CE 120 – Spring 2019
Instructor: M.J. DeJong

Name:______________________________

CE 120 – Structural Engineering

Final Examination

Instructions:

- Do not open the exam until instructed to do so.
- You are allowed two 8-1/2 by 11 inch sheet of notes, both sides, for reference. You may use a calculator and watch, but no other electronic devices are permitted.
- Do all problems. Show all relevant work.
- Start solutions alongside or immediately following problem statements. If additional space is required, insert additional sheets. Do not show the work for more than one problem on any given sheet of paper.
- Organize and write solutions neatly. Points may be taken off for messy solutions.
- Indicate units in final solutions. Points will be taken off if units are missing or signs are unclear.
- If you have any questions, or need any paper or other materials, walk to the front of the classroom and ask the instructor. Do not raise your hand to get the instructor's attention, and do not call out questions from your seat.

Please sign the following Honor Pledge before starting the exam:

"I have neither given nor received aid during this examination. I have not concealed any violation of the Honor Code. I did not use any unapproved notes or electronic devices during the examination."

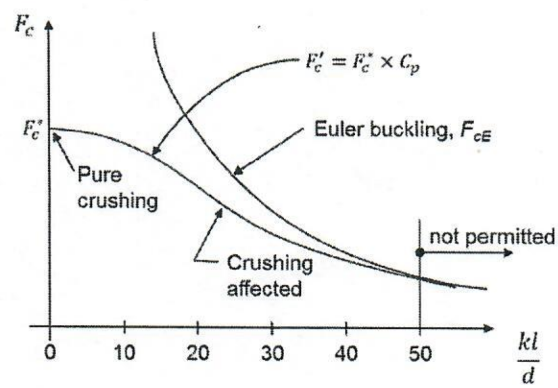
Signature: ______________________________________

Wood Column Design

$$f_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 E_m}{\left(\frac{kl}{r}\right)^2} = 0.82\frac{E_m}{\left(\frac{kl}{d}\right)^2} \equiv F_{cE}$$

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

$c = 0.8;\ F_c^* = LDF \times F_c$



Some other expressions

U = 1.4D
U = 1.2D + 1.6L
U = 1.2D + 1.0L + E
U = 0.9D + E

$V_n = V_c + V_s$

$V_c = 2\sqrt{f_c'}bd$

$V_s = \frac{A_v f_y d}{s}$

$M_n = ZF_y$

$V_n = 0.6F_y td$

simply supported beam under distributed load: $\delta = \frac{5}{384}\frac{wl^4}{EI}$

simply supported beam under concentrated load : $\delta = \frac{1}{48}\frac{Pl^3}{EI}$

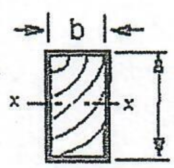
Score	
Problem 1:	______
Problem 2:	______
Problem 3:	______
Problem 4:	______
Problem 5:	______
TOTAL:	______

Construction	L	S	$KD+L$
Roof members:			
Supporting plaster ceiling	$l/360$	$l/360$	$l/240$
Supporting non-plaster ceiling	$l/240$	$l/240$	$l/180$
Not supporting ceiling	$l/180$	$l/180$	$l/120$
Floor members	$l/360$	–	$l/240$

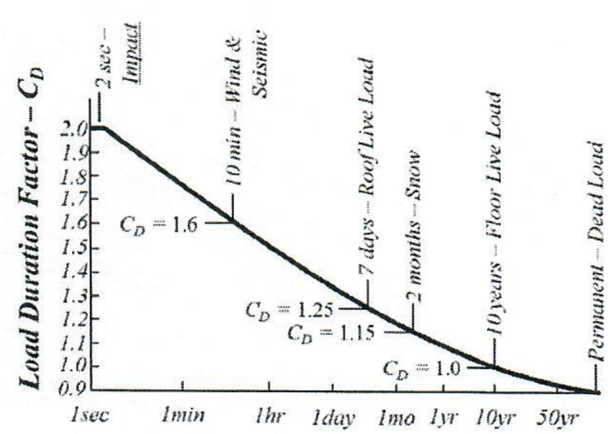
Species and Commercial Grade	Allowable Unit Stresses in psi						
	Extreme Fiber in Bending, F_b		Tension Parallel to Grain, F_t	Horizontal Shear Stress, F_v	Compression Perpendicular to Grain, $F_{c\perp}$	Compression Parallel to Grain, F_c	Modulus of Elasticity, E
	Single-member Uses	Repetitive-member Uses*					
Douglas Fir – Larch (North)							
Dense Select Structural	2100	2400	1400	95	730	1650	1,900,000

