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Architecture 324

Structures II

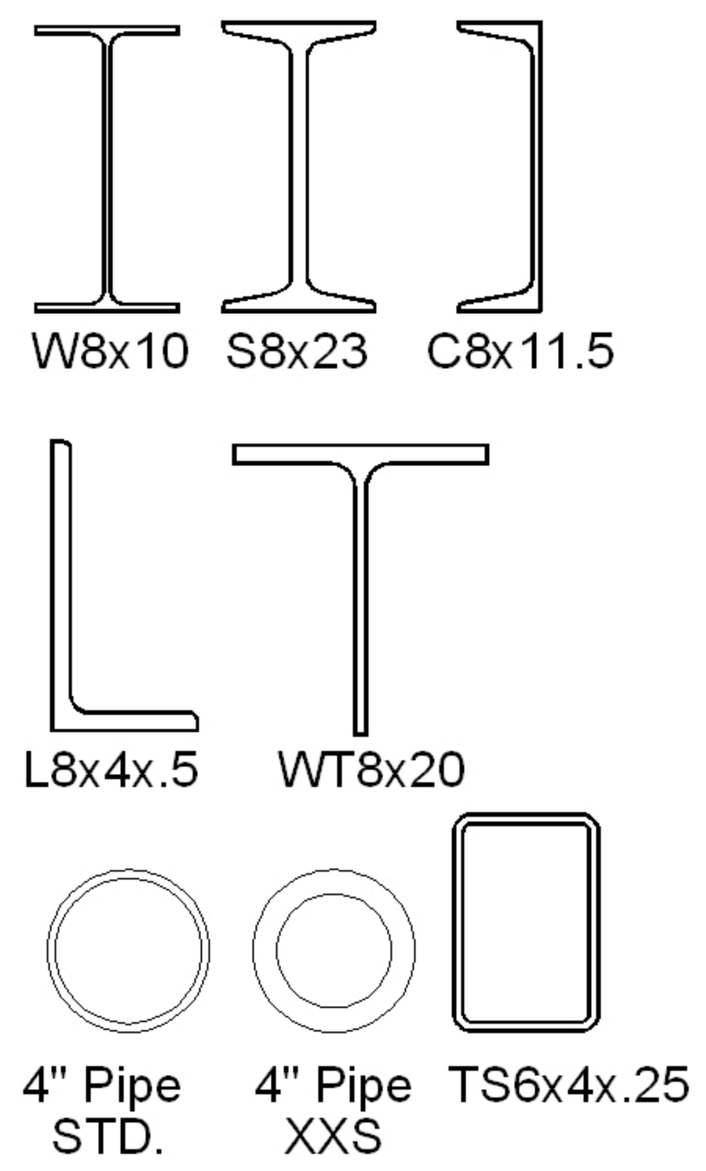
Composite Sections and Steel Beam Design

- •Steel Beam Selection - ASD
- •Composite Sections
- •Analysis Method

Steel W-sections for beams and columns

Standard section shapes:

- W – wide flange
- S – american standard beam
- C – american standard channel
- L – angle
- WT or ST – structural T
- Pipe
- Structural Tubing

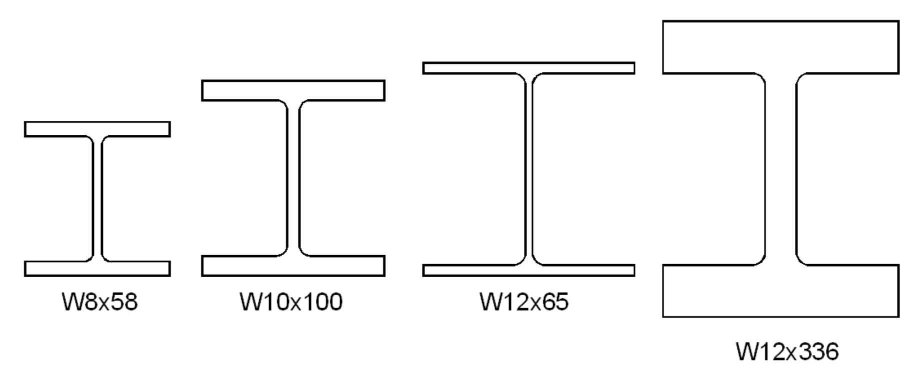


Source: University of Michigan, Department of Architecture

Steel W-sections for beams and columns

Columns:

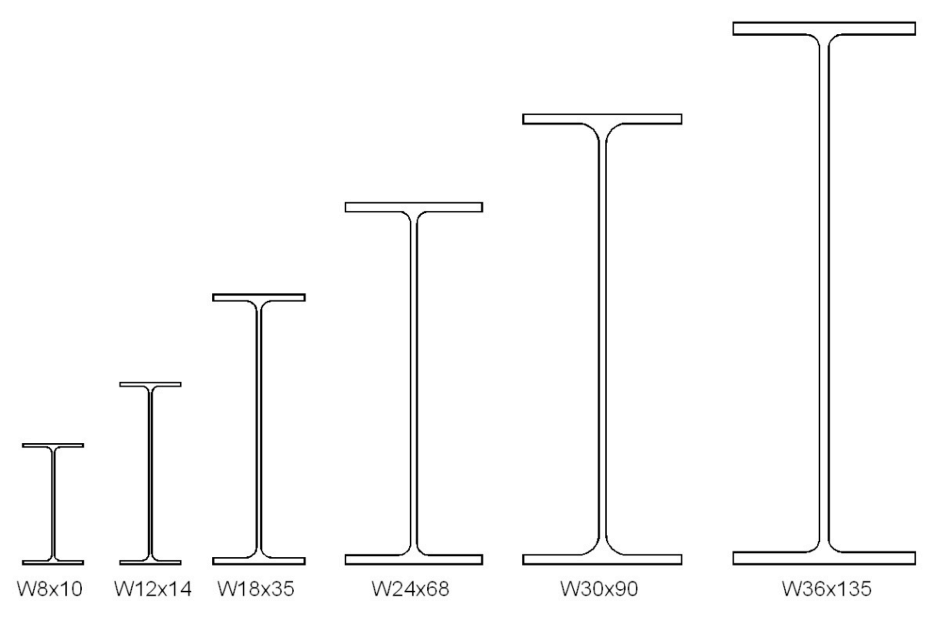
Closer to square
Thicker web & flange



Source: University of Michigan, Department of Architecture

Beams:

Deeper sections
Flange thicker than web



Source: University of Michigan, Department of Architecture

Steel W-sections for beams and columns

Columns:

Closer to square
Thicker web & flange

Beams:

