Arch324
STRUCTURES II

Winter 2026
Recitation

FACULTY: Prof. Peter von Bülow
Mohsen Vatandoost

Arch324: STRUCTURES II

Welcome to Recitation session 02/06

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Office: Room 3122

hours:

Fri: 11:00 – 12:00

Mon, Wed: 11:00 - 12:00

walk-ins welcome!

Click here to make an appointment

Please feel free to ask questions.

Arch324: STRUCTURES II

Welcome to Recitation session 02/06

Outline:

- Quick **Recap** of the week
- Provide the solution for the assignment **(Homework 04)**
- Answering student's questions
- Lab: **---**
- **Tower Project:** how to start/ guidelines

Please feel free to ask questions.

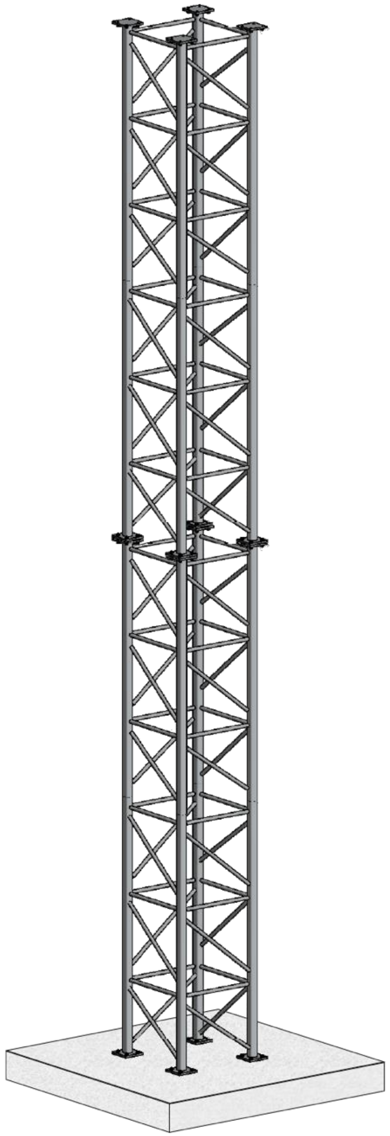
Contact: Mohsenv@umich.edu

Tower Project: How to start

Team up (groups up to 4 persons) and Sign up.

Due date for the Preliminary report is Feb 13

Tower Test : March 23



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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.

Tower Project:

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.

Tower Project:

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).

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Tower Project: How to start

Scoring

Preliminary Report	40 pts
Testing	60 pts
Final Report	150 pts

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.

Use NDS approach

Find load P and stress F'c for each member

Use 1.0 for all factors except C_P

Analysis

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

Capacity

$$P = F'_c A$$

Design

$$A = \frac{P}{F'_c}$$

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Tower Project: Preliminary report

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.

Tower Project: Preliminary report

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.

Tower Project: Preliminary report

Properties of Basswood: (like in the Media Center)

Density (oven dry)	29 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 *

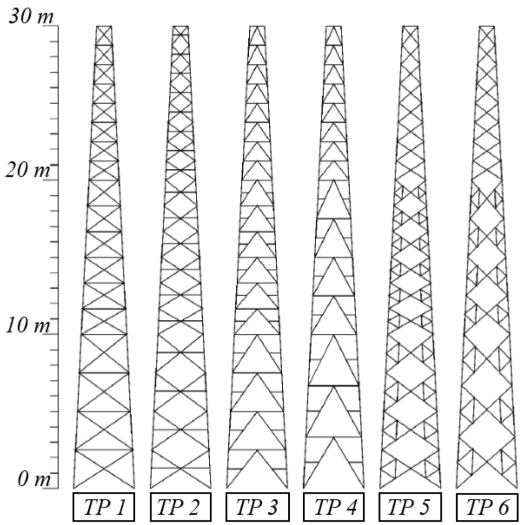
* from http://www.matweb.com/ ** tested by PvB (small pieces in compression)