Wood Section Properties

Nominal $b \times h$, inches	Surfaced Size, $b \times h$, inches	Area $A = bh$, in.^{2}	Section Modulus, $S = \frac{bh^2}{6}$, in.^{3}	Moment of Inertia, $I = \frac{bh^3}{12}$, in.^{4}	Board Feet per Lineal Foot of Piece
4 × 4	3.5 × 3.5	12.25	7.15	12.51	1.33
4 × 6	3.5 × 5.5	19.25	17.65	48.53	2.00
4 × 8	3.5 × 7.25	25.38	30.66	111.15	2.67
4 × 10	3.5 × 9.25	32.38	49.91	230.84	3.33
4 × 12	3.5 × 11.25	39.38	73.83	415.28	4.00
4 × 14	3.5 × 13.25	46.38	102.41	678.48	4.67
4 × 16	3.5 × 15.25	53.38	135.66	1034.42	5.33

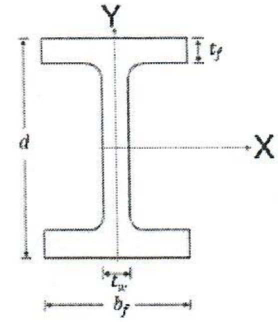


Bar size, no. U.S. (metric)	Nominal diameter, in. (mm)	Nominal area, in.^{2} (mm^2)
3 (10)	0.375 (9.5)	0.11 (71)
4 (13)	0.500 (12.7)	0.20 (129)
5 (16)	0.625 (15.9)	0.31 (199)
6 (19)	0.750 (19.1)	0.44 (284)
7 (22)	0.875 (22.2)	0.60 (387)
8 (25)	1.000 (25.4)	0.79 (510)
9 (29)	1.128 (28.7)	1.00 (645)
10 (32)	1.270 (32.3)	1.27 (819)
11 (36)	1.410 (35.8)	1.56 (1006)
14 (43)	1.693 (43.0)	2.25 (1452)
18 (57)	2.257 (57.3)	4.00 (2581)



W Shapes – Properties for designing

W = weight in plf
A = area, in.^{2}
I in moment of inertia, in.^{4}
Z = plastic modulus, in.^{3}
S = section modulus, in.^{3}
r = radius of gyration, in.
J = torsional constant, in.^{3}
All other dimensions in inches.