Deeper sections
Flange thicker than web

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Steel Beams by ASD

Yield Stress Values

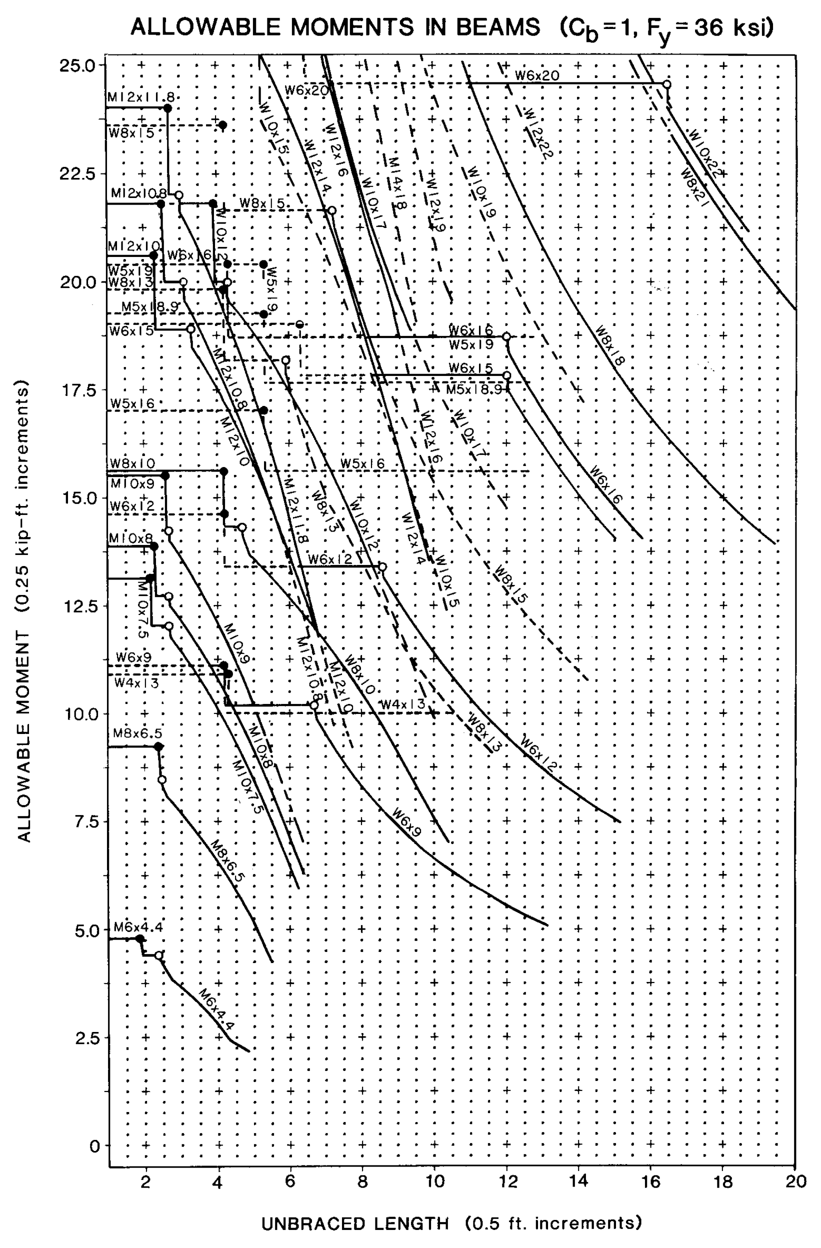
- A36 Carbon Steel   Fy = 36 ksi
- A992 High Strength Fy = 50 ksi

Allowable Flexure Stress

- Fb = 0.66 Fy   • = Lc
  - Compact Section
  - Braced against LTB (l <Lc)
- Fb = 0.60 Fy   ° = Lu
  - Compact or Not
  - Lc < l < Lu
- Fb < 0.60 Fy
  - Compact or Not
  - LTB failure mode (l >Lu)

Allowable Shear Stress

- Fv = 0.40 Fy
  - $f_v = V/(t_w d)$



Source: AISC, Manual of Steel Construction
Allowable Stress Design, 9th ed. 1989

Section Modulus Table

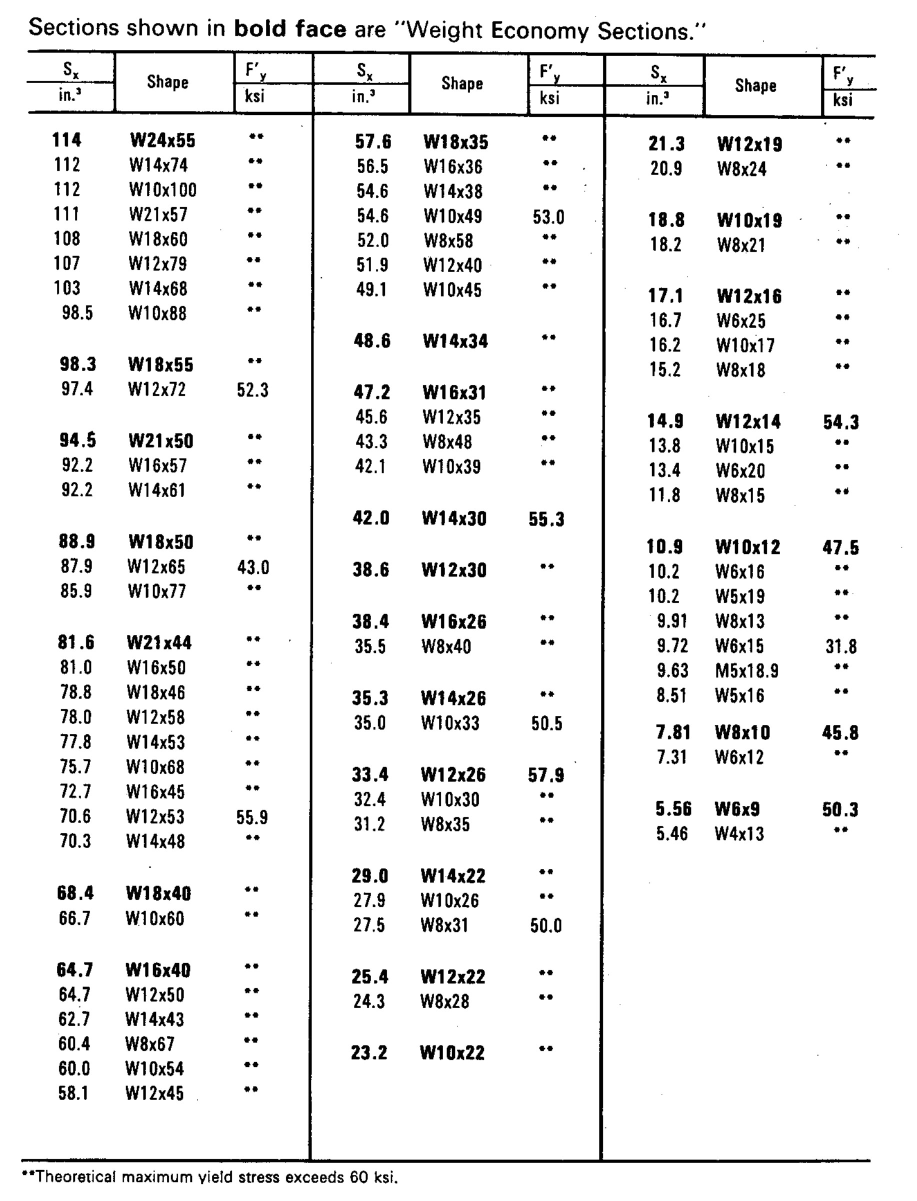
- Calculate Required Moment
- Assume Allowable Stress
    - Fb = 0.66Fy = 24 ksi (A36)
    - Fb = 0.60Fy = 21.6 ksi (A36)

- Using the flexure equation,
    - set fb=Fb and solve for S

$$f_b = \frac{Mc}{I} = \frac{M}{S} = F_b$$

$$S = \frac{M}{F_b}$$

- Choose a section based on S from the table (D-35 and D-36)
    - Bold faced sections are lighter
    - F'y is the stress up to which the section is compact (•• is ok for all grades of Fy)



Sections shown in **bold face** are "Weight Economy Sections."

S_x in.^{3}	Shape	F'_y ksi
114	**W24x55**	**
112	W14x74	**
112	W10x100	**
111	W21x57	**
108	W18x60	**
107	W12x79	**
103	W14x68	**
98.5	W10x88	**
98.3	**W18x55**	**
97.4	W12x72	52.3
94.5	**W21x50**	**
92.2	W16x57	**
92.2	W14x61	**
88.9	**W18x50**	**
87.9	W12x65	43.0
85.9	W10x77	**
81.6	**W21x44**	**
81.0	W16x50	**
78.8	W18x46	**
78.0	W12x58	**
77.8	W14x53	**
75.7	W10x68	**
72.7	W16x45	**
70.6	W12x53	55.9
70.3	W14x48	**
68.4	**W18x40**	**
66.7	W10x60	**
64.7	**W16x40**	**
64.7	W12x50	**
62.7	W14x43	**
60.4	W8x67	**
60.0	W10x54	**
58.1	W12x45	**
57.6	**W18x35**	**
56.5	W16x36	**
54.6	W14x38	**
54.6	W10x49	53.0
52.0	W8x58	**
51.9	W12x40	**
49.1	W10x45	**
48.6	**W14x34**	**
47.2	**W16x31**	**
45.6	W12x35	**
43.3	W8x48	**
42.1	W10x39	**
42.0	**W14x30**	**55.3**
38.6	**W12x30**	**
38.4	**W16x26**	**
35.5	W8x40	**
35.3	**W14x26**	**
35.0	W10x33	50.5
33.4	**W12x26**	**57.9**
32.4	W10x30	**
31.2	W8x35	**
29.0	**W14x22**	**
27.9	W10x26	**
27.5	W8x31	50.0
25.4	**W12x22**	**
24.3	W8x28	**
23.2	**W10x22**	**
21.3	**W12x19**	**
20.9	W8x24	**
18.8	**W10x19**	**
18.2	W8x21	**
17.1	**W12x16**	**
16.7	W6x25	**
16.2	W10x17	**
15.2	W8x18	**
14.9	**W12x14**	**54.3**
13.8	W10x15	**
13.4	W6x20	**
11.8	W8x15	**
10.9	**W10x12**	**47.5**
10.2	W6x16	**
10.2	W5x19	**
9.91	W8x13	**
9.72	W6x15	31.8
9.63	M5x18.9	**
8.51	W5x16	**
7.81	**W8x10**	**45.8**
7.31	W6x12	**
5.56	**W6x9**	**50.3**
5.46	W4x13	**

