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/weight in OZ) + (load in LBS/50) + (load LBS/weight OZ)x1.5

- 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 ½" 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 Requirements

Explanation – describe how the design was developed, the basis of the structural concept, and how the principles of column behavior influenced the design decisions.

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

Analysis – the report should include the following:

- **Choose wood type and stress properties**. Either use values below for typical model grade Basswood or use values in the NDS or find test values online. Indicate in the report which values you choose.
- **Determine the cross-sectional area of each member**. Find the axial force P and the allowable stress F'c. The force P can be determined either by a hand calculated truss analysis or as a second order analysis in Dr. Frame or STAAD.Pro. The stress F'c should be found using the NDS equations for C_P and F'c. Other NDS stress adjustment factors (C_D, C_M, C_t, C_F and C_i) can be taken equal to 1.0. Size members based on the predicted load, P and the allowable stress F'c. Target (or predict) some total capacity load for the tower. A minimum of 50 LBS is required. Then size the members based on the force in each member.
- **Predict the total weight of the tower**. Provide a table with each member type showing, length, section and weight for each. Make an estimate of the weight added by glue joints and/or gusset plates. The total weight should be under 4 OZ.
- **Predict Capacity**. Predict the ultimate capacity in pounds that the entire tower can carry based on the actual cross-sections chosen. Produce a utilization table to show for each member type (e.g. main vertical, horizontal tie, diagonal brace) the utilization ratio fc/F'c based on the predicted total capacity load. This ratio should be below 1.0 for all members.
- **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 the tower cross-section, and use it to calculate the critical buckling load using the Euler equation. An example of this calculation is given in the slides from the class lecture. The ultimate capacity is the lower of the two capacities (critical member or tower as a whole).

Note: If an excel spreadsheet is used to make calculations, provide the equations being used for each cell or column in the table. If STAAD.Pro or Dr. Frame is used to do any of the above, include print-outs showing the applied loads and resulting member forces.

Format - Reports should be formatted for **8½ X 11** paper. 11X17 format reports will not be accepted. Once returned to you graded, **save the original copy of the preliminary report** for submission together with the Final Report.

The report is a professional document. Text should be clear, grammatically correct, and language should be appropriate and professional. All calculations should be legible and clearly described – not just numbers or results, but with a clear description of what is being calculated included.

Properties of Basswood: (like in the Media Center)

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)

Peter von Buelow

Preliminary Report Grading Rubric

Your interim report should address these points:

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

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 bucking (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 Bucking 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.

Architecture 324 **Group_____**

Structures II **Tower Project Tally Sheet** Winter 2019

(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!**

PRELIMINARY REPORT (re-submit original)	**40**	
TESTING	**60**	
Tower weight ≤ 4oz (15 pts); height = 48" (5 pts); holds ≥ 50 lbs (5 pts) Correct Materials (5 pts) (scaled if doesn't meet requirements)	30	
Efficiency (4/weight OZ)+(load LBS/50)+(load LBS/weight OZ)x1.5 (scaled based on class rank)	30	
FINAL REPORT REQUIREMENTS	**150**	
Preliminary Design Development	**20**	
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	
Revised/Tested Tower Design Analysis [SHOW WORK AND UNITS!]	**50**	
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, utilization ratio)	7	
Indicate critical member (largest utilization ratio)	8	
Tower stability (as a whole) - buckling calculation	8	
Prediction of capacity of tower and mode of failure	10	
Illustration of Final/Tested Design	**20**	
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	
Testing Results	**30**	
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	
Post-Testing Analysis	**30**	
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	
FINAL GRADE	**250**	

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