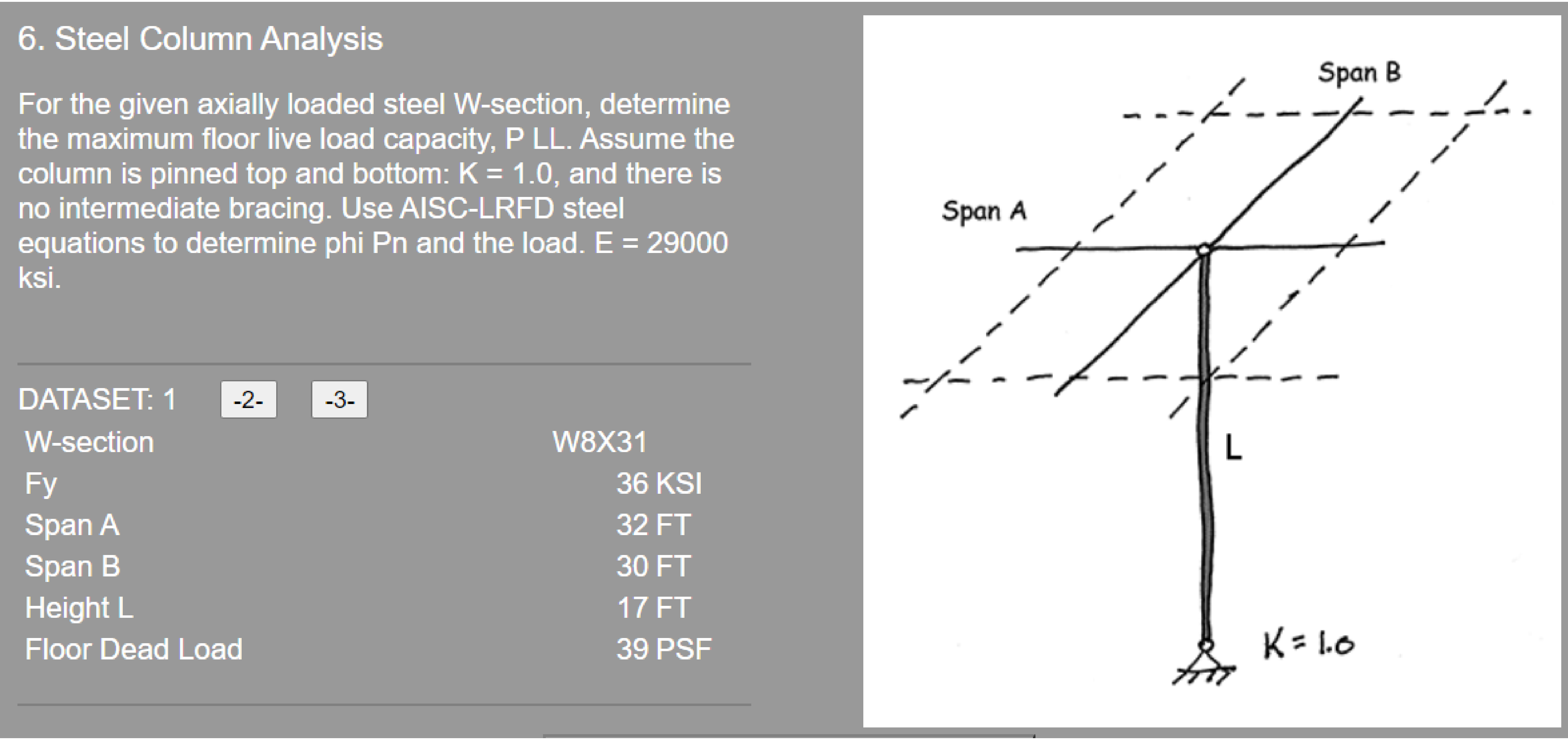
Recitation 6

Steel Column Analysis

Homework problem

Steel Column Analysis



6. Steel Column Analysis

For the given axially loaded steel W-section, determine the maximum floor live load capacity, P LL. Assume the column is pinned top and bottom: K = 1.0, and there is no intermediate bracing. Use AISC-LRFD steel equations to determine phi Pn and the load. E = 29000 ksi.