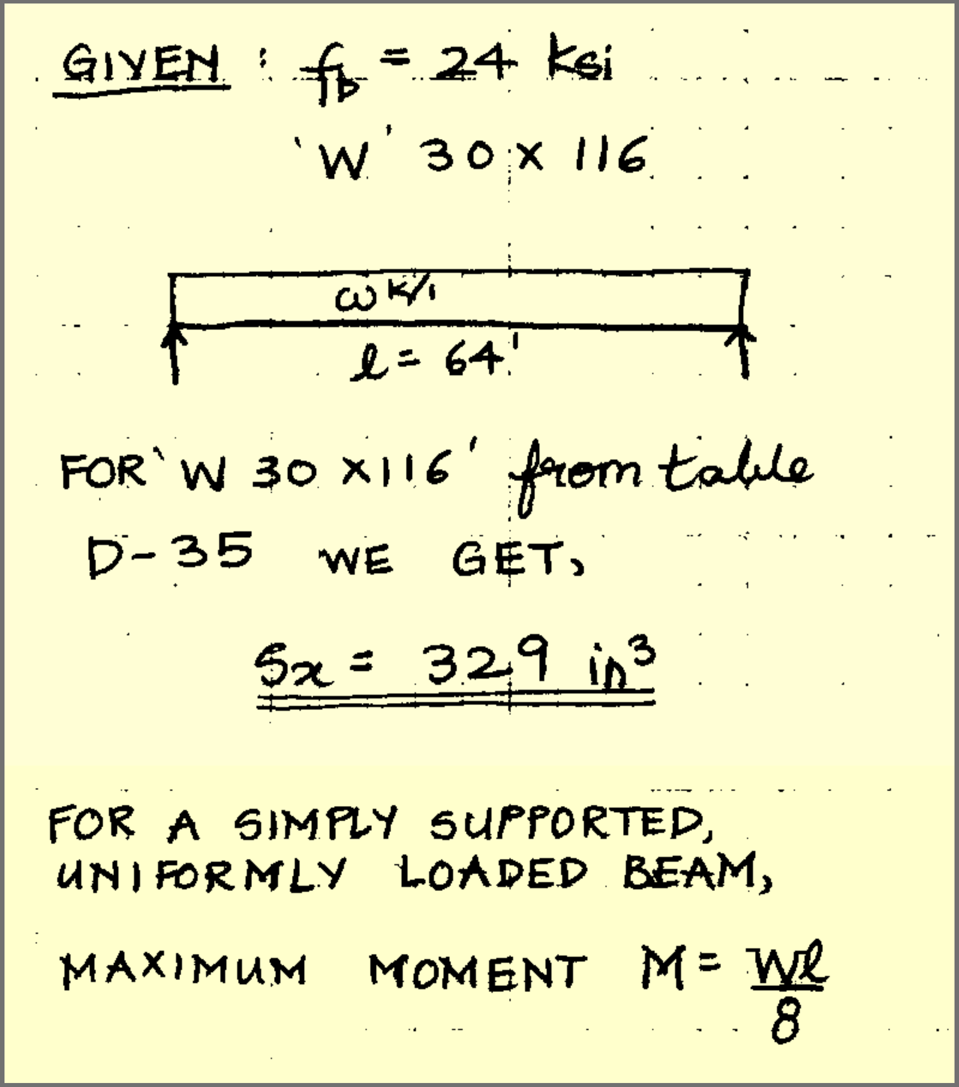
**Theoretical maximum yield stress exceeds 60 ksi.

Source: Structural Principles, I. Engel 1984

Example – Load Analysis of Steel Beam

1. Find the Section Modulus for the given section from the tables (D-35 and D-36).
2. Determine the maximum moment equation.

Find Load w in KLF



GIVEN : $f_b = 24$ ksi

'W' 30 x 116

ω k/'

$l = 64'$

FOR 'W 30 x116' from table D-35 WE GET,

$S_x = 329 \text{ in}^3$

FOR A SIMPLY SUPPORTED, UNIFORMLY LOADED BEAM,

MAXIMUM MOMENT $M = \frac{Wl}{8}$

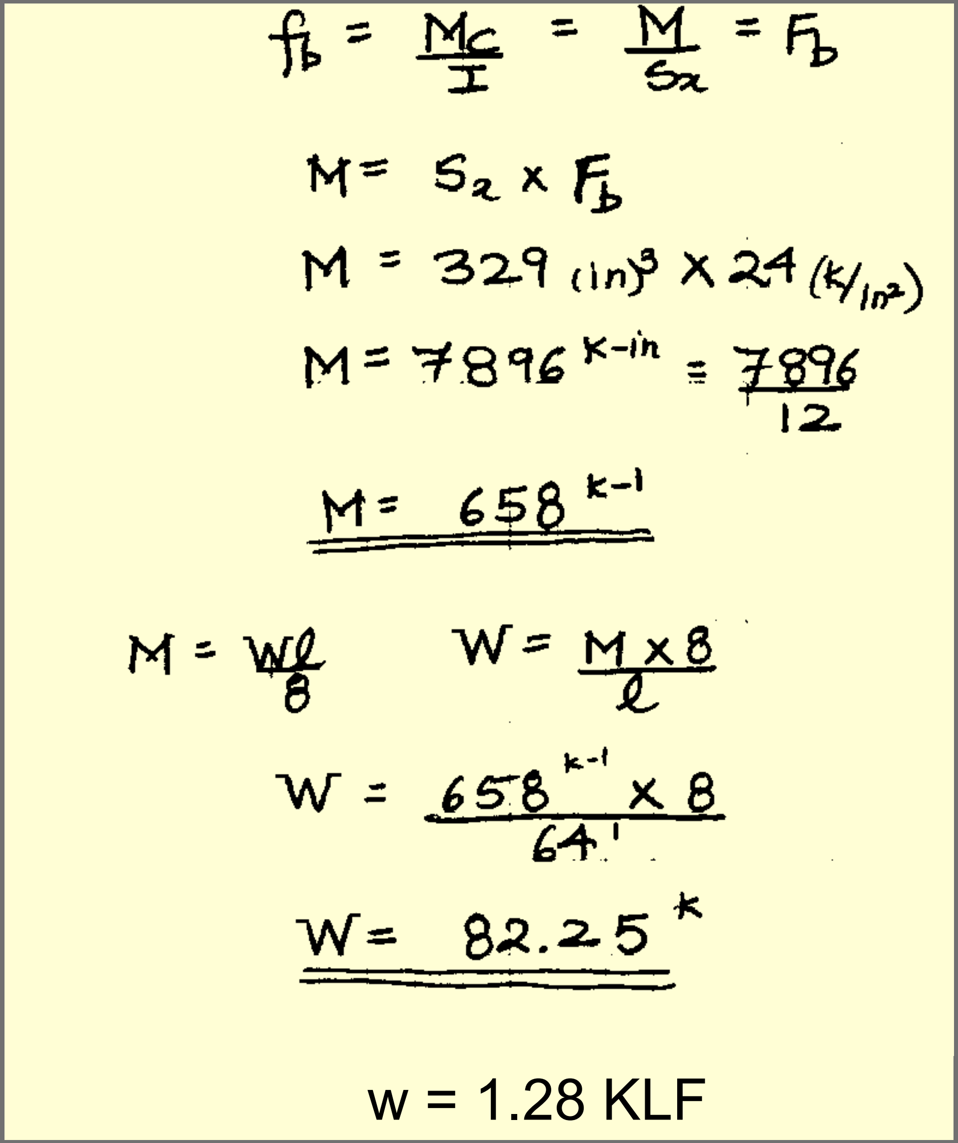
Source: University of Michigan, Department of Architecture

Example – Load Analysis cont.

