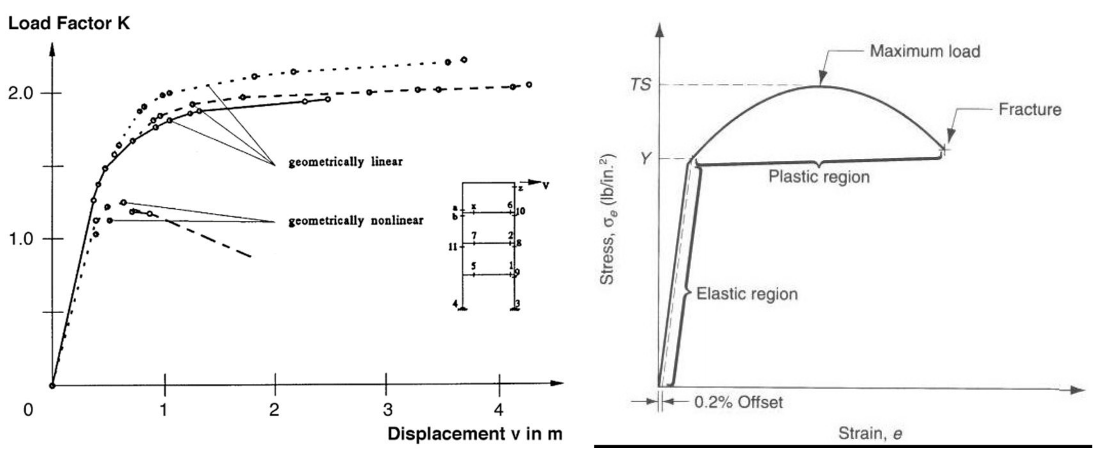

Figure 1. Typical load versus displacement [3] and stress versus strain [4] curves.

METHOD

The three point bend test is performed on small scale (10lb load cell) and on large scale (500lb load cell) equipment. The small scale would provide tighter precision of the measurements used to calculate the elasticity. The large scale serves two purposes: to determine the yield point, and to test the thicker samples. Equation (3) is valid under the thin beam condition assumption. To accommodate the thicker sections, the samples must be longer in length. The longer sections are not able to fit in the small scale equipment. The samples are supported at both ends and a load is then applied midpoint between the supports (Fig. 2). The equipment will measure and record the applied load and the deflection over a specified range. The distances between the supports on the small and large equipment are 2.487in and 5.118in, respectively. The data collected are used to determine the elasticity using equation (3).

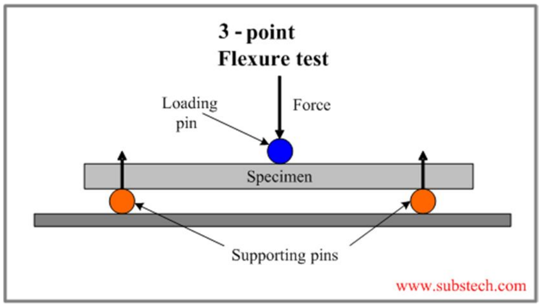

Figure 2. Three point bend test diagram

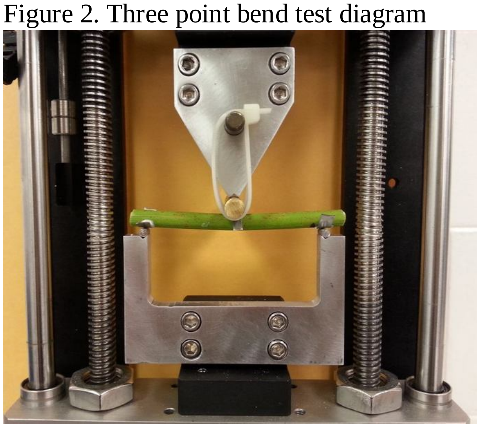
Figure 3. Small scale three point bend test equipment

The cattail plants were cut at the base as close to the ground as possible from its natural environment. The plant leaves were carefully cut off at the point of separation from its stalk (Fig. 4). The stalks were sectioned, being careful to minimize the stress due to shear. A stalk was sectioned and shaved to the inner core in order to test the plant's elasticity at the core. The sections were labeled and measured individually. The major and minor diameters were measured at two points along the section and the major and minor averages were taken for each section. The distance from the base of the plant to the midpoint of each section was noted as a reference to determine the exact location of each section. The samples were mounted with the minor diameter oriented in the vertical direction. Aluminum strips were lightly wrapped around the support and loading points on the samples in order to minimize local damage.