DATASET: 1 -2- -3-

W-section	W8X31
Fy	36 KSI
Span A	32 FT
Span B	30 FT
Height L	17 FT
Floor Dead Load	39 PSF

Q6) Steel Column Analysis

→ Given :-

① Axially loaded steel W-section

② Column pinned on top } (Assume)
and bottom

③ K = 1

④ No intermediate bracing.

⑤ E = 29000

⑥ W section :- 8 × 31

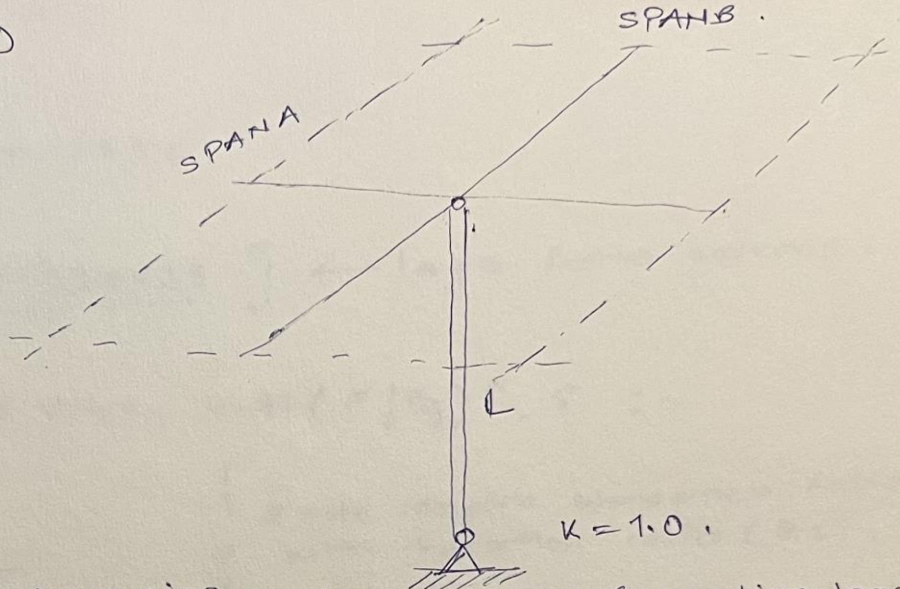
⑦ Fy = 36 KSI

⑧ Span A = 32 FT

⑨ Sqpan B = 30 FT

⑩ Height L = 17 FT

⑪ Floor Dead load = 39 PSF



To determine :- the maximum floor live load capacity (P_{LL}).

Q.) Total unfactored floor dead load on column :-

$$DL_{KIPS} = \text{Floor Dead load} \times \text{Area}$$

$$= DL_{PSF} \times \text{Span A} \times \text{Span B} \times \frac{1\ KIP}{1000\ LB}$$