W30x116

3. Using the flexure equation, fb=Fb, solve for the moment, M.

5. Using the maximum moment equation, solve for the distributed loading, w.



$$f_b = \frac{Mc}{I} = \frac{M}{S_x} = F_b$$

$$M = S_x \times F_b$$

$$M = 329\,(in)^3 \times 24\,(k/in^2)$$

$$M = 7896^{k-in} = \frac{7896}{12}$$

$$\underline{\underline{M = 658^{k-1}}}$$

$$M = \frac{Wl}{8} \qquad W = \frac{M \times 8}{l}$$

$$W = \frac{658^{k-1} \times 8}{64'}$$

$$\underline{\underline{W = 82.25^{k}}}$$

w = 1.28 KLF

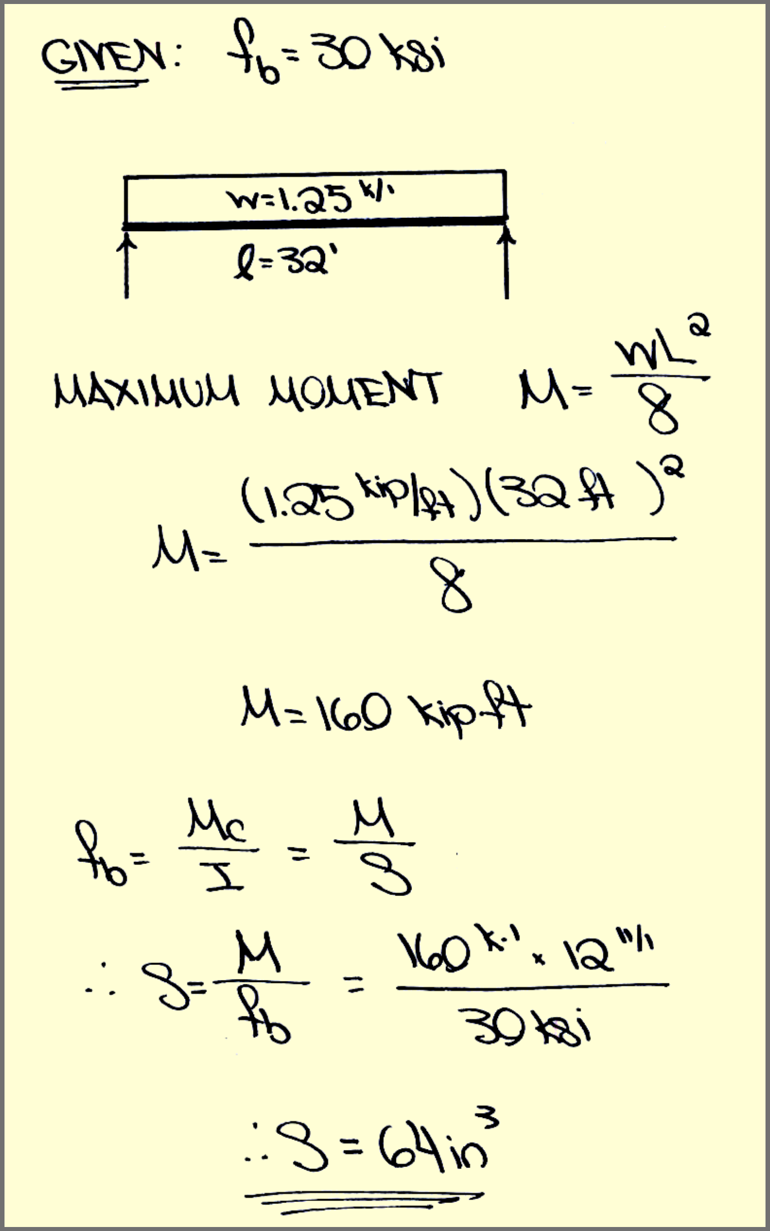
Source: University of Michigan, Department of Architecture

Design of Steel Beam

Example

1. Use the maximum moment equation, and solve for the moment, M.

2. Use the flexure equation to solve for S_x.



GIVEN: $f_b = 30 \text{ ksi}$

$w = 1.25^{k/'}$

$\ell = 32'$

MAXIMUM MOMENT $M = \frac{wL^2}{8}$

$$M = \frac{(1.25 \text{ kip/ft})(32 \text{ ft})^2}{8}$$

$M = 160 \text{ kip ft}$

$$f_b = \frac{Mc}{I} = \frac{M}{S}$$

$$\therefore S = \frac{M}{f_b} = \frac{160^{k'} \times 12^{''/'}}{30 \text{ ksi}}$$

$$\underline{\underline{\therefore S = 64 \text{ in}^3}}$$

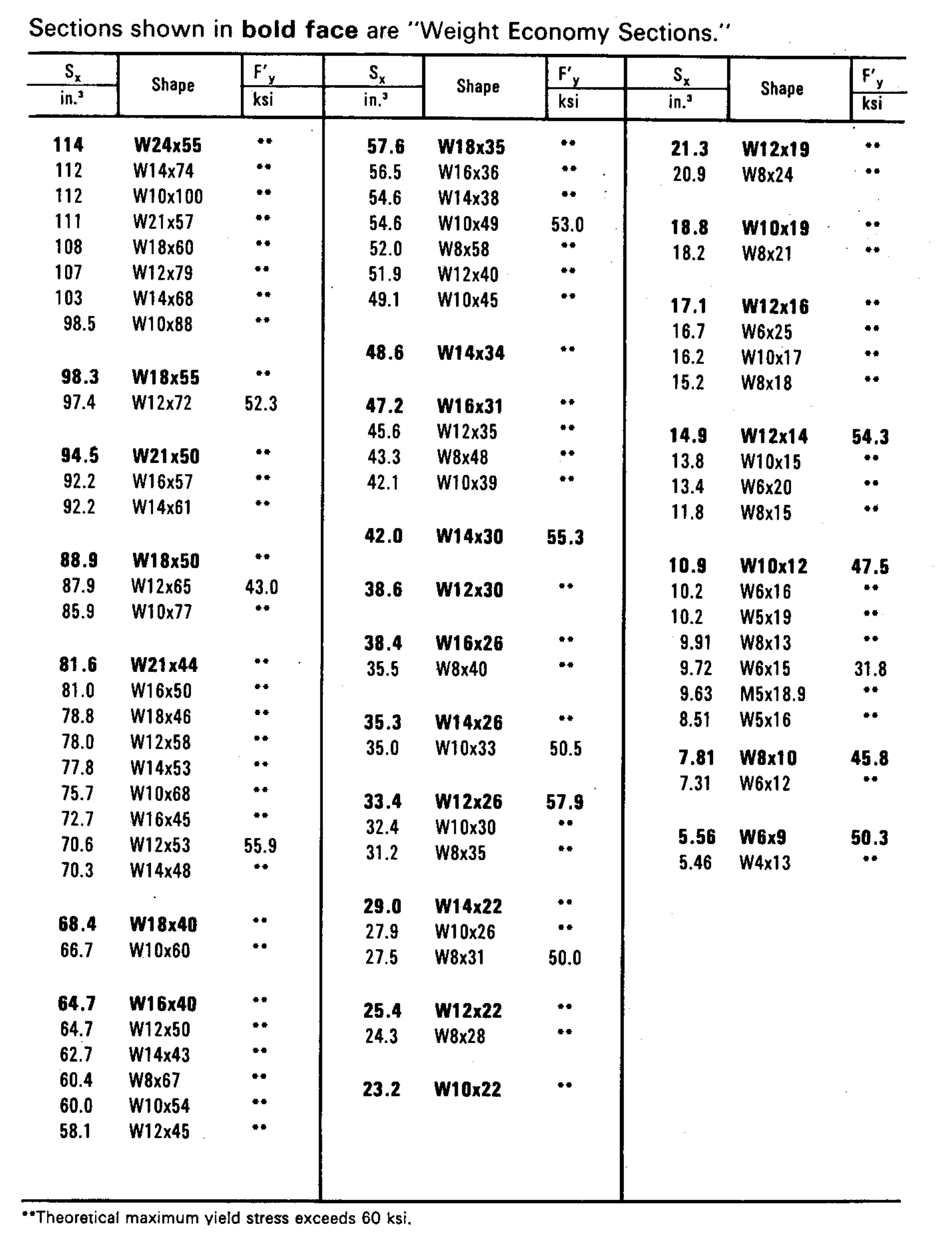
Source: University of Michigan, Department of Architecture