Tower Project: How to start

- ✓ Team up!
- ✓ Look at examples online: similar towers and high-rise buildings
- ✓ Look at student's work in the last semester in the course website
- ✓ Familiar yourself with Dr. Frame (download it on the course website)
- ✓ Test different material
- ✓ Sketch your idea
- ✓ Develop your design

Tower Project: How to start

- ✓ Taper tower (optional)
- ✓ For the sake of material saving, the top and bottom sections, could be different
- ✓ Control the Lateral stability
- ✓ Test different patterns
- ✓ Test different geometry
- ✓ Be creative!



lattice tower structure

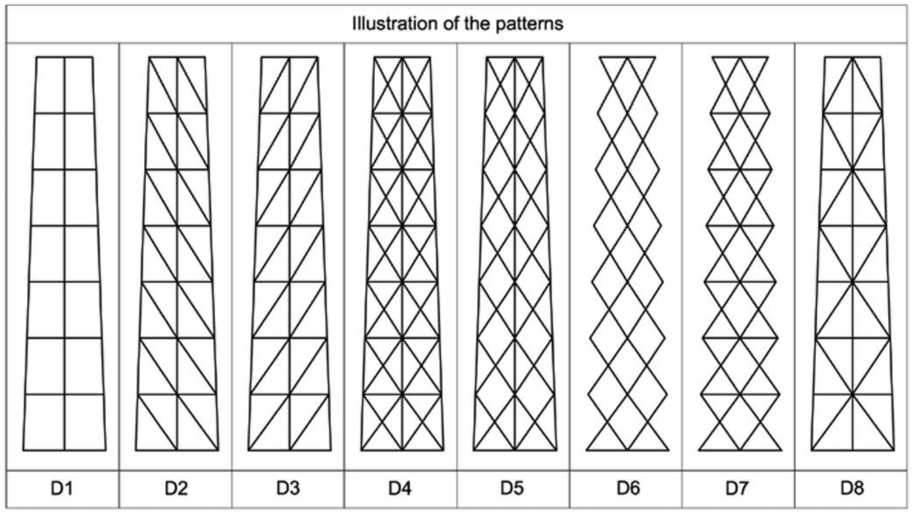


Figure 3: The patterns that are used in designing the lattice tapered towers

Khodadadi, A., & Buelow, P. V. (2014, September). Form exploration and GA-based optimization of lattice towers comparing with Shukhov water tower. In *Proceedings of IASS Annual Symposia* (Vol. 2014, No. 16, pp. 1-8). International Association for Shell and Spatial Structures (IASS).