$$= 39 \times 32 \times 30 \times \frac{1}{1000} = 37.44\ KIPS.$$

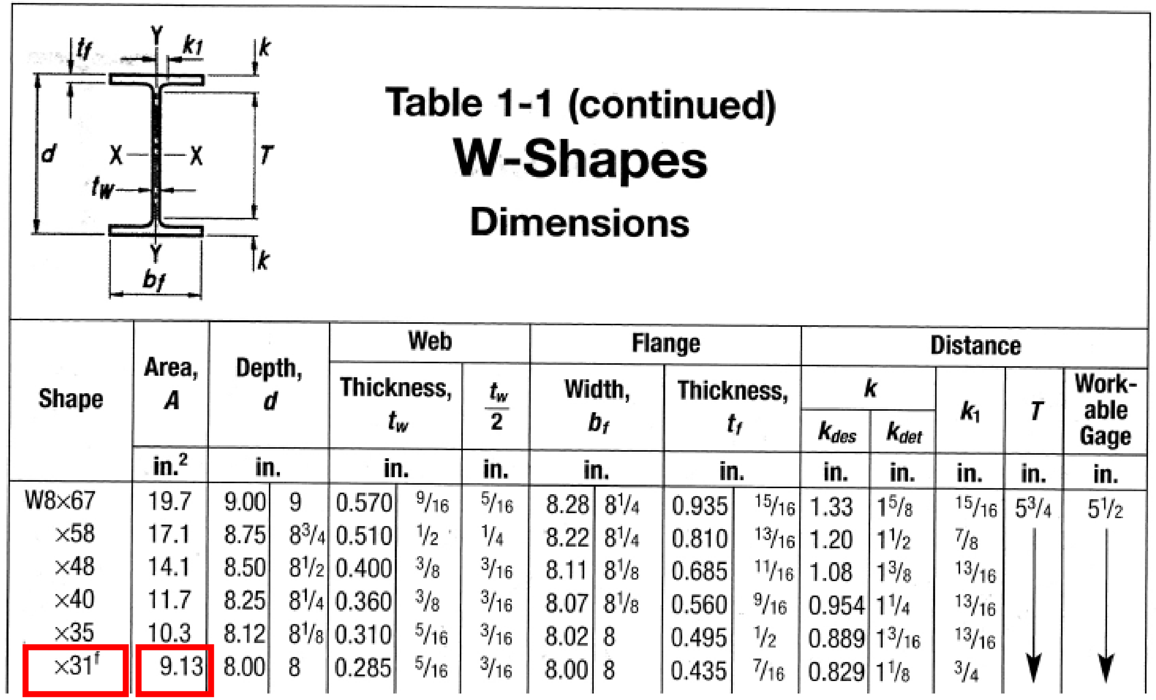


Table 1-1 (continued)
W-Shapes
Dimensions

Shape	Area, A	Depth, d		Web			Flange				Distance				
				Thickness, t_w		$\frac{t_w}{2}$	Width, b_f		Thickness, t_f		k		k_1	T	Workable Gage
											k_{des}	k_{det}			
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W8×67	19.7	9.00	9	0.570	$\frac{9}{16}$	$\frac{5}{16}$	8.28	$8\frac{1}{4}$	0.935	$\frac{15}{16}$	1.33	$1\frac{5}{8}$	$\frac{15}{16}$	$5\frac{3}{4}$	$5\frac{1}{2}$
×58	17.1	8.75	$8\frac{3}{4}$	0.510	$\frac{1}{2}$	$\frac{1}{4}$	8.22	$8\frac{1}{4}$	0.810	$\frac{13}{16}$	1.20	$1\frac{1}{2}$	$\frac{7}{8}$	↓	↓
×48	14.1	8.50	$8\frac{1}{2}$	0.400	$\frac{3}{8}$	$\frac{3}{16}$	8.11	$8\frac{1}{8}$	0.685	$\frac{11}{16}$	1.08	$1\frac{3}{8}$	$\frac{13}{16}$		
×40	11.7	8.25	$8\frac{1}{4}$	0.360	$\frac{3}{8}$	$\frac{3}{16}$	8.07	$8\frac{1}{8}$	0.560	$\frac{9}{16}$	0.954	$1\frac{1}{4}$	$\frac{13}{16}$		
×35	10.3	8.12	$8\frac{1}{8}$	0.310	$\frac{5}{16}$	$\frac{3}{16}$	8.02	8	0.495	$\frac{1}{2}$	0.889	$1\frac{3}{16}$	$\frac{13}{16}$		
×31^f	9.13	8.00	8	0.285	$\frac{5}{16}$	$\frac{3}{16}$	8.00	8	0.435	$\frac{7}{16}$	0.829	$1\frac{1}{8}$	$\frac{3}{4}$		