Design of Steel Beam

Example

3. Choose a section based on S_x from the table (D35 and D36).

4. Most economical section is:
   W16 x 40
   $S_x = 64.7 \text{ in}^3$



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87.9	W12x65	43.0
85.9	W10x77	**
81.6	**W21x44**	**
81.0	W16x50	**
78.8	W18x46	**
78.0	W12x58	**
77.8	W14x53	**
75.7	W10x68	**
72.7	W16x45	**
70.6	W12x53	55.9
70.3	W14x48	**
68.4	**W18x40**	**
66.7	W10x60	**
64.7	**W16x40**	**
64.7	W12x50	**
62.7	W14x43	**
60.4	W8x67	**
60.0	W10x54	**
58.1	W12x45	**
57.6	**W18x35**	**
56.5	W16x36	**
54.6	W14x38	**
54.6	W10x49	53.0
52.0	W8x58	**
51.9	W12x40	**
49.1	W10x45	**
48.6	**W14x34**	**
47.2	**W16x31**	**
45.6	W12x35	**
43.3	W8x48	**
42.1	W10x39	**
42.0	**W14x30**	**55.3**
38.6	**W12x30**	**
38.4	**W16x26**	**
35.5	W8x40	**
35.3	**W14x26**	**
35.0	W10x33	50.5
33.4	**W12x26**	**57.9**
32.4	W10x30	**
31.2	W8x35	**
29.0	**W14x22**	**
27.9	W10x26	**
27.5	W8x31	50.0
25.4	**W12x22**	**
24.3	W8x28	**
23.2	**W10x22**	**
21.3	**W12x19**	**
20.9	W8x24	**
18.8	**W10x19**	**
18.2	W8x21	**
17.1	**W12x16**	**
16.7	W6x25	**
16.2	W10x17	**
15.2	W8x18	**
14.9	**W12x14**	**54.3**
13.8	W10x15	**
13.4	W6x20	**
11.8	W8x15	**
10.9	**W10x12**	**47.5**
10.2	W6x16	**
10.2	W5x19	**
9.91	W8x13	**
9.72	W6x15	31.8
9.63	M5x18.9	**
8.51	W5x16	**
7.81	**W8x10**	**45.8**
7.31	W6x12	**
5.56	**W6x9**	**50.3**
5.46	W4x13	**

**Theoretical maximum yield stress exceeds 60 ksi.

Source: I. Engel, Structural Principles, 1984

Design of Steel Beam

Example

5. Add member self load to M and recheck Fb (we skip this step here)

7. Check shear stress:

Allowable Stress

Fv = 0.40 Fy

Actual Stress

fv=V/(t_wd)

fv ≤ Fv

$$F_v = 0.40(50\text{ KSI})$$

$$F_v = 20\text{ KSI}$$

$$V = \frac{w\ell}{2} = \frac{1.25\text{ KLF }(32')}{2}$$

$$V = 20^{K}$$

$$f_v = \frac{V}{t_w d}$$

$$f_v = \frac{20}{(0.305)(16.01)} = 4.09\text{ KSI}$$

$4.09 < 20$ ✓ OK

Design of Steel Beam

Example

6. Check Deflections

calculate actual deflection

$$\Delta_{\text{℄}} = \frac{5 w l^4}{384 EI}$$

$$= \frac{5(1.25^{KSI})(32')^4(1728)}{384\,(29000^{KSI})(518\text{ in}^4)}$$

$$= 1.96''$$

compare to code limits

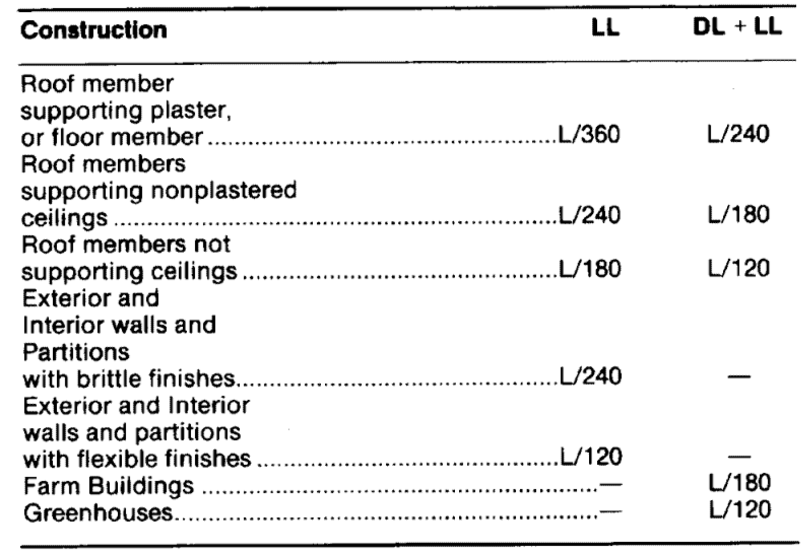
$$\frac{l}{240} = \frac{32'(12)}{240} = 1.6''$$

$$\frac{l}{120} = \frac{32'(12)}{120} = 3.2''$$

if the actual deflection

exceeds the code limit

a stiffer section is needed



Construction	LL	DL + LL
Roof member supporting plaster, or floor member	L/360	L/240
Roof members supporting nonplastered ceilings	L/240	L/180
Roof members not supporting ceilings	L/180	L/120
Exterior and Interior walls and Partitions with brittle finishes	L/240	—
Exterior and Interior walls and partitions with flexible finishes	L/120	—
Farm Buildings	—	L/180
Greenhouses	—	L/120

Source: Standard Building Code, 1991

Composite Design

Steel W section with concrete slab “attached” by shear studs.

The slab acts as a wider and thicker compression flange.

Source: University of Michigan, Department of Architecture

Source: University of Michigan, Department of Architecture

Effective Flange Width

Slab on both sides:

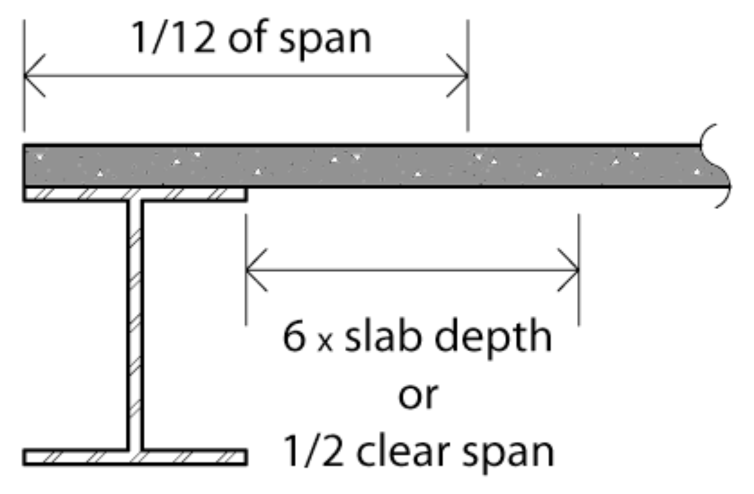
(Least of the three)