Tower Project: How to start

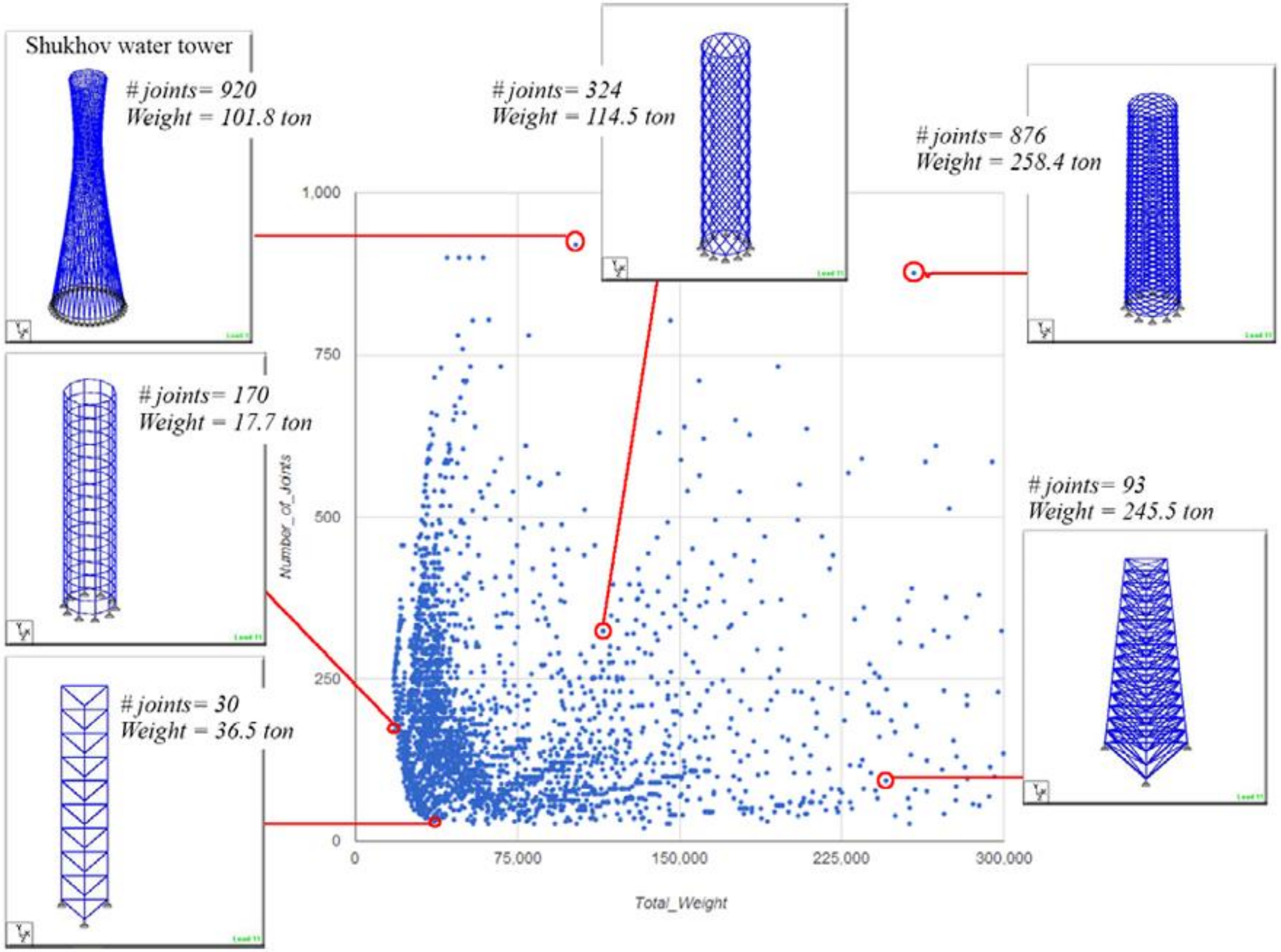


Figure 10: A graph that illustrate the number of joints vs. total weight of the solutions.

Khodadadi, A., & Buelow, P. V. (2014, September). Form exploration and GA-based optimization of lattice towers comparing with Shukhov water tower. In *Proceedings of IASS Annual Symposia* (Vol. 2014, No. 16, pp. 1-8). International Association for Shell and Spatial Structures (IASS).