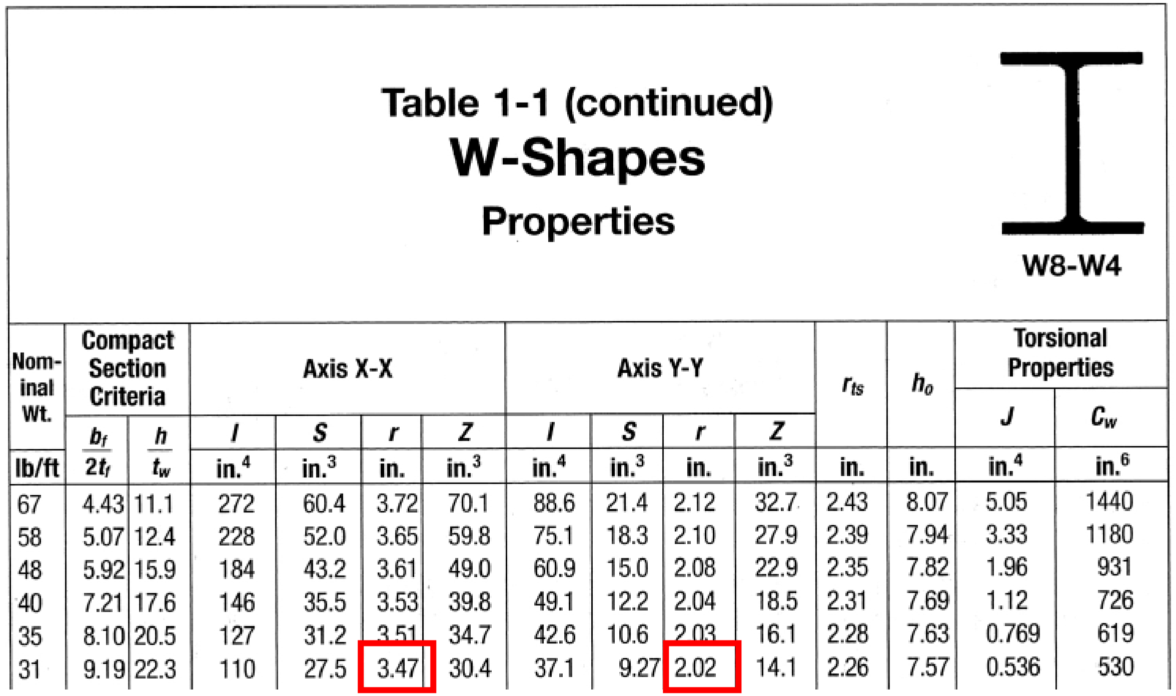


Table 1-1 (continued)
W-Shapes
Properties

W8-W4

Nominal Wt.	Compact Section Criteria		Axis X-X				Axis Y-Y				r_{ts}	h_o	Torsional Properties	
	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	I	S	r	Z	I	S	r	Z			J	C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
67	4.43	11.1	272	60.4	3.72	70.1	88.6	21.4	2.12	32.7	2.43	8.07	5.05	1440
58	5.07	12.4	228	52.0	3.65	59.8	75.1	18.3	2.10	27.9	2.39	7.94	3.33	1180
48	5.92	15.9	184	43.2	3.61	49.0	60.9	15.0	2.08	22.9	2.35	7.82	1.96	931
40	7.21	17.6	146	35.5	3.53	39.8	49.1	12.2	2.04	18.5	2.31	7.69	1.12	726
35	8.10	20.5	127	31.2	3.51	34.7	42.6	10.6	2.03	16.1	2.28	7.63	0.769	619
31	9.19	22.3	110	27.5	3.47	30.4	37.1	9.27	2.02	14.1	2.26	7.57	0.536	530