- Total width: ¼ of the beam span
- Overhang: 8 x slab thickness
- Overhang: ½ the clear distance to next beam (i.e. the web on center spacing)

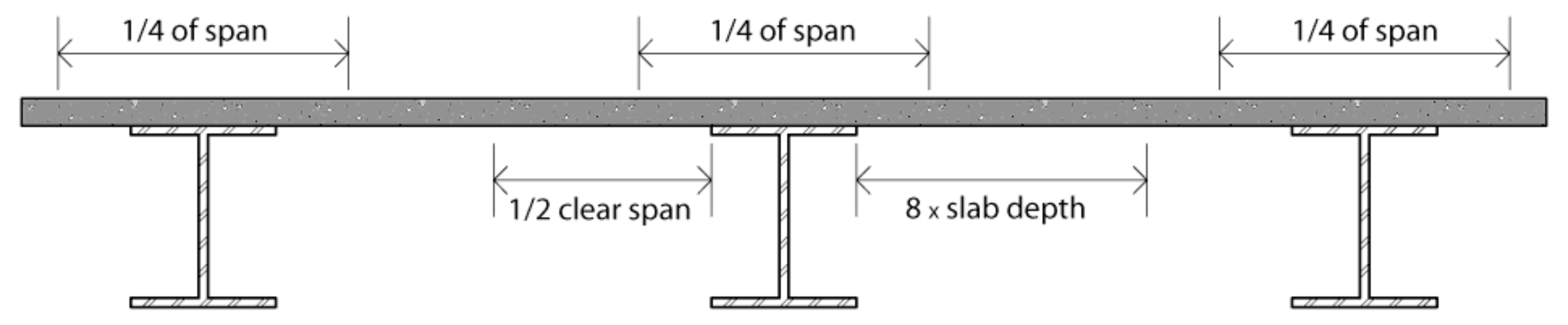
Slab on one side:

(Least of the three)

- Total width: 1/12 of the beam span
- Overhang: 6 x slab thickness
- Overhang: ½ the clear distance to next beam



Source: University of Michigan, Department of Architecture



Source: University of Michigan, Department of Architecture

Analysis Procedure

1. Define effective flange width
2. Calculate n = Ec/Es
3. Transform Concrete width = n b_c
4. Calculate Transformed I_{tr}
   do NOT include concrete in tension

5. If load is known, calculate stress

   or

6. If finding maximum load use allowable stresses. The lesser M will determine which material controls the section.

$$f_{steel} = \frac{Mc}{I_{tr}}$$

$$f_{conc} = \frac{Mc \cdot n}{I_{tr}}$$

$$M_s = \frac{F_{steel} I_{tr}}{c}$$

$$M_c = \frac{F_{conc} I_{tr}}{c \cdot n}$$

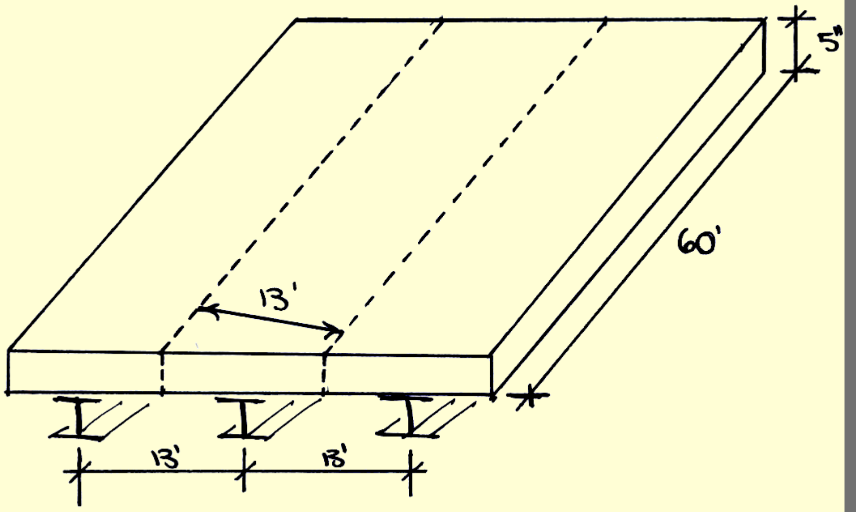
Non-composite vs. Composite Sections

Given:

- DL_{slab} = 62.5 psf
- DL_{beam} = 135 plf
- n = 1/9
- f_{steel} = 24 ksi (Fy = 36)
- f_{conc} = 1.35 ksi

For this example the floor capacity is found for two different floor systems:

1. Find capacity of steel section independent from slab
2. Find capacity of steel and slab as a composite



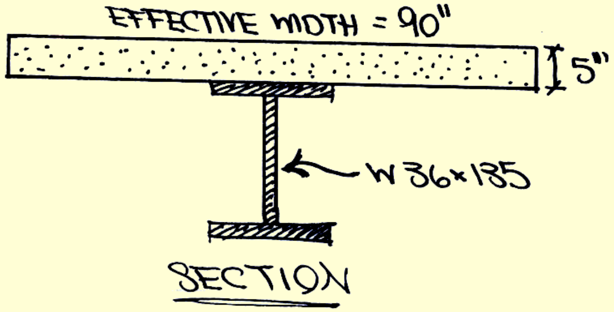
TRIBUTARY AREA

13'×60' = 780 sf

CONCRETE SLAB WEIGHT

$\frac{5"}{12}$ ×150 plf = 62.5 psf

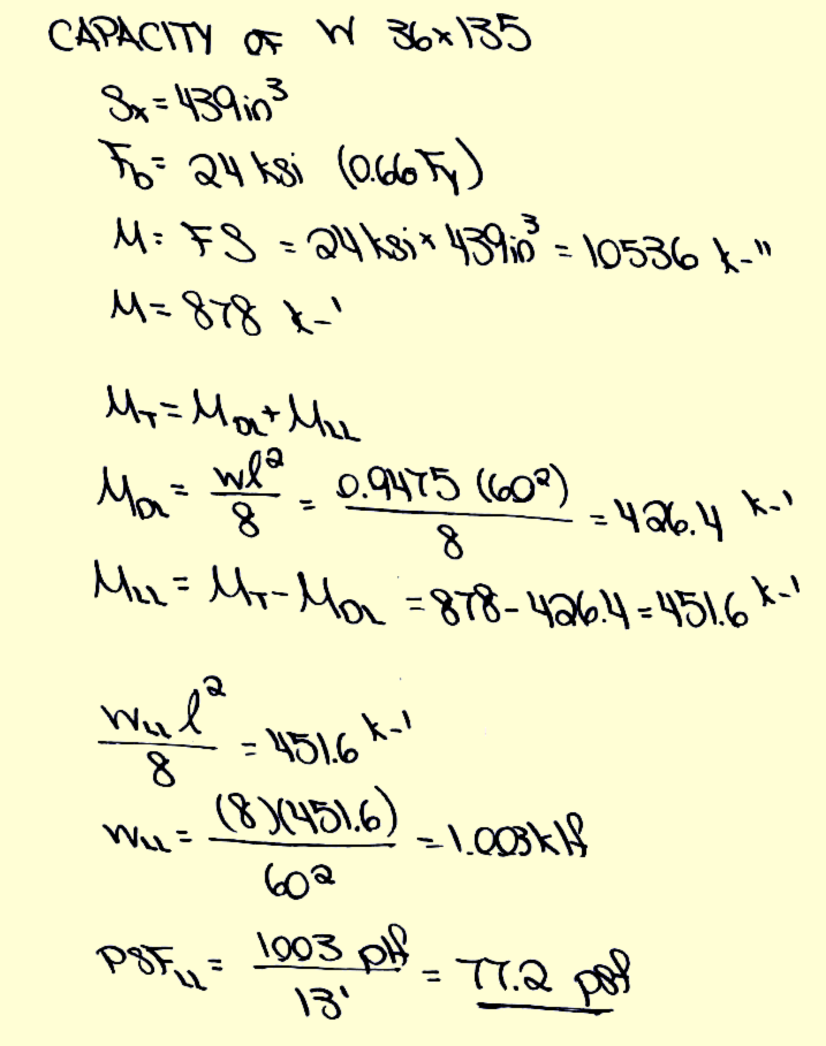
13'×62.5 = 812.5 plf



Source: University of Michigan, Department of Architecture

Part 1 Non-composite Analysis

- Find section modulus, S_x in chart.
- Assume an allowable stress, Fb.
- Determine the total moment capacity of the section, M.
- Subtract the DL moment to find the remaining LL moment.
- Calculate LL capacity in PSF.



