

## Tower Project

### Description

This project gives students the chance to apply concepts learned in column analysis to the design of a structural system that carries primarily a compression load – a tower. Work is to be done in groups of four people. The project is divided into 3 parts: 1) initial conceptual design, 2) design development and testing, 3) final analysis and documentation.

### Goals

- to explore design parameters of geometry and material under compression.
- to develop a design of a compression member to meet the criteria below.
- to make some rough hand calculation to estimate the expected performance.
- to test the compression member and record the results.
- to document the results in a well organized and clear report format.

### Criteria

- The tower is to be made of wood. Either linear wood (sticks) or wood panels (sheets) can be used. Glue can be used to connect the elements. Gusset plates at the joints are allowed and can also be glued. But no steel pins or fasteners may be used.
- Wood: **any species. maximum cross-sectional dimension = 1/4"**.
- **NO Paper**, mylar or plastic or string or dental floss.
- If a member is made by laminating multiple pieces together, the maximum cross-sectional dimension or thickness still cannot exceed 1/4".
- The **height of the tower = 48"**.
- The tower **must hold at least 50 lbs.**
- The entire tower **can weigh no more than 4 oz.**
- The top of the tower must be loadable. The weights will be stacked on top of the tower, but you may optionally use a loose piece of MDF or plywood as a tray under the weights. (It will not be counted in either weight or load)
- Towers will be graded on their low weight, high load-carrying capacity, and the load/weight ratio. The evaluation formula is:  
$$(4/\text{weight in OZ}) + (\text{load in LBS}/50) + [(\text{load}/\text{weight})/12.5] \times 25$$
- The score will be normalized to a range of 50 to 100. It is used together with report scores to assess your project (a detailed evaluation form is given separately).

### Procedure

1. Develop a structural concept for a tower meeting the above criteria.
2. Analyze the design concept with either hand calculations or a computer program (e.g. Dr Frame)
3. Determine the capacity of the major members and of the overall tower (total capacity in LBS)
4. Estimate your expected score using the formula above.
5. Write the preliminary report.
6. Construct the structural model.
7. Test the model. 5-pound steel bars will be placed on top of the model, until the model fails. (bar size: 1 1/2" x 2" x 5 13/16").
8. Produce final report documenting requirements and process. See also score sheet.

### Due Dates

See Course Schedule

### Grade

Preliminary Report	40 pts
Testing	60 pts
Final Report	150 pts

## Tower Project – Preliminary Report

### Preliminary Report Requirements:

**Explanation** – describe how you developed your design, what the structural concept is, how you used the principles of column design to influence your decision process.

**Illustration** – include diagrams/drawings so that your structure can be understood in its entirety. At least a horizontal cross-section and an elevation of your column are required. Dimensions are to be included and the member sizes labeled.

**Analysis** – calculations should include the following:

- **Derivation of cross-sectional areas of each member** – all should be within the given requirements. This can be done as a second order analysis in Dr Frame or by hand (or Excel)  $C_P$  and  $F'_c$  (as we did using the NDS). This is a design project, so either assume a load on the tower of 50 lbs and calculate what cross-sectional areas are required for the members in order to meet that loading, or choose a target load value for the tower and assume that you are going to stress the members to the elastic limit (see  $F$  below), and calculate what cross-sectional areas will result with that stress in the members. Be very clear as to which method you are employing.
- **Predicted weight estimate of entire tower** – breakdown should include each member and take into consideration the weight of connections (i.e. glue, wood) – total should be under 4 oz.
- **Predicted Capacity** - predict the ultimate capacity in pounds that the *entire tower* can carry based on actual cross-sections chosen. Choose critical members (for example a vertical member) and calculate their capacity (check that  $f_c < F'_c$  based on the given allowable) in order to support your prediction.
- Separately **calculate the buckling capacity of the tower as a whole**. This is done by treating the tower as one column loaded at the top, made up in cross section of multiple columns. Show the moment of inertia of this cross section, and use it to calculate the critical buckling load using the Euler equation. An example of this will be covered in class.

Note: If an excel spreadsheet is used to make calculations for any portion of the analysis, make sure to provide the equations being used for each column in the table. If you used STAAD or Dr. Frame to do any of the above, include all requisite print-outs showing all values entered into and calculated by the program.

The Preliminary Design Proposal is worth 10% of the total score for this project. **SUBMIT ONLY ON 8½ X 11 PAPER. NO 11X17 PAPER SUBMISSIONS WILL BE ACCEPTED.** Once returned to you graded, save the original copy of the Preliminary report for submission with the Final Report.

Remember that the report is to be a professional document. Writing should be clear, grammatically correct, and language should be appropriate and professional. (*See Report Guidelines for more details.*) All calculations should be legible and clearly described – not just numbers or results but make it clear what you are calculating.

### Properties of Basswood:

Density (oven dry)	20 pcf *
E (buckling)	1,650,000 psi **
F (Compression    to grain)	4745 psi *
F (Compression ⊥ to grain)	377 psi *
F (Tension    to grain)	4500 psi (estimate)
F (Tension ⊥ to grain)	348 psi *
F (Shear    to grain)	986 psi *
F (Flexure)	5900 psi *

\* from <http://www.matweb.com/>

\*\* tested by PvB (small pieces in compression)

## Interim Report Grading Rubric

<b>Explanation</b> goal concept	<b>5 pts.</b>
<b>Illustrations:</b> cross-section elevation	<b>5 pts.</b>
<b>Member size derivation:</b> description of method actual calculations	<b>10 pts.</b>
<b>Weight estimate</b> total volume of wood density used estimate for glue	<b>5 pts.</b>
<b>Predicted capacity</b> individual member failure tower as a whole failure	<b>10 pts.</b>
<b>Overall Clarity and Presentation</b>	<b>5 pts.</b>
<hr/> <b>TOTAL</b>	<b>40 PTS.</b>

# Guidelines for Final Report

After tower testing is over and you begin to write the final reports, here are some guidelines to follow.