AISC_Manual_Label	W	A	d	b_f	t_w	t_f	I_x	Z_x	S_x	r_x	I_y	Z_y	S_y	r_y	J
W14X82	82.0	24.0	14.3	10.1	0.510	0.855	881	139	123	6.05	148	44.8	29.3	2.48	5.07
W14X74	74.0	21.8	14.2	10.1	0.450	0.785	795	126	112	6.04	134	40.5	26.6	2.48	3.87
W14X68	68.0	20.0	14.0	10.0	0.415	0.720	722	115	103	6.01	121	36.9	24.2	2.46	3.01
W14X61	61.0	17.9	13.9	10.0	0.375	0.645	640	102	92.1	5.98	107	32.8	21.5	2.45	2.19
W14X53	53.0	15.6	13.9	8.06	0.370	0.660	541	87.1	77.8	5.89	57.7	22.0	14.3	1.92	1.94
W14X48	48.0	14.1	13.8	8.03	0.340	0.595	484	78.4	70.2	5.85	51.4	19.6	12.8	1.91	1.45
W14X43	43.0	12.6	13.7	8.00	0.305	0.530	428	69.6	62.6	5.82	45.2	17.3	11.3	1.89	1.05
W14X38	38.0	11.2	14.1	6.77	0.310	0.515	385	61.5	54.6	5.87	26.7	12.1	7.88	1.55	0.798
W14X34	34.0	10.0	14.0	6.75	0.285	0.455	340	54.6	48.6	5.83	23.3	10.6	6.91	1.53	0.569
W14X30	30.0	8.85	13.8	6.73	0.270	0.385	291	47.3	42.0	5.73	19.6	8.99	5.82	1.49	0.380
W14X26	26.0	7.69	13.9	5.03	0.255	0.420	245	40.2	35.3	5.65	8.91	5.54	3.55	1.08	0.358
W14X22	22.0	6.49	13.7	5.00	0.230	0.335	199	33.2	29.0	5.54	7.00	4.39	2.80	1.04	0.208
W12X336	336	98.9	16.8	13.4	1.78	2.96	4060	603	483	6.41	1190	274	177	3.47	243
W12X305	305	89.5	16.3	13.2	1.63	2.71	3550	537	435	6.29	1050	244	159	3.42	185
W12X279	279	81.9	15.9	13.1	1.53	2.47	3110	481	393	6.16	937	220	143	3.38	143
W12X252	252	74.1	15.4	13.0	1.40	2.25	2720	428	353	6.06	828	196	127	3.34	108
W12X230	230	67.7	15.1	12.9	1.29	2.07	2420	386	321	5.97	742	177	115	3.31	83.8
W12X210	210	61.8	14.7	12.8	1.18	1.90	2140	348	292	5.89	664	159	104	3.28	64.7
W12X190	190	56.0	14.4	12.7	1.06	1.74	1890	311	263	5.82	589	143	93.0	3.25	48.8
W12X170	170	50.0	14.0	12.6	0.960	1.56	1650	275	235	5.74	517	126	82.3	3.22	35.6
W12X152	152	44.7	13.7	12.5	0.870	1.40	1430	243	209	5.66	454	111	72.8	3.19	25.8
W12X136	136	39.9	13.4	12.4	0.790	1.25	1240	214	186	5.58	398	98.0	64.2	3.16	18.5
W12X120	120	35.2	13.1	12.3	0.710	1.11	1070	186	163	5.51	345	85.4	56.0	3.13	12.9
W12X106	106	31.2	12.9	12.2	0.610	0.990	933	164	145	5.47	301	75.1	49.3	3.11	9.13
W12X96	96.0	28.2	12.7	12.2	0.550	0.900	833	147	131	5.44	270	67.5	44.4	3.09	6.85
W12X87	87.0	25.6	12.5	12.1	0.515	0.810	740	132	118	5.38	241	60.4	39.7	3.07	5.10
W12X79	79.0	23.2	12.4	12.1	0.470	0.735	662	119	107	5.34	216	54.3	35.8	3.05	3.84
W12X72	72.0	21.1	12.3	12.0	0.430	0.670	597	108	97.4	5.31	195	49.2	32.4	3.04	2.93
W12X65	65.0	19.1	12.1	12.0	0.390	0.605	533	96.8	87.9	5.28	174	44.1	29.1	3.02	2.18
W12X58	58.0	17.0	12.2	10.0	0.360	0.640	475	86.4	78.0	5.28	107	32.5	21.4	2.51	2.10
W12X53	53.0	15.6	12.1	10.0	0.345	0.575	425	77.9	70.6	5.23	95.8	29.1	19.2	2.48	1.58
W12X50	50.0	14.6	12.2	8.08	0.370	0.640	391	71.9	64.2	5.18	56.3	21.3	13.9	1.96	1.71
W12X45	45.0	13.1	12.1	8.05	0.335	0.575	348	64.2	57.7	5.15	50.0	19.0	12.4	1.95	1.26
W12X40	40.0	11.7	11.9	8.01	0.295	0.515	307	57.0	51.5	5.13	44.1	16.8	11.0	1.94	0.906
W12X35	35.0	10.3	12.5	6.56	0.300	0.520	285	51.2	45.6	5.25	24.5	11.5	7.47	1.54	0.741
W12X30	30.0	8.79	12.3	6.52	0.260	0.440	238	43.1	38.6	5.21	20.3	9.56	6.24	1.52	0.457
W12X26	26.0	7.65	12.2	6.49	0.230	0.380	204	37.2	33.4	5.17	17.3	8.17	5.34	1.51	0.300
W12X22	22.0	6.48	12.3	4.03	0.260	0.425	156	29.3	25.4	4.91	4.66	3.66	2.31	0.848	0.293
W12X19	19.0	5.57	12.2	4.01	0.235	0.350	130	24.7	21.3	4.82	3.76	2.98	1.88	0.822	0.180
W12X16	16.0	4.71	12.0	3.99	0.220	0.265	103	20.1	17.1	4.67	2.82	2.26	1.41	0.773	0.103