CAPACITY OF W 36×135

$S_x = 439 in^3$

$F_b = 24 ksi \ (0.66 F_y)$

$M = FS = 24 ksi \times 439 in^3 = 10536$ k-"

$M = 878$ k-'

$M_T = M_{DL} + M_{LL}$

$M_{DL} = \frac{wl^2}{8} = \frac{0.9475 (60^2)}{8} = 426.4$ k-'

$M_{LL} = M_T - M_{DL} = 878 - 426.4 = 451.6$ k-'

$\frac{w_{LL} l^2}{8} = 451.6$ k-'

$w_{LL} = \frac{(8)(451.6)}{60^2} = 1.003$ klf

$PSF_{LL} = \frac{1003 \text{ plf}}{13'} = \underline{77.2 \text{ psf}}$

Source: University of Michigan, Department of Architecture

Part 2 - Composite Analysis

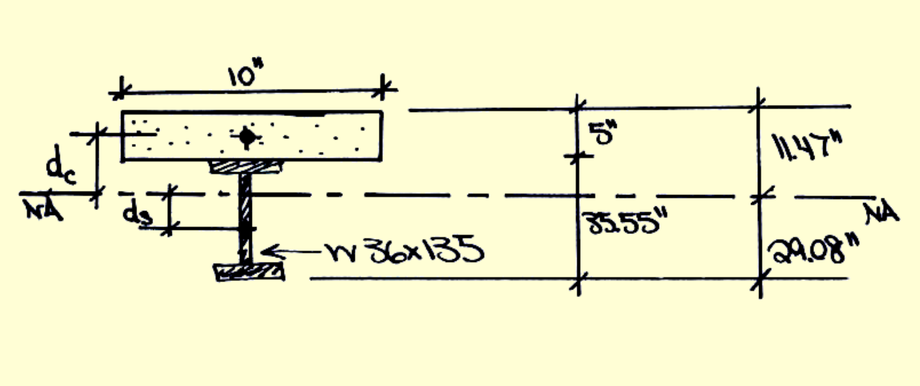
1. Determine effective width of slab.
   (using 90”y92”)

2. Find n=Ec/Es (1/9)

3. Draw transformed section (transform the concrete)

4. Calculate Transformed I_x:

   - Locate neutral axis.



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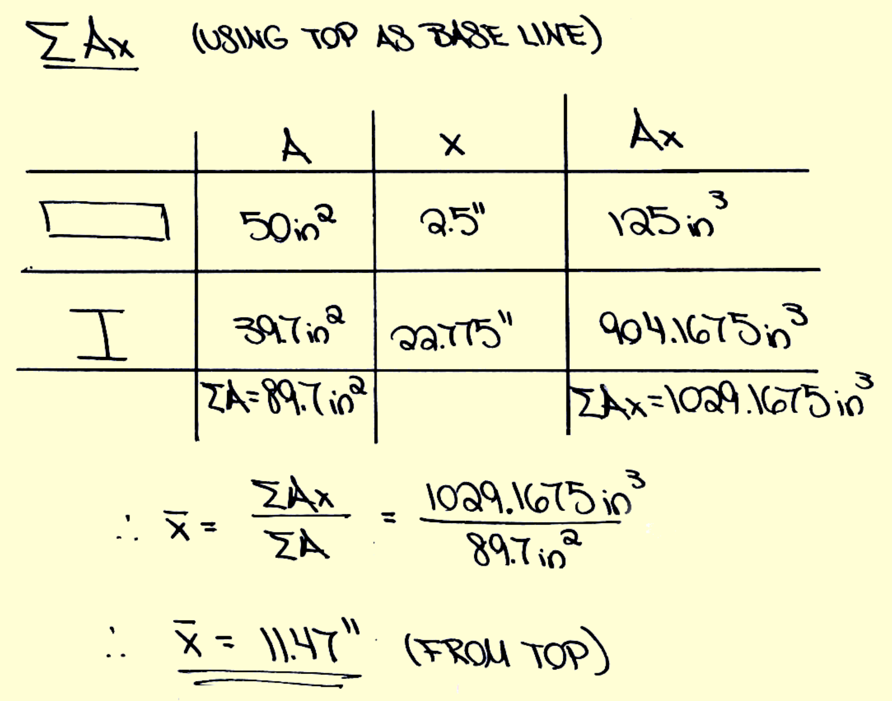


$\underline{\Sigma Ax}$ (USING TOP AS BASE LINE)

	A	x	Ax
▭	50 in^2	2.5"	125 in^3
I	39.7 in^2	22.775"	904.1675 in^3
	$\Sigma A = 89.7$ in^2		$\Sigma Ax = 1029.1675$ in^3

$$\therefore \bar{x} = \frac{\Sigma Ax}{\Sigma A} = \frac{1029.1675 \text{ in}^3}{89.7 \text{ in}^2}$$

$$\therefore \underline{\bar{x} = 11.47''} \text{ (FROM TOP)}$$

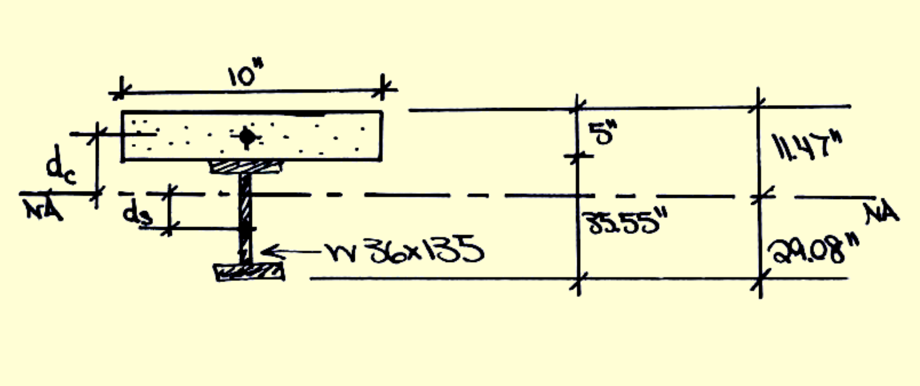
Source: University of Michigan, Department of Architecture

