MEMO

TO: Aunt Ada

CC: Prof. Webb

FROM: [redacted]

DATE: 9/25/15

RE: Finalized Treehouse Design and Analysis

This memo will summarize the finer points of the treehouse design, problems that arose in analysis of the previous design, and design modifications to account for these problems. These results will be in regard to the "Sustainably Saavy" treehouse design proposal.

Final Design

The final treehouse features a tapered trunk whose radius varies linearly from 2.2ft to 1.5ft. The structure is made out of beech, which has a density of 0.45kips/ft^2, a yield stress of 7.41ksi, and a Young's Modulus of 1720ksi. Since beech trees can typically have diameters of 3-5ft, the structure will have an aesthetic very similar to a real tree. The trunk will be hollowed out, with a wall thickness of 6in. This will leave adequate space for a geothermal heat pump should one wish to be installed. The entire structure has a factor of safety (FOS) of 4, which is typical in buildings.

Computational Analysis Tool

A MatLab script was utilized to perform the finite element analysis on the tree trunk. The trunk was divided into 35 sections (or 36 nodes), with a total of 6 forces acting upon the trunk at various distances. Those nodes located near a node were adjusted to align with the force, and so the section lengths are not uniform.

The base of the trunk was assumed to be fixed, and thus have no displacement. This was the only location whose behavior could be assumed, and so the reduced matrix only eliminated one row and column. The resulting displacements are shown in Figure 1.

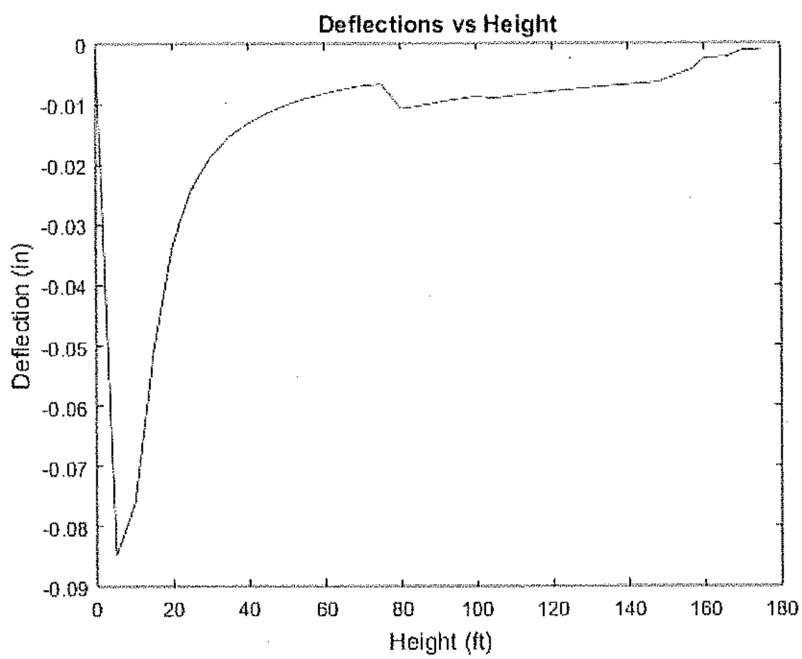

Figure 1
Deflections compared to height above ground for the trunk.

While the addition of the cable is shown in jumps in the deflections around 80ftand 100ft, the deflections at that point are not critical and so the cables' main effect is not to minimize displacement, but rather to play an instrumental role in the buckling analysis of the trunk. By adding the cables, and having them symmetrically aligned, the buckling equation for the bottom half of the trunk was assumed to be a better fit with n for both ends fixed, than n for a free top. While this is not the case because the deflection was not set to zero at those locations, this assumption is valid because the deflections around those points are very small (~0.01 in) without the added resistance from the stiffness of the cables. The maximum allowable force given the fixed end assumption is shown in Figure 2.