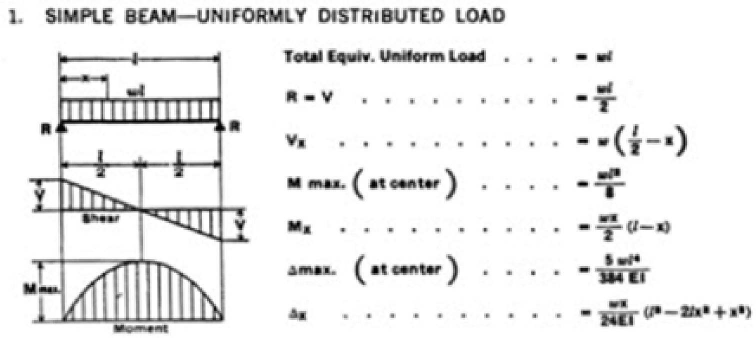
Recap of the week

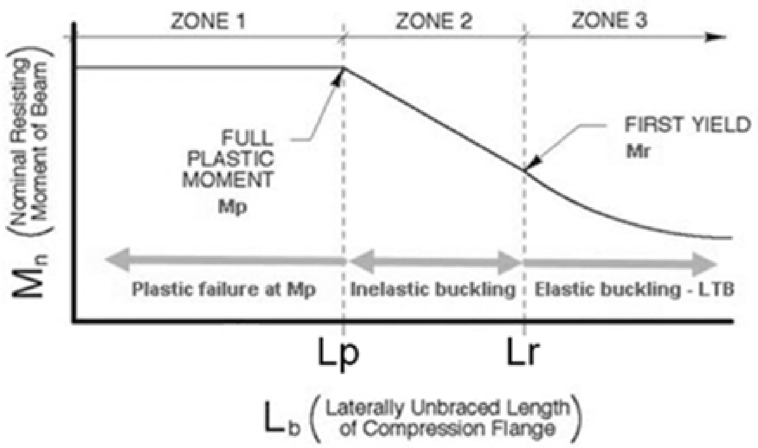
Procedure - Analysis of Steel Beams – **for Zone 1** $L_b < L_p$

Pass/Fail

Given: yield stress, steel section, loading, bracing (L_b)
Find: pass/fail of section

1. Calculate the factored design load w_u
   $w_u = 1.2w_{DL} + 1.6w_{LL}$
2. Determine the design moment M_u.
   M_u will be the maximum beam moment using the factored loads
3. Insure that $L_b < L_p$ (zone 1)
   $L_p = 1.76\ r_y \sqrt{E/Fy}$
4. Determine the nominal moment, Mn
   $M_n = F_y Z_x$ (look up Z_x for section)
5. Factor the nominal moment
   $øM_n = 0.90\ M_n$
6. Check that $M_u < øM_n$
7. Check shear
8. Check deflection



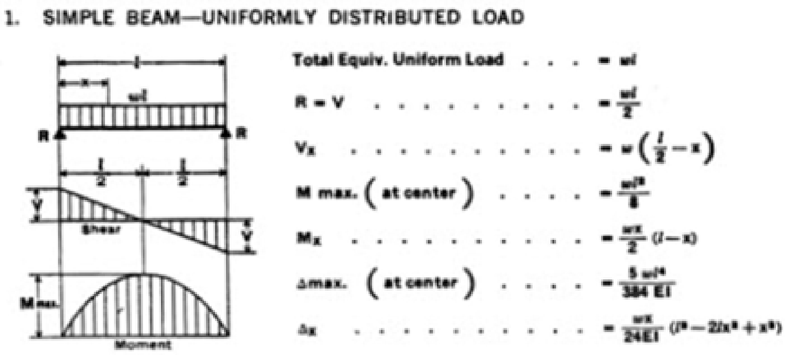


Recap of the week

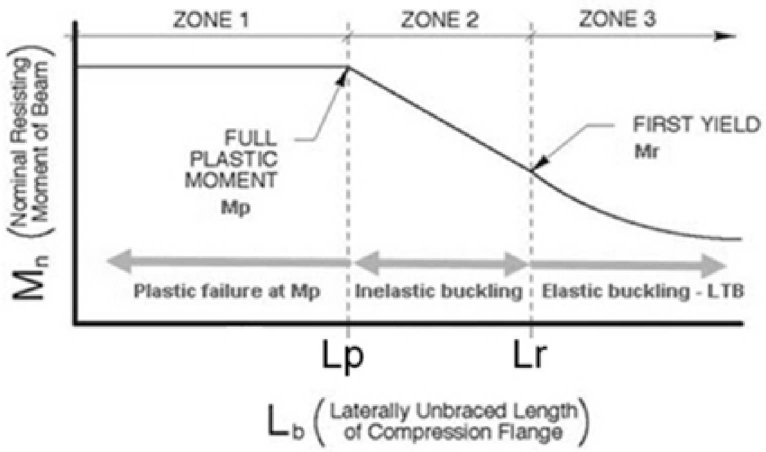
Procedure - Analysis of Steel Beam - **Capacity**

Given: yield stress, steel section, bracing

Find: moment or load capacity



1. Determine the unbraced length of the compression flange (L_b).
2. Find the L_p and L_r values from the AISC Z_x Table 3-2
3. Compare L_b to L_p and L_r and determine which equation for M_n or M_{cr} to be used.
4. Determine the beam load equation for maximum moment in the beam.
5. Calculate load based on maximum moment. $M_u = \phi_b \ M_n$