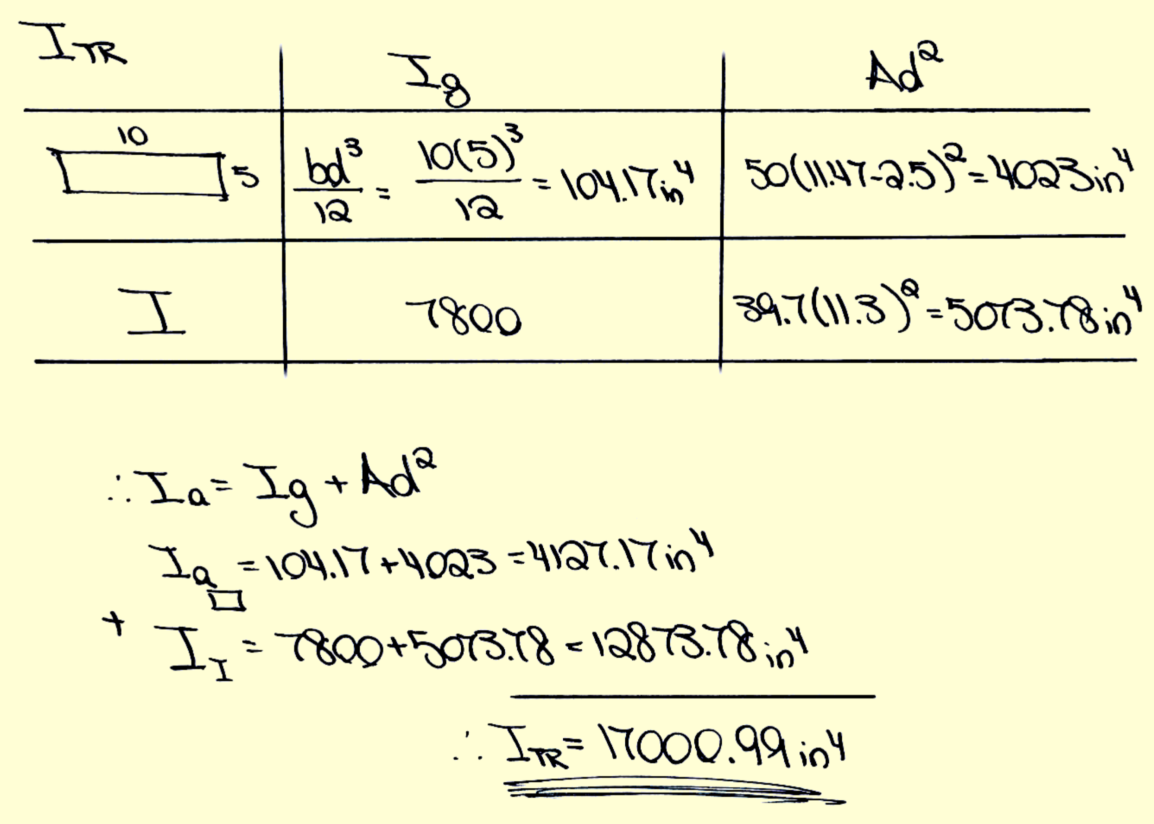
Composite Analysis cont.

4. Calculate Transformed Ix:

   Use parallel axis theorem.

$$I_a=I_g+Ad^2$$





I_{TR}	I_g	Ad^2
10 5	$\frac{bd^3}{12} = \frac{10(5)^3}{12} = 104.17 in^4$	$50(11.47-2.5)^2 = 4023 in^4$
I	7800	$39.7(11.3)^2 = 5073.78 in^4$

$$\therefore I_a = I_g + Ad^2$$

$$I_{a_\square} = 104.17 + 4023 = 4127.17 in^4$$

$$+ \quad I_I = 7800 + 5073.78 = 12873.78 in^4$$

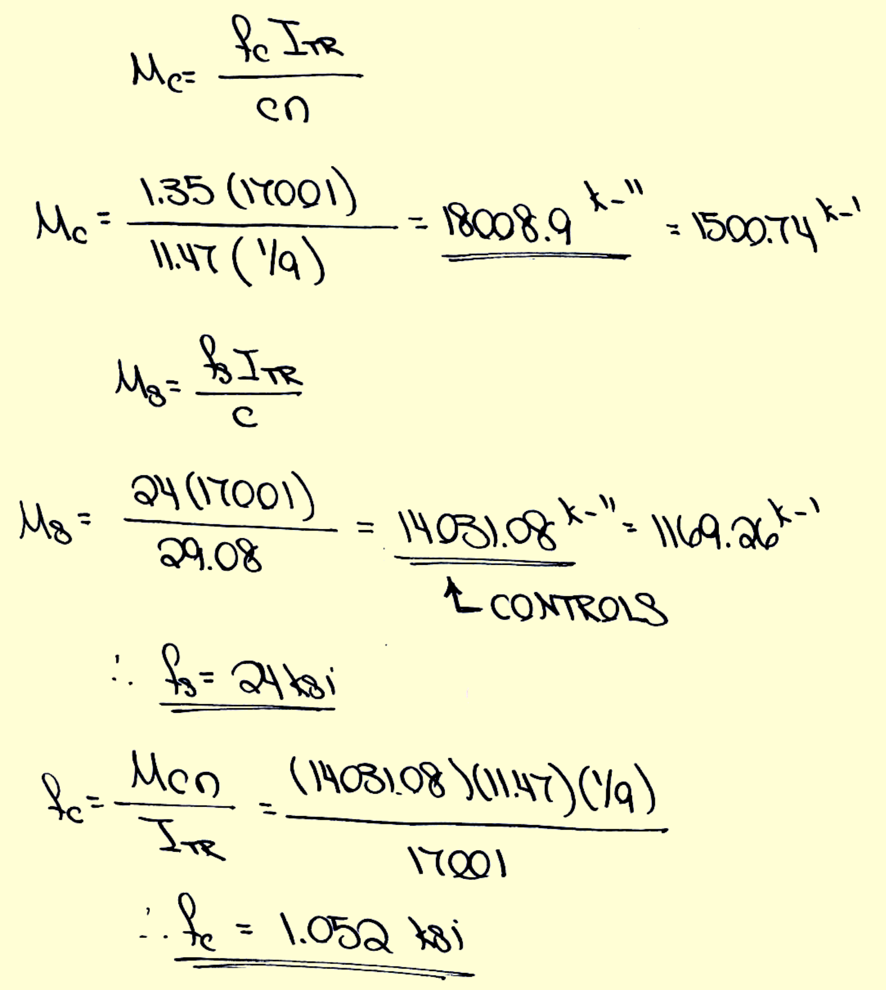
$$\therefore I_{TR} = 17000.99 in^4$$

Source: University of Michigan, Department of Architecture

Composite Analysis cont.

5. Calculate moment capacity for steel and concrete each assuming full allowable stress level.

6. Choose the smaller moment. It will control capacity.



$$M_c = \frac{f_c I_{TR}}{cn}$$

$$M_c = \frac{1.35(17001)}{11.47(1/9)} = \underline{18008.9^{k\text{-}''}} = 1500.74^{k\text{-}'}$$

$$M_s = \frac{f_s I_{TR}}{c}$$

$$M_s = \frac{24(17001)}{29.08} = \underline{14031.08^{k\text{-}''}} = 1169.26^{k\text{-}'}$$

↑ CONTROLS

$$\therefore \underline{f_s = 24\,ksi}$$

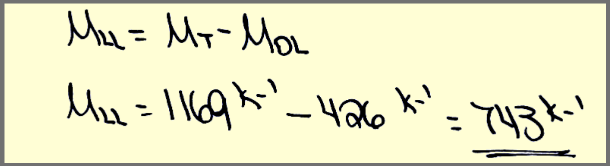
$$f_c = \frac{Mcn}{I_{TR}} = \frac{(14031.08)(11.47)(1/9)}{17001}$$

$$\therefore \underline{f_c = 1.052\,ksi}$$

Source: University of Michigan, Department of Architecture

Composite Analysis cont.

7. Subtract the DL moment to find the remaining LL moment.

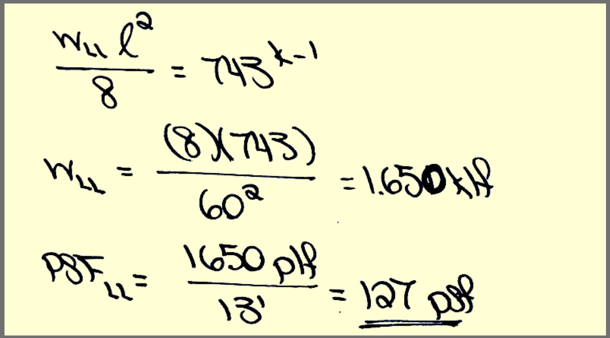


$$M_{LL} = M_T - M_{DL}$$

$$M_{LL} = 1169^{k\text{-}'} - 426^{k\text{-}'} = \underline{743^{k\text{-}'}}$$

Source: University of Michigan, Department of Architecture

8. Calculate the LL in PSF based on the M_{LL}.



$$\frac{w_{LL}\,\ell^2}{8} = 743^{k\text{-}'}$$

$$w_{LL} = \frac{(8)(743)}{60^2} = 1.650\ \text{klf}$$

$$PSF_{LL} = \frac{1650\ \text{plf}}{13'} = \underline{127\ \text{psf}}$$

Source: University of Michigan, Department of Architecture