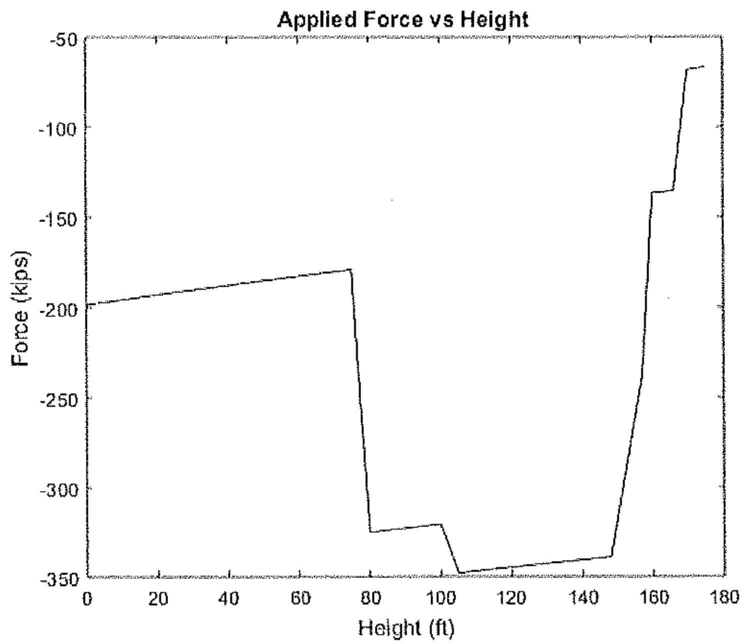

Figure 2
Applied force at the height above ground for the trunk.

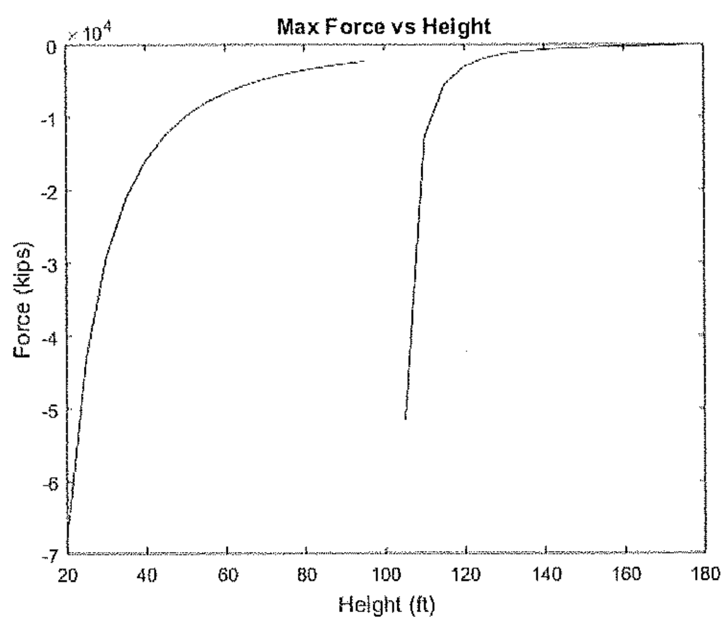

Figure 3
Applied force at heights throughout the trunk.

Comparing Figure 2 and Figure 3 shows that the addition of cables keeps the treehouse well away from buckling, with a factor of safety of 4. For the majority of the trunk, the maximum allowable force is an order of magnitude greater than the force being applied, and in some cases being two orders of magnitude greater than what is applied. The only location where the buckling force is within reasonable proximity to the applied force is at the very top of the trunk, where the buckling force with the factor of safety is -179kips, and at that location (the top) the force applied is only -66kips. Therefore, even at this location, the structure is well within the safe range.

Lastly, the final stresses in the structure end up being negligible in comparison to the yield stress, as was predicted in earlier calculations. The maximum magnitude of stress (with a FOS of 4) is 1.7525ksi, and the maximum stress that the trunk actually undergoes is -0.5ksi. Based solely on stresses, the structure is within safe limits to the point of almost being overdesigned.