1. **Clarity of calculations:** Don't just show numbers but give equations and define variables. Make it legible. Either very neatly by hand or use an equation editor like in Microsoft Word. In Word, go to Insert->Object and select Microsoft Equation. In just a few minutes you should be able to get a hang of producing equations. It's pretty simple to use. If you use Excel make sure you label the equations – don't just show results.
2. **Quality of graphics.** You should have clear line-drawings from programs such as Illustrator, AutoCAD, or similar to produce dimensioned drawings of your models. If using Rhino, use the Make2D function to get clear illustrations. Photographs of your final model before and/or after testing will be required in addition to your drawings.
3. **Submit reports on 8-1/2" x 11" paper only.** Reports on 11x17 paper will not be accepted.
4. **Be clean, polished, and professional.** Write clearly, legibly, and with good grammar. Proofread your report before turning it in. Use appropriate professional language in your report. The mark of a good report is one that is easy to understand by someone not familiar with the project.
5. **Turn in the ORIGINAL graded copy of your Preliminary Report with your Final Report.**
6. In the Revised/Tested Tower section of the Final Report (as listed on the Tower Project Tally Sheet - Final Report Requirements), do all the listed calculations for your tower as tested. That is, you should be analyzing the tower that you actually built and tested. This is not a reiteration of the Preliminary Report. We expect that certain changes were made from the preliminary design in your final design.
7. In calculating the overall tower buckling (buckling of whole tower as opposed to individual member buckling), you should use the Moment of Inertia (I) for the tower as a whole. I is taken from the tower cross-section ignoring any cross bracing (only primary vertical members). Using that value for I, you then apply the Euler Buckling Equation, using  $K = 1.0$  (this assumes the mass of the load has an inertial force that holds the top in place at the moment of buckling).
8. Mechanical properties for basswood, are given on the preliminary requirements sheet. If you used materials other than basswood, show what values you used for E, F and density. Cite your sources.
9. Throughout your report, check that your numbers are reasonable. If you get, for example, a predicted load capacity of 70 kips, you probably did something wrong.

**(Note: re-submit your Pre-Test Design Proposal with your Final Report.)**

In addition to the specific categories below, up to 10 pts may be withheld for a lack of clarity or professional quality in the overall delivery of the report. **8.5"x11" PAPER ONLY!**

<b>PRELIMINARY REPORT (re-submit original)</b>	<b>40</b>	
<b>TESTING</b>	<b>60</b>	
Tower weight $\leq$ 4oz (15 pts); height = 48" (5 pts); holds $\geq$ 50 lbs (5 pts)	30	
Correct Materials (5 pts) (scaled if doesn't meet requirements)		
Efficiency $(4/\text{weight OZ}) + (\text{load in LBS}/50) + [(\text{load}/\text{weight})/12.5] \times 25$ (scaled based on class rank)	30	
<b>FINAL REPORT REQUIREMENTS</b>	<b>150</b>	
<b>Preliminary Design Development</b>	<b>20</b>	
How cross-sectional design of preliminary tower was chosen	4	
How elevation of preliminary tower was developed (e.g. bracing, taper, etc.)	4	
Why/how cross-section was or was not adjusted from preliminary report	4	
Why/how elevation of tower was or was not adjusted from preliminary report	4	
Discussion of how basic principles of columns supported these decisions	4	
<b>Revised/Tested Tower Design Analysis [SHOW WORK AND UNITS!]</b>	<b>50</b>	
Calculated/modeled axial forces and derivation of required member cross-sectional areas from axial forces (consider both crushing and buckling)	10	
Estimated weight calculation using actual member sizes used – include weight from members, glue, and gussets, etc.	7	
Member properties table (A, I, r, slenderness ratio)	7	
Indicate critical member (where failure was anticipated)	8	
Tower stability (as a whole) - buckling calculation	8	
Prediction of capacity of tower and mode of failure	10	
<b>Illustration of Final/Tested Design</b>	<b>20</b>	
Cross-section and elevations(s) of tower	5	
Perspective(s) or isometric of tower (no screenshots!)	5	
Overall dimensions labeled (height, width, etc.) with units	5	
Member sizes labeled (cross-sectional area, length of vertical members and cross-bracing) with units	5	
<b>Testing Results</b>	<b>30</b>	
Final weight and height of tower	6	
Tested capacity of tower	6	
Observations of testing (loading, any buckling observed, etc.)	6	
Description of mode of failure	6	
Images of failure	6	
<b>Post-Testing Analysis</b>	<b>30</b>	
Comparison of testing results with predicted capacity and modes of failure	10	
Discussion of discrepancies between results	10	
Suggested improvements for future designs with reasoning discussed	10	
<b>FINAL GRADE</b>	<b>250</b>	

**(Note: re-submit your Preliminary Design Proposal with your Final Report.)**