Q2) Controlling Slenderness Ratio :-

$$\left.\begin{aligned} A &= 9.13 \text{ in}^2 \\ r_x &= 3.47 \text{ in} \\ r_y &= 2.02 \text{ in} \end{aligned}\right\} \text{Table 1.1}$$

$$\frac{L_x}{r_x} = \frac{17}{3.47} \times \frac{12 \text{ in}}{1 \text{ FT}} = 58.7896$$

$$\frac{L_y}{r_y} = \frac{17}{2.02} \times \frac{12 \text{ in}}{1 \text{ FT}} = \underline{100.990099} \; \} \leftarrow \text{larger Ratio governs.}$$

Q3) Transition slenderness ~~Ratio~~ value, 4.71 (E / Fy) ^ .5 :-

$$\text{Tratio} = 4.71 \sqrt{E/F_y}$$

$$= 4.71 \sqrt{\frac{29000 \text{ KSI}}{36 \text{ KSI}}}$$

$$= 133.680.$$

* note compare slenderness Ratio (Q2) with transition ratio (Q3).

if $Q_2 < Q_3$, you have short column.

if $Q_2 > Q_3$, you have long column.

since $100.99 < 133.68$, in my case it is a short column.

Q4) Euler stress, Fe :-

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} = \frac{\pi^2 \times 29000 \text{ KSI}}{(100.990099)^2} = \frac{286218.527}{10199.00009}$$

$$= 28.0633 \text{ KSI}$$

Q5) Critical stress, F_{cr} :-

* see question 3 to determine if you have shorter or long column

for short column :- $F_{cr} = \left[0.658^{F_y/F_e}\right] F_y$ ← For this case we'll use this formula

for long column :- $F_{cr} = 0.877\ F_e$

$$F_{cr} = \left[0.658^{36/28.0633}\right] 36$$

$$= \left[0.658^{1.281}\right] 36$$

$$= 21.0436 \text{ ksi}$$

Q6) Nominal strength, P_n

$P_n = F_{CR} \times A_g$ ← AISC Table 1.1 (from Q2).

$= 21.0436 \times 9.13$

$= 192.1284$ KIPS.

Q7) Factored Nominal strength, ϕP_n :-

$\phi P_n = 0.9 \times P_n$

$= 0.9 \times 192.1284 = 172.91556$ KIPS.

Q8) unfactored live load on column (actual total LL) :-

$$\phi P_n = 1.2\ DL_{KIP} + 1.6\ LL_{KIP}$$

$$1.6\ LL_{KIP} = \phi P_n - 1.2\ DL_{KIP}$$

$$LL_{KIP} = \frac{\phi P_n - 1.2\ DL_{KIP}}{1.6} = \frac{\overset{(Q7)}{172.91556} - 1.2(\overset{(Q1)}{37.44})}{1.6}$$