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Problem 1 (15 points) – A 4"x10" wood column is subjected to axial loading. The wood is dense select structural grade Douglas Fir. The column is supported by pins at each end.

(a) Calculate the maximum allowable unbraced length of the column.

(b) The column is 10 feet tall and carries both dead load and floor live load. The column is unbraced in the strong direction of buckling. The column is braced at mid-height in the weak direction of buckling.
Calculate the maximum design axial load *P* that can be sustained by the column.

(a) $\frac{kl}{d} = 50 \rightarrow \frac{l(12''/ft)}{4''} = 50 \rightarrow \underline{\underline{l = 16.6'}}$

(b) strong: $\frac{kl}{d} = \frac{10(12)}{10} = 12$

weak: $\frac{kl}{d} = \frac{5'(12)}{4} = 15$ ← governs

$E_m = \frac{E}{1.76} = 1.08 \times 10^6$ psi

$f_{cr} = 0.82 \frac{E_m}{\left(\frac{kl}{d}\right)^2} = 3934 = F_{cE}$

$F_c^* = LDF(F_c) = 1.0(1650) = 1650$

$\frac{F_{cE}}{F_c^*} = 2.38$

$C_p = \frac{1+2.38}{2(0.8)} - \sqrt{\left(\frac{1+2.38}{2(0.8)}\right)^2 - \frac{2.38}{0.8}} = 0.895$

$P_{max} = F_c(C_p)(1.0)A = 1650(0.895)(1.0)(32.38 \text{ in}^2) = \underline{\underline{47.8 \text{ k}}}$

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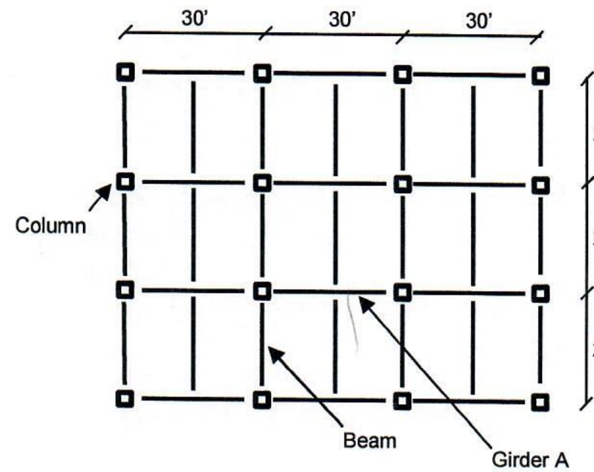
Problem 2 (20 points) – The figure below shows the roof framing plan of a steel building. The roof has a dead load of 120 psf, which includes all dead load apart from the girders. The ceiling below is plaster. The roof live load is 40 psf. In addition, a point live load of 10 kips, which can be applied at any location on the roof, needs to be considered in the design. The steel is Grade A36 and E_s = 30,000 ksi.