Recap of the week

Design of Steel Beam –Procedure (zone 1)

1. Use the maximum moment equation, and solve for the ultimate moment, M_u.
2. Set $\phi M_n = M_u$ and solve for M_n
3. Assume Zone 1 to determine Z_x required
4. Select the lightest beam with a Z_x greater than the Z_x required from AISC table
5. Determine if $h/tw < 59$
   (case 1, most common)
6. Determine A_w:
   $Aw = d\ t_w$
7. Calculate V_n:
   $V_n = 0.6\ F_y\ A_w$
8. Calculate Vu for the given loading
   $V_u = w_u\ L / 2$ (e.g. unif. load)
9. Check $V_u < \phi\ V_n$
   ϕ for V = 1.0
10. Check deflection

Provide the solution for the assignment – **HW4**

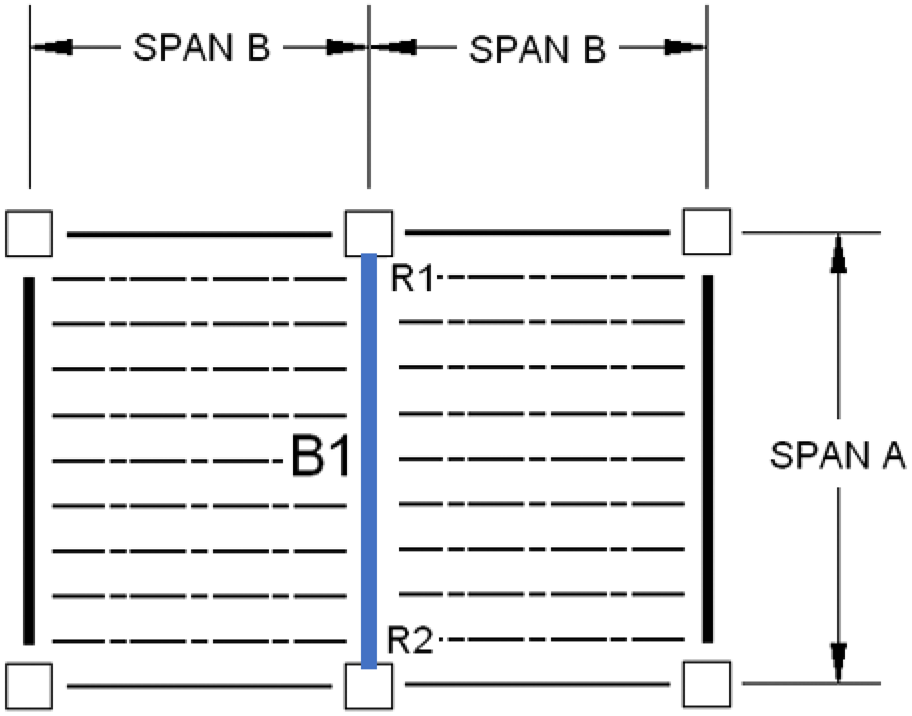
- **Problem:**

4. Steel Beam Analysis

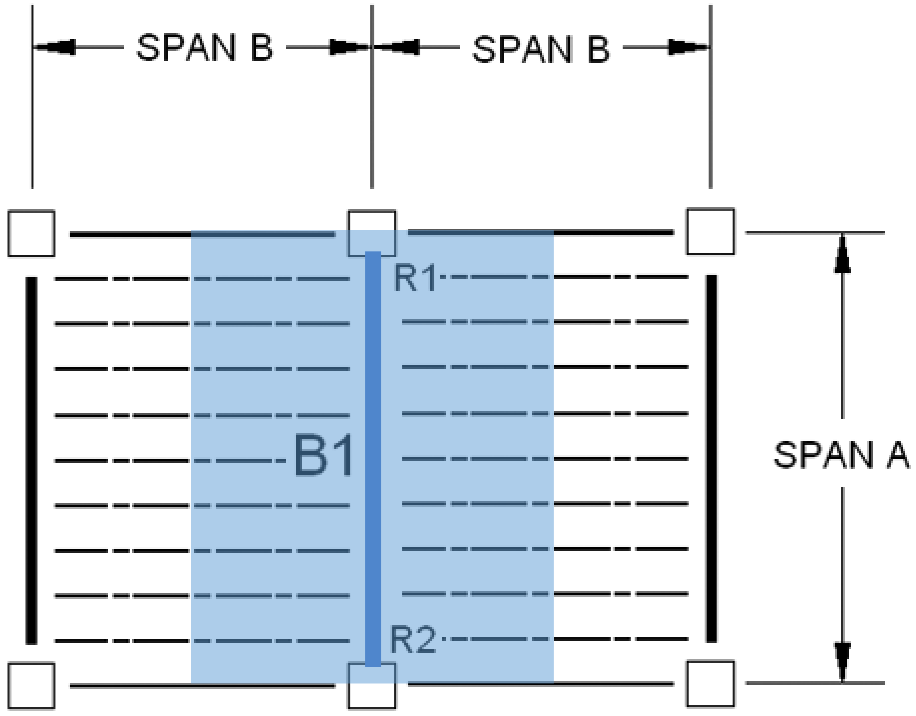
Analyze the given W-section for beam B1, to determine the maximum live load capacity the floor can carry. Determine the shear and bending forces and check the maximum deflection against an allowable of L/180. Assume the beam is fully braced, Lb < Lp (zone 1).

DATASET: 1 -2- -3-

W-section	W12X19
Fy	50 KSI
Span A	21 FT
Span B	14 FT
Floor DL	10 PSF



Provide the solution for the assignment – **HW3**



#	Question	Your Response	
1	The plastic modulus of the section, Zx		IN3
2	The nominal bending moment, Mn		K-IN
3	The factored bending resistance, phi Mn		K-IN
4	The factored design moment, Mu		K-FT
5	The total factored design load, wu		KLF
6	The total unfactored dead load on the beam, w_DL		KLF
7	The total factored dead load on the beam, wu_DL		KLF
8	The factored live load on the beam, wu_LL		KLF
9	The actual beam live load (capacity), w_LL		KLF
10	The actual floor live load (floor capacity), LL		PSF