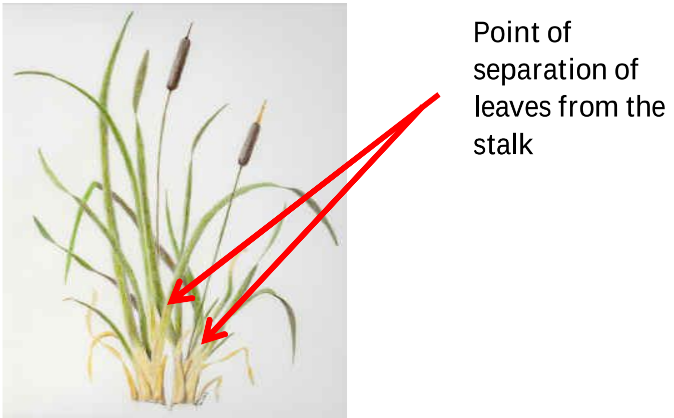

Figure 4. The leaves were cut at the point of separation instead of peeling them off. Pressure from peeling may introduce unwanted damage to the interior structure. Image from: http://pages.uoregon.edu/ecostudy/elp/ntfp/Cattails%20FINAL.htm

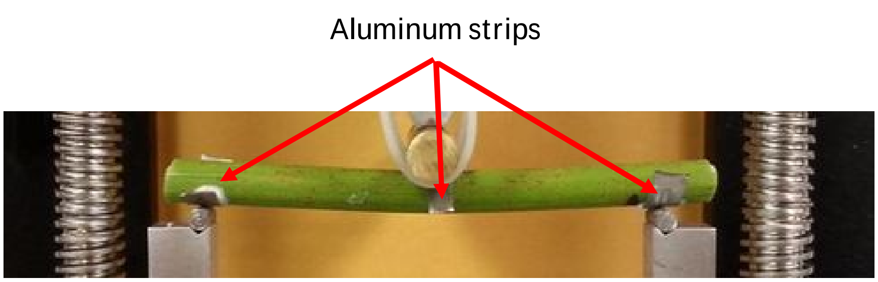

Figure 5. Aluminum strips minimize local damage

DATA

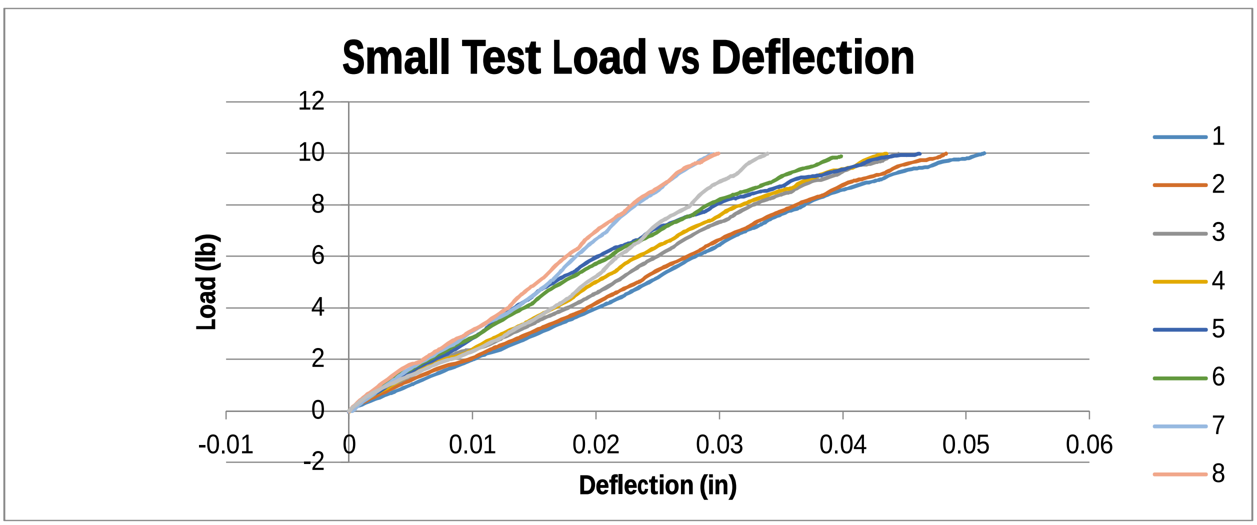

Figure 6. Load versus deflection plot with maximum load of 10lbs. Deflection is measured at the center of each sample where the load is applied.