Design "Girder A" considering bending, shear and deflection. Neglect the weight of "Girder A" itself.



Roof plan view

$F = (15' \times 25')\left[1.2(120) + 1.6(40)\right] = 78\text{ k}$

Max. Moment! Point load @ middle → $F_1 = 78^k + 1.6(10^k) = 94^k$

↳ $M_{max} = \frac{F_1 L}{4} = \frac{94(30')}{4} = 705\text{ k-ft} = 8460\text{ k-in}$

Max Shear ! Point load @ end → $V_{max} = \frac{78}{2} + 1.6(10^k) = 55^k$

$M_n = \frac{8460}{0.9} = f_y Z$ (36 ksi) → $Z = 261\text{ in}^4$

$\delta = \frac{PL^3}{48EI} = \frac{\left[(15\times25)(40) + 10^k\right](30')^3(12''/')^3}{48(30{,}000\text{ ksi})(I)} = \frac{30'(12''/')}{360} = 1'' \rightarrow I = 810\text{ in}^4$

Try W12×170:

$V_u = \phi V_n = 0.9(0.6 \times 36\text{ ksi})(14.0)(0.96) = 261^k > 55^k$ → OK

Use W12×170

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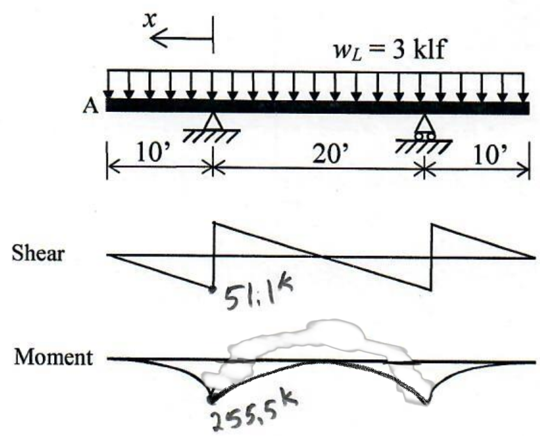
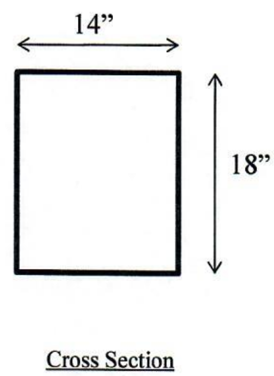
Problem 3 (20 points) – The concrete beam shown in the figure below is subjected to a uniform downward live load of $w_L = 3$ klf. The beam has a uniform cross-section that is 14" wide by 18" deep. Assume that the concrete has $f'_c = 4$ ksi, the density of concrete is 150 pcf, and the steel is Grade 60. The shape of the shear and bending moment diagrams are provided.

(a) Design the longitudinal reinforcement in the beam at the left support. Note: a minimum of 1" gap (i.e. clear spacing) is required between longitudinal reinforcement bars.

(b) Design the shear reinforcement (both size and spacing) above the left support. Sketch and label the beam cross-section at the left support, showing your final reinforcement design.

(c) You, as the designer, decide to specify the shear reinforcement spacing that you found in part (b) for the region $0 < x < \delta$. For $x > \delta$, you wish to specify the maximum allowable spacing of the shear reinforcement. Find the required distance δ.