11	The maximum factored design beam shear force, Vu_max		K
12	The web area, Aw		IN2
13	The factored shear resistance, phi Vn		K
14	Is the section safe for shear? (1=yes, 0=no)		
15	The actual (unfactored) deflection due to total DL + LL		IN
16	The deflection limit L/180		IN
17	Is the actual deflection less than the limit L/180? (1=yes, 0=no)		

Provide the solution for the assignment – **HW4**

Given W-section : W12x19 → AISC , Table 1-1

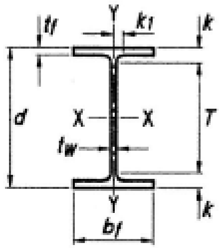


Table 1-1 (continued)
W-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		$\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k k_{des}	k_{det}	k_1	T	Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W12×58	17.0	12.2	12 1/4	0.360	3/8	3/16	10.0	10	0.640	5/8	1.24	1 1/2	15/16	9 1/4	5 1/2
×53	15.6	12.1	12	0.345	3/8	3/16	10.0	10	0.575	9/16	1.18	1 3/8	15/16	9 1/4	5 1/2
W12×50	14.6	12.2	12 1/4	0.370	3/8	3/16	8.08	8 1/8	0.640	5/8	1.14	1 1/2	15/16	9 1/4	5 1/2
×45	13.1	12.1	12	0.335	5/16	3/16	8.05	8	0.575	9/16	1.08	1 3/8	15/16	↓	↓
×40	11.7	11.9	12	0.295	5/16	3/16	8.01	8	0.515	1/2	1.02	1 3/8	7/8	↓	↓
W12×35[c]	10.3	12.5	12 1/2	0.300	5/16	3/16	6.56	6 1/2	0.520	1/2	0.820	1 3/16	3/4	10 1/8	3 1/2
×30[c]	8.79	12.3	12 3/8	0.260	1/4	1/8	6.52	6 1/2	0.440	7/16	0.740	1 1/8	3/4	↓	↓
×26[c]	7.65	12.2	12 1/4	0.230	1/4	1/8	6.49	6 1/2	0.380	3/8	0.680	1 1/16	3/4	↓	↓
W12×22[c]	6.48	12.3	12 1/4	0.260	1/4	1/8	4.03	4	0.425	7/16	0.725	15/16	5/8	10 3/8	2 1/4[g]
×19[c]	5.57	12.2	12 1/8	0.235	1/4	1/8	4.01	4	0.350	3/8	0.650	7/8	9/16	↓	↓
×16[c]	4.71	12.0	12	0.220	1/4	1/8	3.99	4	0.265	1/4	0.565	13/16	9/16	↓	↓
×14[c,v]	4.16	11.9	11 7/8	0.200	3/16	1/8	3.97	4	0.225	1/4	0.525	3/4	9/16	↓	↓