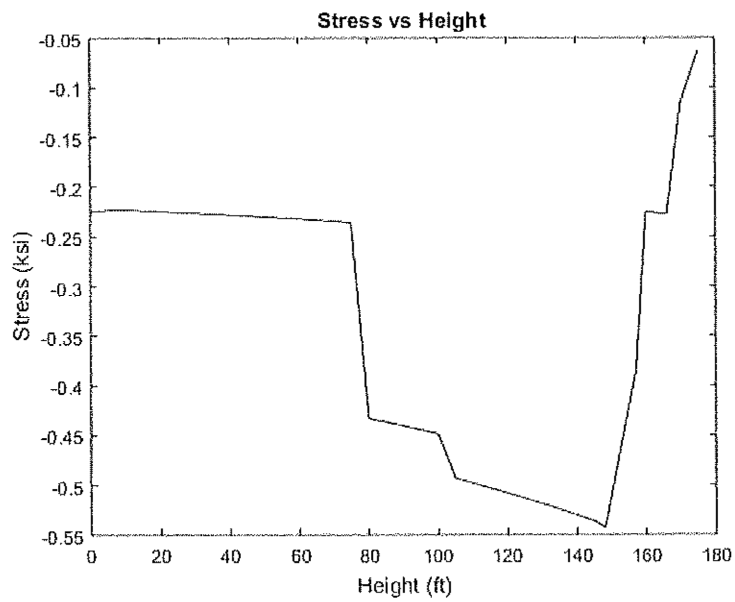

Figure 4
Stress at heights throughout the trunk.

Using this method of analysis provides for accurate calculations of an otherwise complicated trunk shape. In this analysis, the use of 35 nodes was not detrimental to the final calculations. The use of this number of nodes is only particularly relevant for the deflection and maximum force calculations, as they are the only equations that feature non-linear curves. While increasing the number of nodes would eliminate the linear segments in both graphs, the critical information was still well presented. For deflection, it is shown that the most effected node is at the base of the trunk, and that the deflection at the cables is small enough to allow for a fixed end assumption. For buckling, the graph demonstrates that the buckling force is well above that applied, and so refining the graph by increasing the nodes will not change the fact that the structure is within acceptable limits.

Material Analysis

From a strictly mechanical perspective, the use of American Beech Wood is highly reliable. The computational analysis shows the structure to be sound in terms of stresses, buckling force, and deflections. However, there are several benefits and drawbacks of this material that are not related to the mechanical properties.

The main reason that Beech was chosen was due to the environment in which the treehouse will be built. To attempt to match this environment, only locally found woods were considered to be used in the treehouse. The added benefit of the aesthetics of using local materials is that they are readily available. Among Yellow Birch, Beech, and Sugar Maple (all common in the Poconos), Beech was chosen for its high stiffness and strength, and its low density and cost. The cost of Beech is approximately $0.62/lb, bringing the total cost of the treehouse to $25,101.00. This is considerably less than the cost to build the structure out of steel; while stainless steel only costs $0.25/lb, it is over ten times as dense as Beech. Because the stiffness of steel is 16 times as great as wood, it would seem that choosing metal would not be a bad option; however, because it is so stiff, the trunk diameter could be so small as to make the user feel unsafe. Increasing the diameter to rectify this would hike up the cost substantially. Wood, therefore, seem a better option than metal for the given scenario in terms of price, aesthetics, and mechanical design.

However, there are several drawbacks to building the trunk out of wood. The first is that the final trunk would need to be treated with a waterproofing resin as the wood would be susceptible to the elements and the treehouse is designed to last for many years. While this would require extra labor to complete, the cost of the waterproofing material itself is negligible compared to the price of the entire treehouse. Another problem is the process of constructing such a trunk. To create a hollow, circular trunk with the given height would require a significant amount of woodworking; while much of it may be able to be machined, machining a piece of lumber this large as one unit is not practical by any means. This indicates that some type of joining will have to be used, and the effect of this on the structure will have to be determined.

Treehouse Summary

This multi-tiered, offset, balcony treehouse will be well suited to summer evening firework viewings, nature observance, and still embody sustainability. With a hollow trunk made of locally found Beech wood, the material will provide a natural aesthetic matching that of the Poconos which will not disrupt the habits of local wildlife, and even encourage its interaction. Should a geothermal heat pump be installed, this will be best done during construction. As a large concrete base will need to be dug in to support the trunk itself, the ground will have to be primed for digging. As such, installing the piping deep underground can simply be done before implementing the concrete base. The means of reaching the treehouse itself will be left to the choice of the user; the trunk design could have a staircase added to its exterior without greatly effecting the structure, or other means such as ladders could be employed that would be in keeping with the natural aesthetic. Adding an elevator inside the tree trunk is *not* currently an option for this design because of the need to add an access point from outside the trunk, to inside. An opening of this sort would cause a severe stress concentration that has not been accounted for. Because of the natural aesthetic of this tree trunk, as well as the careful integration of the treehouse atop it, this treehouse will be a safe and comfortable weekend getaway.