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ABSTRACT

The key characteristic of balsa wood is that it is lightweight, malleable, and has a high strength-to-weight ratio. A balsa structure was constructed with the goal of maximizing the overall strength-to-weight ratio which is calculated from stress and buckling analysis. This report demonstrates the design process for such a structure.

PROBLEM STATEMENT

An efficient structure is constructed using Cyanoacrylate glue and balsa wood. The objective of this project is to explore the light-weight and high strength-to-weight ratio material, balsa wood, and to compare analysis results with test results. This project provided the valuable experience of working in a group of engineers. From optimization using computer software to hands-on construction, the design process involves several fundamental engineering concepts.

The goal in designing this structure was to maximize failure load and minimize weight of the structure while adhering to several other requirements and geometric constraints. These requirements and geometric constraints are as follows. The size of individual balsa members cannot be changed, and the dimensions are as stated in Table-1. The laminations/overlapping joints are unlimited, no paint/stain are to be applied to the structure, and no curved sections are allowed. The total structure must weigh less than 0.15 lbf, the maximum allowable analysis load in either buckling or stress must be no more than 250 lbf, and the minimum load that the structure must handle is 10 lbf. As far as geometric constraints, the base of the structure can be no larger than a circular area of 20” in diameter. As shown in Figure-1, a cone shaped “keep out zone” is prompted with a base diameter of 12”, height of 15” and upper diameter of 5”. The efficient structure is placed in between the keep out zone and a 6” in diameter load plate, subjected with a force from a load rod.

DESIGN APPROACH

The design inspiration for this project was the Eiffel tower. The initial goal set by the team was to focus the applied load to specific sections of the structure so that bending would be minimized. Another goal was to make the structure symmetric, so it would carry loads evenly. Beams at an angle higher than 77˚ with respect to the base was found to be best for avoiding slipping.

The model was constructed in NX using lines to represent the sections that would contain beams in the structure. The lines were later meshed and merged using 1D element sections and each section was divided into 5 elements to allow for accurate buckling calculations. A RBE2 was used to simulate the uniform load from the load plate, the load is set to be 1 lb_f to ease scaling. The model’s profiles are described in *Table-2.* It is also important to note the reaction constraints towards the bottom of the design is not entirely fixed, therefore, they are only fixed in direction 1, 2 and 3.

Using NX and Nastran, the initial design was optimized by iteratively changing the structure and calculating the ratio of strength-to-weight after each iteration. In order to calculate this ratio, Finite Element Analysis (FEA) was performed using Nastran Solution 105 to obtain buckling, linear stresses as well as the overall mass of the structure. The equations used to calculate the maximum applied load on the systems are expressed as *Eqn. 1* for tensile and compressive strength and *Eqn. 2* for buckling.

The methods to increase the strength to weight varied depending on what condition would minimum the load. If failure was caused by high compressive stress, the system would be optimized by increasing the profile area, relocating nodes with high-stress concentrations, and by decreasing the number of smaller, diagonal members in the structure. If the failure was caused by buckling, more diagonal members were added, or the profile was changed to increase the moment of inertia of the member. If the failure loads surpassed the maximum load of 250 lbf, the structure was optimized by eliminating members or decreasing its cross-sectional area causing a reduction in mass.

After settling for the design, a convergence study was carried out to ensure accurate results. Number of members subjected on each line increased from 5 members up to 15 members.

RESULTS

After a series of design optimization, *Figure-2*, illustrates the final design. The FEA results from Nastran, both the maximum compressive and tensile stresses, and the first buckling mode of structure, are stated as the first three columns from *Table-3.* Besides a step-by-step calculation of strength-to-weight ratio, *Table-3* provides information about the convergence study carried out. Using *Eqn. 1* and *Eqn. 2*, the corresponding failure loads was calculated, as stated in *Table-3,* since bucking has a smaller maximum load, it is concluded that the structure would fail due to buckling. The deformation of structure is also illustrated in *Figure-3*. The mass of the entire structure was found to be 1.57E-4 lb_f-s^2/in through the f06 file. Dividing the maximum applied load with the weight calculated through *Eqn. 3*, the strength-to-weight of the design was then found. At the same time, results of strength-to-weight are consistent to around ± 70 under convergence study, it is concluded that results are reliable, and the expected strength-to-weight is around 4000.