Table 1-1 (continued)
W-Shapes
Properties

W12-W10

Nom-inal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	Axis X-X I	S	r	Z	Axis Y-Y I	S	r	Z	r_{ts}	h_o	Torsional Properties 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}
58	7.82	27.0	475	78.0	5.28	86.4	107	21.4	2.51	32.5	2.81	11.6	2.10	3570
53	8.69	28.1	425	70.6	5.23	77.9	95.8	19.2	2.48	29.1	2.79	11.5	1.58	3160
50	6.31	26.8	391	64.2	5.18	71.9	56.3	13.9	1.96	21.3	2.25	11.6	1.71	1880
45	7.00	29.6	348	57.7	5.15	64.2	50.0	12.4	1.95	19.0	2.23	11.5	1.26	1650
40	7.77	33.6	307	51.5	5.13	57.0	44.1	11.0	1.94	16.8	2.21	11.4	0.906	1440
35	6.31	36.2	285	45.6	5.25	51.2	24.5	7.47	1.54	11.5	1.79	12.0	0.741	879
30	7.41	41.8	238	38.6	5.21	43.1	20.3	6.24	1.52	9.56	1.77	11.9	0.457	720
26	8.54	47.2	204	33.4	5.17	37.2	17.3	5.34	1.51	8.17	1.75	11.8	0.300	607
22	4.74	41.8	156	25.4	4.91	29.3	4.66	2.31	0.848	3.66	1.04	11.9	0.293	164
19	5.72	46.2	130	21.3	4.82	24.7	3.76	1.88	0.822	2.98	1.02	11.9	0.180	131
16	7.53	49.4	103	17.1	4.67	20.1	2.82	1.41	0.773	2.26	0.983	11.7	0.103	96.9
14	8.82	54.3	88.6	14.9	4.62	17.4	2.36	1.19	0.753	1.90	0.961	11.7	0.0704	80.4

Provide the solution for the assignment – **HW4**

plastic modulus of the section,

$F_y = 50$ kSI

W 12X19 $\longrightarrow$ Table 1-1 : $Z_x = 24.7$ in^3

Q1

Assume the beam is fully braced, $L_b < L_p$ (zone 1)

$M_n = M_p$

nominal bending moment

$M_{n_x} = Z_x F_y = \underset{in^3}{(24.7)}\underset{\frac{klb}{in^2}}{(50)} = 1235$ K_IN

Q2

$\varnothing$ in bending : 0.9

$\varnothing M_n = 0.9 \times 1235 = 1111.5$ K_IN

Q3

The factored bending resistance

Provide the solution for the assignment – **HW4**

$M_u \le \phi M_n$

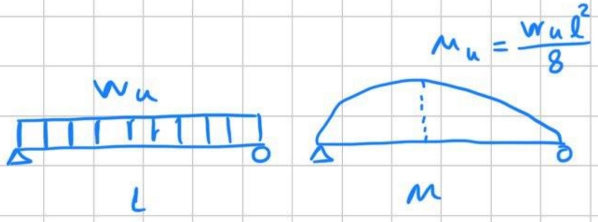
The factored design moment

we Assume M_u equal to ϕM_n

$1111.5 \ K\text{-}IN \times \frac{1}{12} = 92.625 \ K\text{-}ft$

IN to FT

Q4



$M_u = \frac{w_u l^2}{8}$

$92.625 = \frac{w_u \times 21^2}{8} \longrightarrow w_u = \underline{\underline{1.68027}} \ KLF$