$$= \frac{172.91556 - 44.928}{1.6}$$

$$= 79.9922 \text{ KIPS}$$

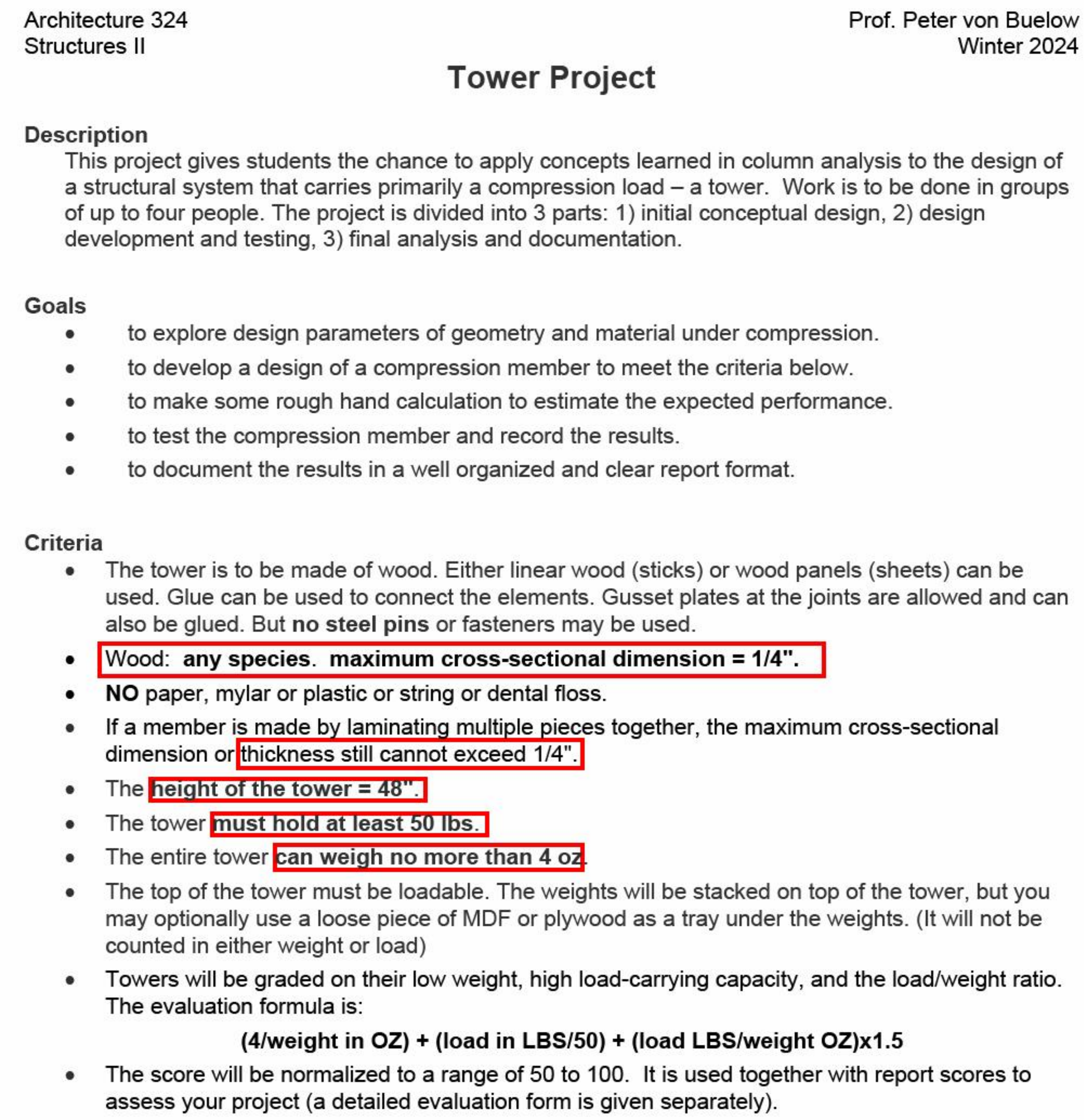
Q9) Actual unfactored live load :-

$$LL_{psf} = \frac{LL_{KIP}}{\text{Area}} = \frac{LL_{KIP}}{\text{span A} \times \text{span B}} \times \frac{1000 \text{ LB}}{1 \text{ KIP}}$$

$$LL_{psf} = \frac{79.9922}{32 \times 30} \times \frac{1000}{1}$$

$$= \frac{79992.2}{32 \times 30} = \frac{79992.2}{960} = 83.32520 \text{ PSF.}$$

Tower project report



Architecture 324
Structures II

Prof. Peter von Buelow
Winter 2024

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 up to four people. The project is divided into 3 parts: 1) initial conceptual design, 2) design development and testing, 3) final analysis and documentation.