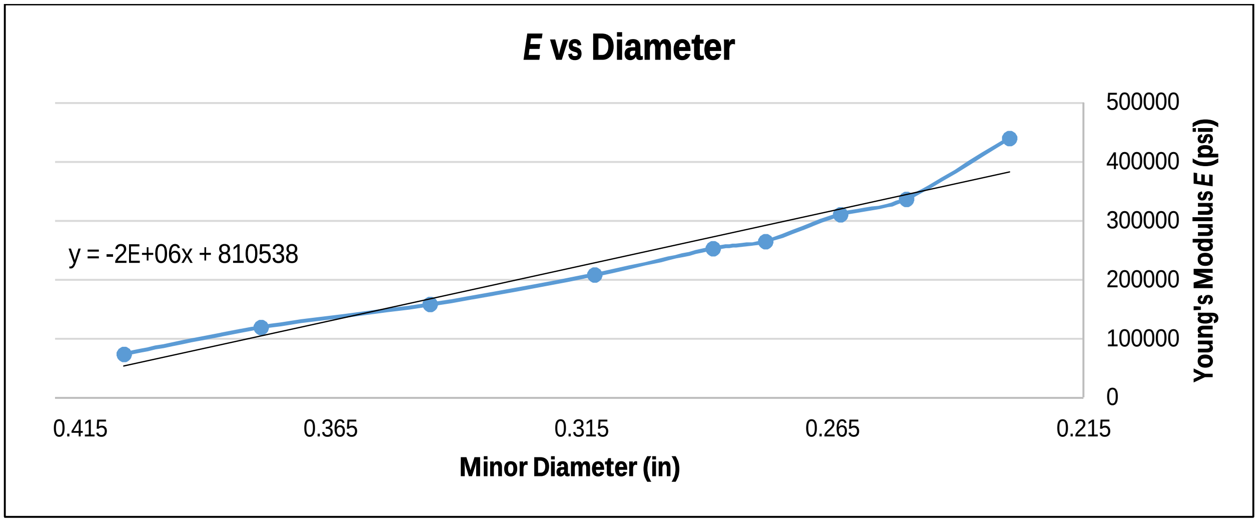

Figure 7. Small test Young's modulus determined from data in Figure 6 and equation (3). *E* increases with decreasing minor diameter size. Diameter shown in the graph is in reverse order for comparison with the following graph.

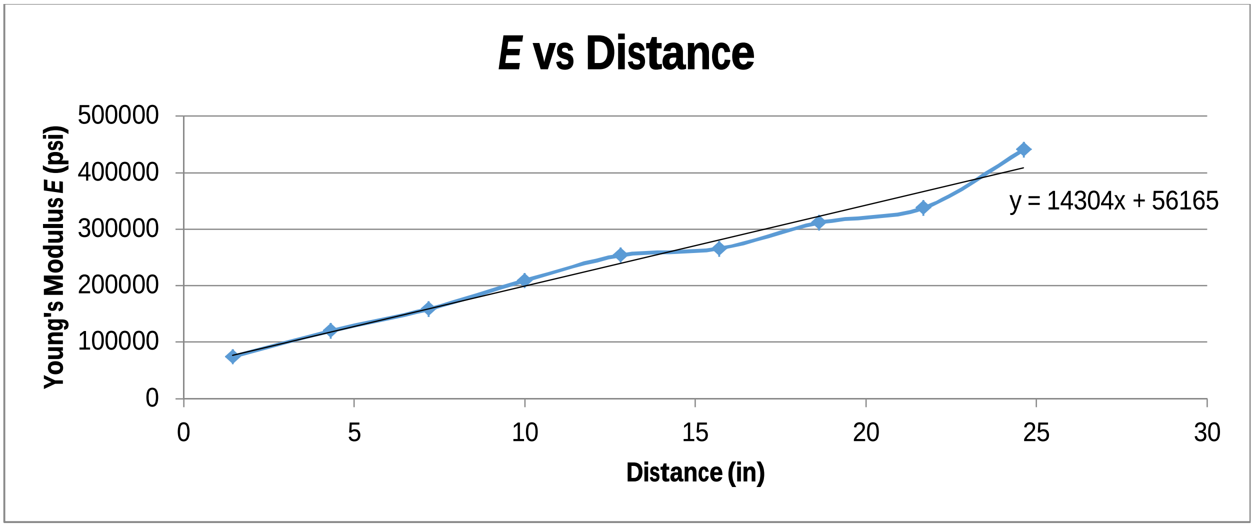

Figure 8. *E* increases towards the top of the plant. Distance is at the midpoint of each sample.