(a) $w_D = 150\left(\frac{14 \times 18}{144}\right) = 262$ plf → $w_{total} = 1.2(.262) + 1.6(3) = 5.11$ klf

@ support: $\frac{M_u}{\phi} = \frac{255.5^k}{0.9} = 284$ k-ft $= 3{,}407$ k-in $= M_n$

$A_s = \frac{M_n}{f_y(0.9d)} = \frac{3407}{60(0.9)(15.5)} = 4.07$ in² → Use 4-#10 ($A_s = 5.08$ in²)

(b) $V_c = 2\sqrt{4000}\,(14 \times 15.5) = 27.5^k$

$V_s = \frac{A_v f_y d}{s}$ → $s = \frac{A_v f_y d}{V_s} = \frac{(2\times0.11)(60)(15.5)}{(68.1^k - 27.5)} = 5.04"$ → Use #3 @ 5" cc

$\frac{V_u}{\phi} = \frac{51.1}{0.75} = 68.1$ k

Check cover: $1.5" + \frac{1.27"}{2} + \frac{3}{8}" = 2.51" \approx 2.5"$ → OK

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Problem 3 (continued)

(c) max spacing $= \frac{d}{2} = \frac{15.5''}{2} = 7.75''$

$$V_s = \frac{2(0.11)(60)(15.5)}{7.75''} = 26.4^k$$

$$V_u = \phi V_n = 0.75(26.4 + 27.5) = 40.4$$

$$S = \frac{51.1 - 40.4}{51.1}(10') = \underline{\underline{2.09'}}$$

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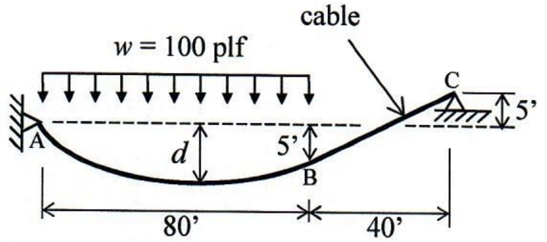
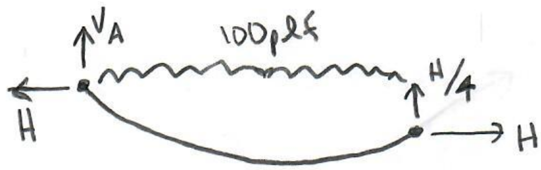
Problem 4 (20 points) – The cable shown below is subjected to a uniform load of 100 plf over part of its span (from point A to point B). At point B the cable is 5 feet below support A. Support C is 5 feet higher than support A. Assume that the cable is weightless.

Find the maximum tension in the cable.



*Note: Not drawn to scale



$\circlearrowleft + \; \Sigma M_A = 0 \rightarrow \quad H(5') + \frac{H}{4}(80') - 100(80)(40) = 0 \rightarrow H = 12.8^k$

$\Sigma F_y = 0 \rightarrow \quad V_A + \frac{12.8}{4} - \frac{100(80)}{1000} = 0 \rightarrow V_A = 4.8\text{ k}$

$T_{max} = \sqrt{12.8^2 + 4.8^2} = \underline{\underline{13.7\text{ k}}}$

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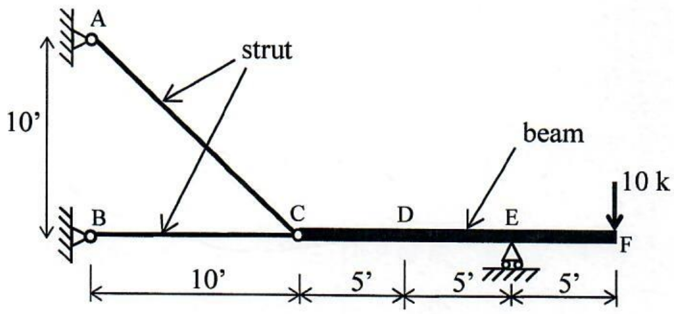
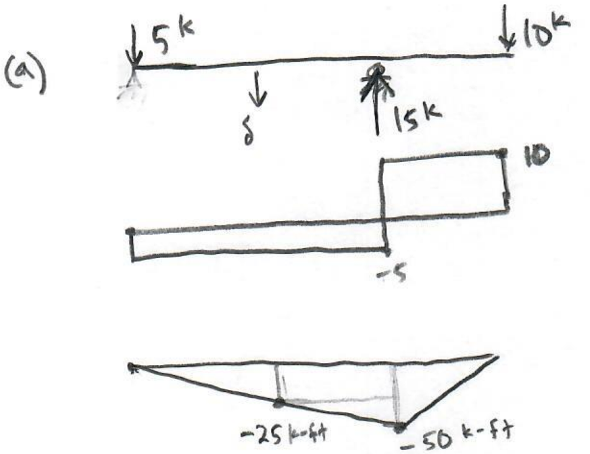
Problem 5 (25 points) – The continuous beam in the figure below is supported by a pin connection at C, and a roller at point E. The beam has a bending stiffness of $EI = 1\text{x}10^6$ k-in^2. Shear deformations are negligible. Members AC and BC are struts that can carry both tension and compression, and that do not buckle.