Goals

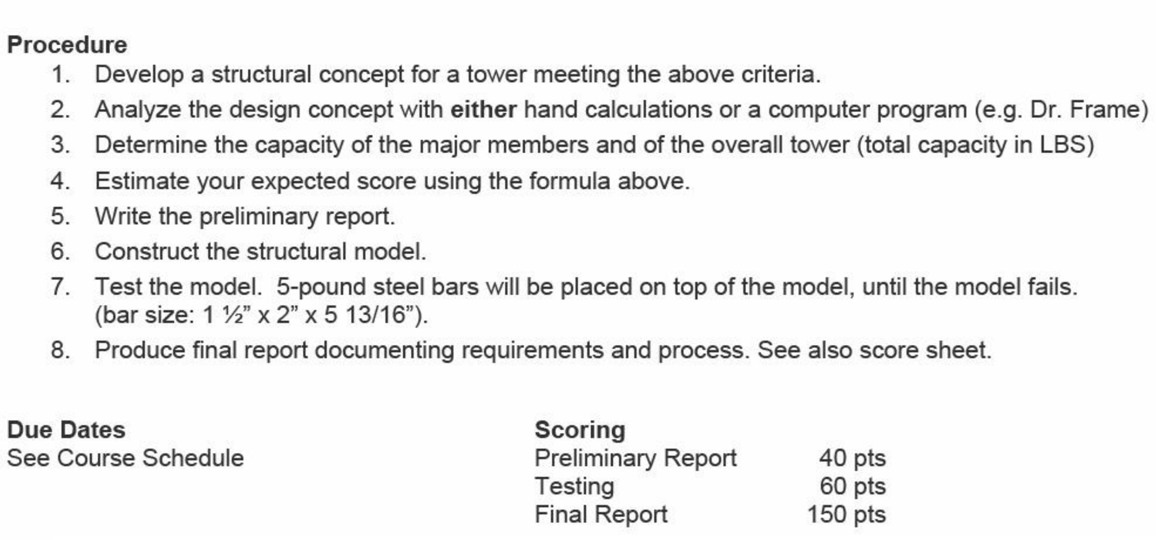
- to explore design parameters of geometry and material under compression.
- to develop a design of a compression member to meet the criteria below.
- to make some rough hand calculation to estimate the expected performance.
- to test the compression member and record the results.
- to document the results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

Scoring

Preliminary Report	40 pts
Testing	60 pts
Final Report	150 pts

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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, show 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)

Pointers that can be covered in the report:-

- Types of precedents you looked at (may be inference of that) (some references can be given based on the learnings from precedents) (you can also refer previous project and analyze which is the best suited solution for your case)
- Chose wood type
- cross sectional dimension of tower
- Dimension of Column (cross section)
- Dimension of diagonal bracings (cross section)
- Dimension of horizontal bracings (cross section)
- Weight of members (total weight of tower should be under 4OZ)

Pointers that can be covered in the report:-

- Explanation for type of cross section used. (why you chose a certain type of cross section for tower)
- Type of joints you are planning to use / design (for the members)
- Illustration of Elevation and cross section (showing dimensions)

Analysis :-

- Derivation of cross sectional areas of each member
- Predicted weight estimate of entire tower
- Predicted capacity (vertical members, tower as whole (moment of inertia / critical buckling load).

Step 1:- Determine cross sectional area of each member :-

(Things you'll require for project).

- Calculate Allowable stress :- (F_c')

$$F'_c = F_c \text{ (Given)} \times C_p \text{ (calculated)}.$$

$$\left\{ F_c' = F_c \times (C_D, C_M, C_t, \ldots, C_F). \right.$$

- Use $A = P/F'_c \longrightarrow$ this will give estimated A.

- Pick the dimensions of materials with cross sectional area bigger than estimated A.

- Again calculate capacities for members.

$\downarrow$

(Buckling and crushing)

$$C_p = \frac{1 + (F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1 + (F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}}$$

$$F_c^* = F_c \text{ (given).}$$

- All factors except $C_p = 1$
- $L_e = K \times L$

$(K = 1)$ $\therefore$ $L_e = L$

$$F_{cE} = \frac{0.822 \times E'_{min}}{(l_e/d)^2}$$

use $E = E_{min}$ (given in Question)

Buckling load :-

$$P_{cr} = \frac{\pi^2 A E}{(KL/r)^2} = \frac{\pi^2 I E}{(KL)^2}$$

Crushing load. :-

$$P_{max} = F_c \times A$$

Analysis	Capacity	Design
$f_c = \frac{P}{A} \le F'_c$	$P = F'_c A$	$A = \frac{P}{F'_c}$