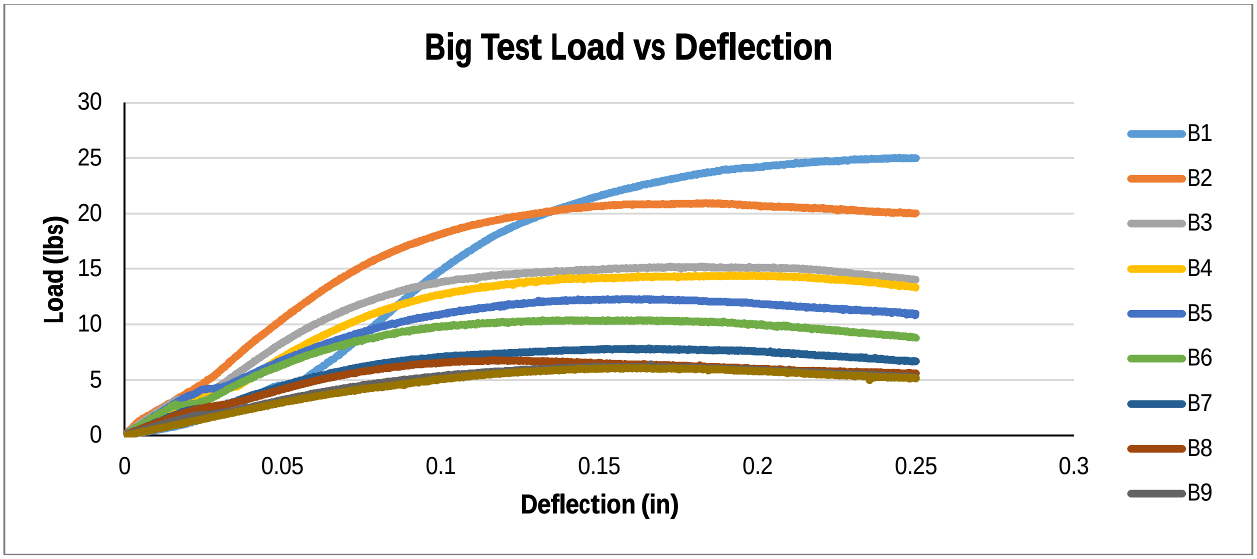

Figure 9. Load versus deflection plot with maximum output load of 25lbs. Deflection is measured at the center of each sample where the load is applied.

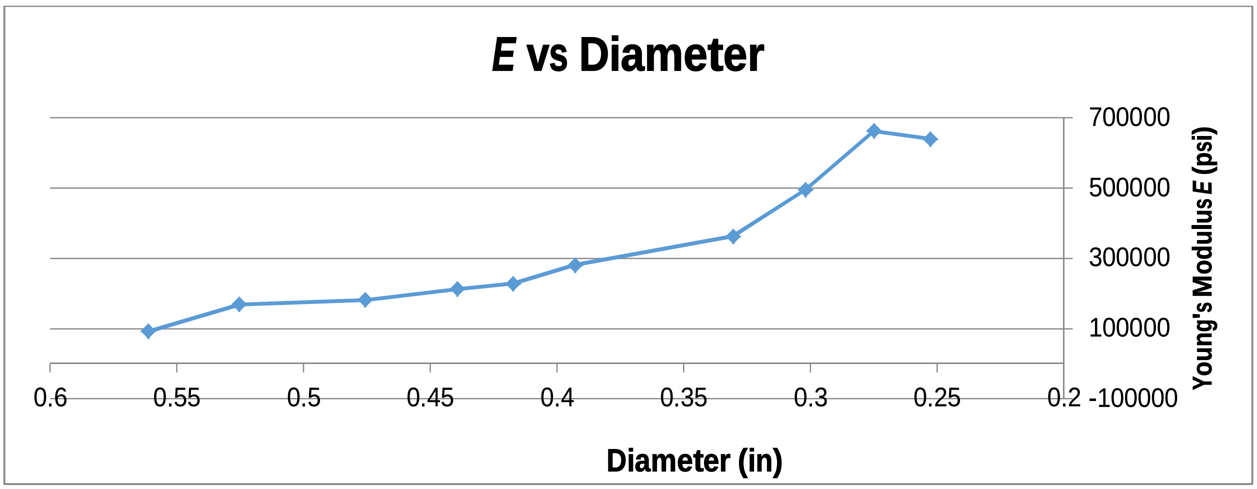

Figure 10. Big test Young's modulus determined from data in Figure 9 and equation (3). *E* increases with decreasing minor diameter size. Diameter shown in the graph is in reverse order for comparison with the following graph.