Q5

The total factored design load,

Provide the solution for the assignment – **HW4**

Total unfactored Dead load: Floor DL + beam selfweight

$$\underbrace{\underset{psf}{10} \times 2\left(\frac{span\ B}{2}\right)}_{plf} + \underset{plf}{19} = \underset{plf}{159} \xrightarrow{\times \frac{1}{1000}} \underset{klf}{0.159}$$

unite convertion

Q6

Factored DL : 1.2 X 0.159 = 0.1908

Q7

$W_u = 1.2 w_{DL} + 1.6 w_{LL}$

$1.68027 = 1.2\,(0.159) + 1.6\,(w_{LL})$

$\rightarrow 1.6\, w_{LL} = 1.48947$ KLF Factored Live load

Q8

$w_{LL} = 0.9309$ KLF Actual live load

Q9

$$\frac{w_{LL}}{span\ B} = \frac{\overset{KLF}{0.9309}}{14} = 0.06649 \times 1000 = 66.49^{\ plf}$$

Q10

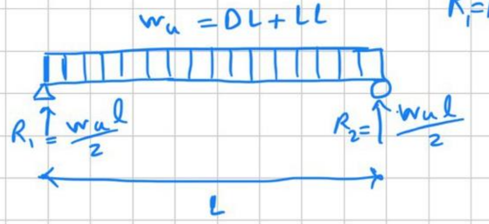
Provide the solution for the assignment – **HW4**

Shear:

Q11

$$R_1 = R_2 = \frac{1.68027 \overset{\text{KLF}}{} \times 21 \overset{\text{FT}}{}}{2} = \underline{\underline{17.6428}}\ \text{K}$$

V_u



$$\begin{cases} \text{if } \frac{h}{t_w} \leq 2.45\sqrt{\frac{E}{F_y}} = 50 \quad (\text{for } 50 \text{ KSI Steel}) \\ V_n = 0.6\, F_y\, A_w \end{cases}$$

Table 1-1 : $46.2 < 50$ ✓

Q12

$$A_w = d\, t_w = (12.2)(0.235) = 2.867 \text{ in}^2$$

$$V_n = 0.6\, F_y A_w = 0.6(50)(2.867) = 86.01$$

Q13

Check Shear: $V_u \leq V_n$?

Q14

$$17.6428 < 86.01 \ \checkmark \ \text{O.K.}$$

Zone 1:

WEB YIELDING (Most beam sections fall into this category)

if $\frac{h}{t_w} \leq 2.45\sqrt{E/F_y} = 59$ (for 50 ksi steel)

then: $V_n = 0.6\, F_y\, A_w$

Provide the solution for the assignment – **HW4**

Deflection :

limit $\frac{L}{180} = \frac{21 \times 12}{180} = (1.4)$ in

Q16

unFactored load
DL+LL

Convert to IN

$$\Delta_{max} = \frac{5wl^4}{384EI} = \frac{5\left(1089.90 \times \frac{1}{12}\right) \times (21 \times 12)^4}{384\,(29 \times 10^6)\,(130)} = 1.2650 \text{ IN}$$

IN^4

PSI

$\frac{lb}{IN^2}$

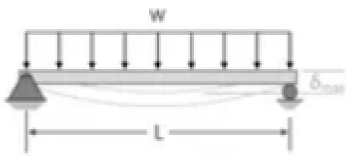
IN^3

Table 1-1

Q15

Total unfactored load $\longrightarrow$ (DL) + (self-weight) + (LL)

$140 + 19 + 930.9 = 1089.90$ plf



$$\delta_{max} = \frac{5wL^4}{384EI}$$

Thank you.

Any question?

Please feel free to ask questions.

Contact: Mohsenv@umich.edu