1) Vertical member Buckling Capacity :-

- $u = 1$ (given).
- Calculated l_e/d. (limit $= 50$).
- $F_{cE} = \dfrac{0.822\, E_{min}}{(l_e/d)^2}$
- $F^*_c = F_c$ (given)
- F_{cE}/F^*_c
- $C_p = \dfrac{1+(F_{cE}/F^*_c)}{2c} - \sqrt{\left[\dfrac{1+(F_{cE}/F^*_c)}{2c}\right]^2 - \dfrac{F_{cE}/F^*_c}{c}}$
- $F'_c = F_c \times (C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_i \cdot C_p)$ (take all factors $= 1$ except C_p).
- $P = F'_c \cdot A$

Per_ members.

Buculing capacity of Tower as whole :-

- $I = \Sigma I + \Sigma Ad^2$ → $\left(I = \frac{bh^3}{12} \right)$. } → if you muiltply this by 4, you will get value for whole tower (Note: each term should be muiltiplied by 4).

- $r = \sqrt{\frac{I}{A}}$. ← } Muiltple this by 4 to get ans. for whole tower

- $\frac{Kl}{r}$ ← equal to 1

- $P_{cr} = \frac{\pi^2 AE}{(KL/r)^2}$ ← Take this as the same in given data

} P_{cr} _ Tower

To calculate P_{cr} for each column :- divide it by 4.

$\frac{P_{cr}}{4}$ = give value for each column.

Predict the ~~total~~ weight of tower :-

Given limit of weight of tower = 4 oz

Member weight = Volume × Density ← given.

= Cross sectional area × length × Density

Cross sectional area ↑ member used

length ↑ Depends on your dosity

Density ↑ given.

include all the obtained value in a Table.

	size (in) (cross section)	Total length (in)	Basswood properties (lb/ft^3)	cross section area	weight	volume
column.						
horizontal bracing						
diagonal bracing.						
Glue						
if more members are used						
Total						

Dr. Frame

Settings to ensure in doctor frame :-

1) **Set units** :-
   - a) Length = in
   - b) Elastic modulus = psi
   - c) Force = lb
   - d) Moment = ft-lb
   - e) Distributed load = lb/ft
   - f) stress = psi

2) **Grid** :-
   - dx, dy → 2, 2
   - origin → -2, -2

(*) Keep snapping on.

(*) Try and draw truss on the scale of cross section dimension of tower you chose

(*) Add supports (to avoid unstable view port).

(*) **Auto truss** :- in modelling tab $\xrightarrow[\text{control}]{\text{you can}}$ shape, Bracing, Number of panels, Total width, Total Height, Grid spacing

(*) turn diagrams off from plots tab.

Materoal property :- 1) Elastic Modulus
2) yield stress.
3) Density
4) shear modulus → look on web.
(site given in tutorial).

Model summary :- in this tab you will have total weight of structure (which will be in lb)
↓
mulitpy by 16 to get in "oz".

in "Modeling tab" :- turn on "2nd order Analysis" → to know buckling in members
↓
shows which member fails.

Options → member display → Display to scale
→ shows member used to scale in view port

- Once your design (elevation) of tower is ready. you can start to put loads on it. (use [↓P] from side tool bar).

- put on a point. If you drag and strectthe valus of Load increass.
(you can scale the force arrow size from top bar using [F↗]).

- from "loads" tab → to → "force" tab → show force
  ↓
  value is seen.

- from "options" tab → member display → select the type OF data you wants

section data

- Select member → a) Define section type
  - b) Give section a name
  - c) Section subtype (cross secton)
  - d) Deph.
  - e) width
  - 4) properties with glue area.

- Turn on joint labels from → "options"

  ↓

  "joint labels"

- To see deflection in members → you can see in output list below the digram.

Thankyou !!!