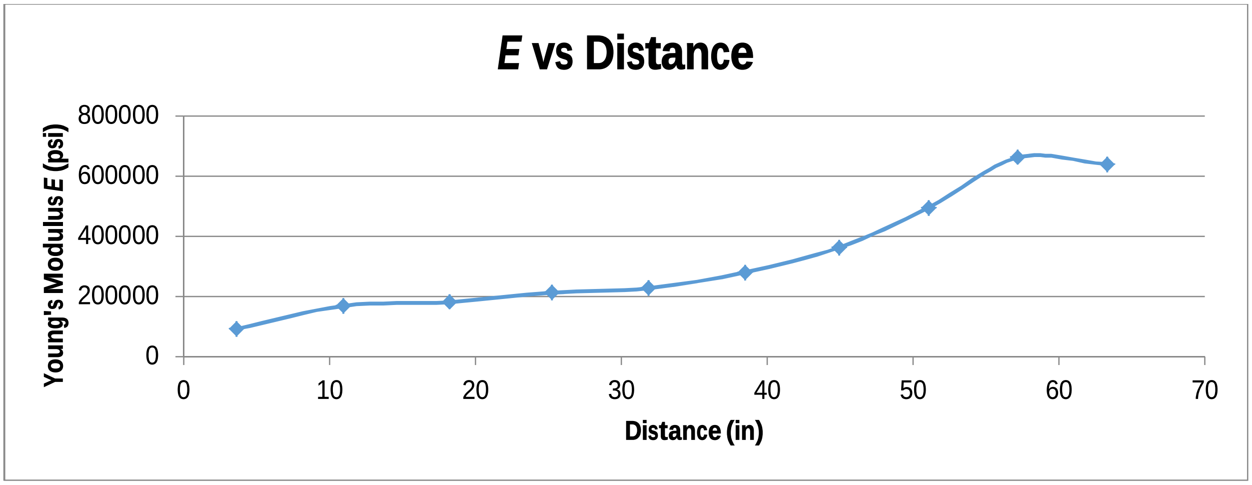

Figure 11. *E* increases towards the top of the plant. Distance is at the midpoint of each sample.

RESULTS

The small scale equipment maxes out at 10lbs, deflecting the samples no more than 0.052in. The specimen fully recovered after the removal of the load, indicating that plastic deformation did not occur. The load and deflection was obtained for each section in order to find the modulus of elasticity, with the average *E* taken to represent the entire section of the sample. The modulus of elasticity was found to be higher at the end with the smaller diameter, with the average *E* value of 435,168psi on the small test. The section with the largest diameter had a significantly lower average value of 63,680psi. The inner core was tested on the small scale equipment, as it required less than 1lb to deflect 0.25in. The average *E* for the core was substantially lower, with a value of 5,814psi. To obtain the yield point accurately, a larger load is required. The large scale equipment was used to deflect the samples 0.25in. The highest load output was found to be 25lbs. The yield point was not attainable from the test due to the stress versus strain curve produced from the data collected. The curve lacked the well-defined shelf as seen in Figure 1.

DISCUSSION

The modulus of elasticity varies widely along the cattail stalk. The value representing each section varies linearly, increasing towards the top end of the plant in the small test experiment. The higher value of *E* indicates that the core-to-outer skin ratio is smaller at top than the thicker, lower sections. The non-linear relationship obtained from the big test experiment is likely due to the equipment’s lack of precision in calculating a small load and deflection that was required for a fragile material, such as the cattail plant. An accurate finding of the yield point is inconclusive from this experiment. The elastic region of each sample is not distinguished well enough from the plastic region in order to deem the results sufficiently accurate.

CONCLUSION

One of the factors enabling the stalk to bend a substantial amount without fracturing is due to its soft core. Had the core have been the same material as the stem, the stalk would be much more rigid; increasing in strength but decreasing in the ability to deflect without fracture. Since the 10lb load cell was unable to cause permanent deformation, a load cell with higher output is required. The 500lb load cell is too high for this type of material, resulting in undesirable values. A 50lb load cell may provide the desired precision to determine additional material properties such as the yield strength of the cattail stalk.

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