MATHEMATICS

$$P_{ULTIMATE} = \frac{\sigma_{ULTIMATE}}{\sigma_{PEAK}} P_{APPLIED} \tag{1}$$

$$P_{CRITICAL} = \lambda P_{APPLIED} \tag{2}$$

$$Weight = Mass \times \frac{386\ in}{s^2} \tag{3}$$

FIGURES

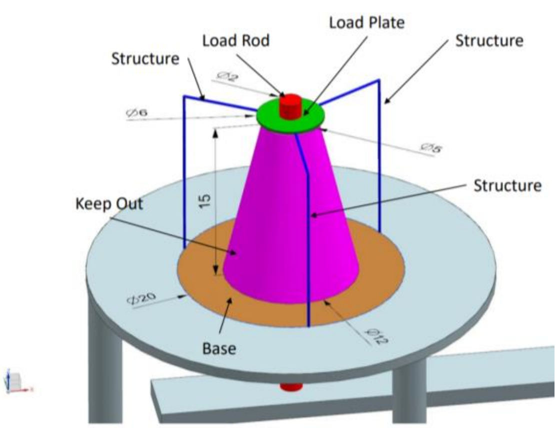


Figure 1. Structure Placement and Keep Out Zone

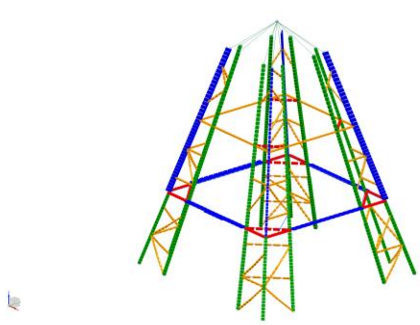


Figure 2. Final Structure Design

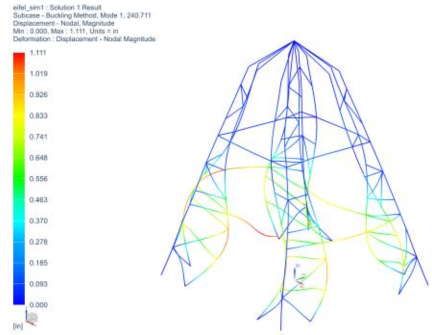


Figure 3. Buckling - Deformation

TABLES

TABLE 1
BALSA WOOD SIZES AND PROPERTIES

Dimensions (in)	Weight Density (lb_f / in^3)	Young's Modulus (psi)	Shear Modulus (psi)	Ultimate Strength (psi)
1/8 x 1/8 x 24	0.0065	0.55E6	0.25E6	1000
3/16 x 3/16 x 24				
3/32 x 3/32 x 24				
1/16 x 1/4 x 24				

TABLE 2
Members Profile Used for Designed Structure

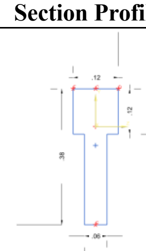
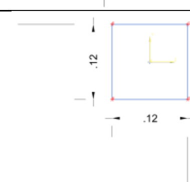
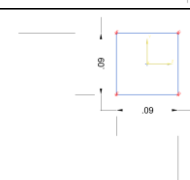
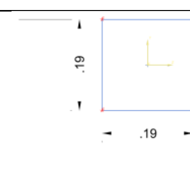
Cross Section	Section Profile	Section Area (in^2)
T-Beam		0.02734
1/8 x 1/8		0.01560
3/32 x 3/32		0.00293
3/16 x 3/16		0.01172

TABLE 3
Strength-to-weight

# of members / line	σ_{max} **(psi)**	σ_{min} **(psi)**	λ	**Mass (lbf - s²/in)**	P_{ULT} **(lbf) – fail in stress**	P_{CR} **(lbf) – fail in buckling**	P^* **(lbf)**	**W (lbf)**	**S/W**
5	1.07	3.608	253.467	1.57E-04	2.77E+02	2.53E+02	2.50E+02	6.06E-02	4123.3
Convergence Study									
10	1.322	-3.925	240.9	1.57E-04	2.55E+02	2.41E+02	2.41E+02	6.06E-02	3973.2
15	1.322	-3.925	240.7	1.57E-04	2.55E+02	2.41E+02	2.41E+02	6.06E-02	3969.9

ACKNOWLEDGMENTS
We stand on the shoulders of giants.

REFERENCES
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ANNEX A

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