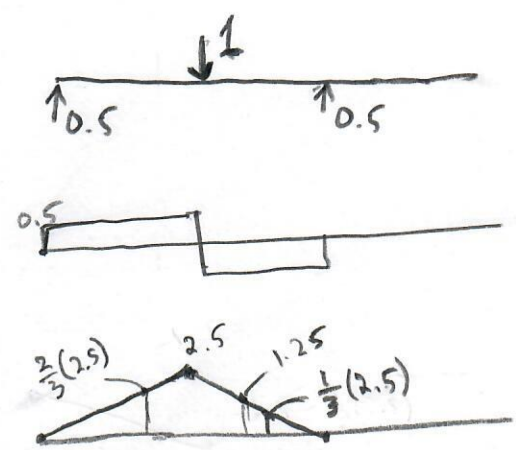
(a) Assume that struts AC and BC are axially rigid. This means that $EA = \infty$ and that point C does not move. Determine the vertical displacement of point D due to the load of 10 kips applied at point F.

(b) Now assume instead that struts AC and BC are not rigid but have an axial stiffness of $EA = 500$ kips. Determine the vertical displacement of point D due to the load of 10 kips applied at point F.



(a)



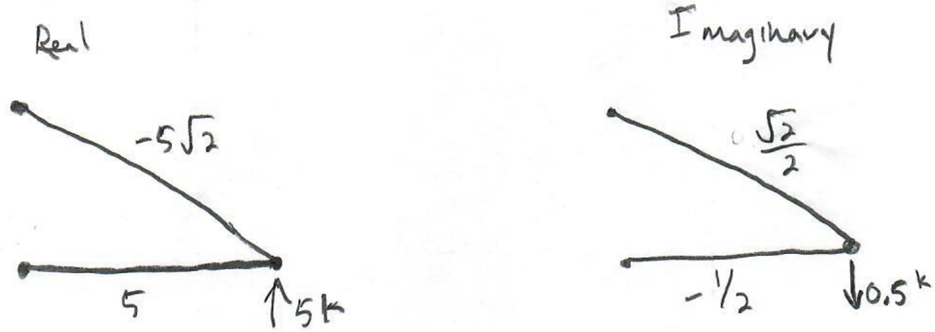


$$\delta(1) = \frac{-1}{EI}\left[25(5)\left(\tfrac{1}{2}\right)\left(\tfrac{2}{3}(2.5)\right) + 25(5)\left(\tfrac{1}{2}\right)\left[\tfrac{1}{3}(2.5)\right] + 25(5)\left[1.25\right]\right]$$

$$= \frac{-312.5\,(12^3)}{EI} = \underline{\underline{-0.54''}}$$

Problem 5 (continued)

(b)



$$\delta = \sum \frac{TL}{AE} T^* = \frac{-5\sqrt{2}(10\sqrt{2})}{AE}\frac{\sqrt{2}}{2} + \frac{5(10)}{AE}\left(-\frac{1}{2}\right) = -\frac{95.7}{AE}$$

$$= -0.19''$$

$$\delta_{total} = -0.54 - 0.19 = \underline{\underline{-0.73''}}$$