CE 415
DESIGN OF STEEL STRUCTURES

LECTURE 16
FLEXURAL MEMBER (CONT.)

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OUTLINE

- Slender flange section
- Laterally supported beam
- Beam moment capacity (Math problem)

Slender Flange Sections

When the width/thickness ratio λ $[=b_f/(2t_f)]$ exceeds the limit λ_r of AISC-B4, the section is referred to as "slender" and must be treated in accordance with AISC-F3.2(b). The nominal strength of such a section is

$$M_n = \frac{0.9 E k_c S_x}{\lambda^2}$$ [Eq. F3-2, page 49, AISC 360-05]

$$k_c = \frac{4}{\sqrt{h/t_w}}, \text{ where } 0.35 \le k_c \le 0.763$$

LATERALLY SUPPORTED BEAMS: LRFD Design

The strength requirement for beams in load and resistance factor design according to AISC-F1 may be stated

$$\phi_b M_n \geq M_u$$

where ϕ_b = resistance (i.e., strength reduction) factor for flexure = 0.90

M_n = nominal moment strength

M_u = factored service load moment

LATERALLY SUPPORTED BEAMS: ASD Design

The strength requirement for beams in allowable strength design according to AISC-FI may be stated

$$\frac{M_n}{\Omega_b} \geq M_a$$

where M_a = required strength, which equals the service load moment

M_n/Ω_b = allowable flexural strength

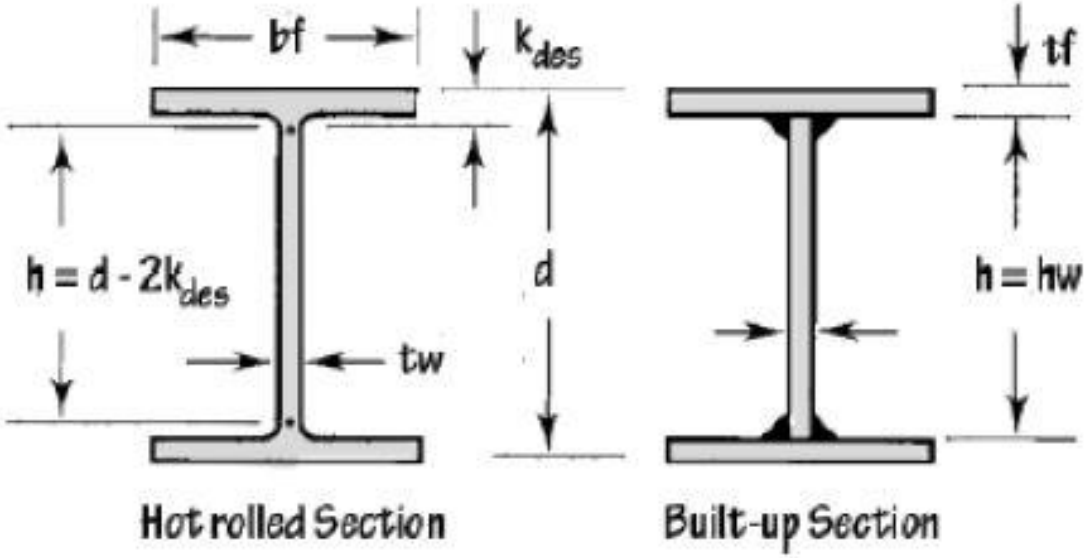
M_n = nominal flexural strength,

Ω_b = safety factor equal to 1.67 according to AISC-F1

AISC classifies cross-sectional shapes in following three categories based on width-to-thickness ratio (λ).

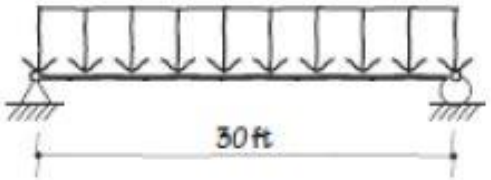
- *Compact*, if $\lambda < \lambda_p$. The section can fully utilize its material strength (plastic moment) and there is no local buckling
- *Noncompact*, if $\lambda_p < \lambda < \lambda_r$. The section cannot fully utilize its material strength. Buckling may occur inelastically or elastically before reaching to plastic moment
- *Slender*, if $\lambda_r < \lambda$. The section definately reaches elastic buckling prior to plastic moment.

Element	λ	λ_p	λ_r
Flange	$\frac{b_f}{2t_f}$	$0.38\sqrt{\frac{E}{F_y}}$	$1.0\sqrt{\frac{E}{F_y}}$
Web	$\frac{h}{t_w}$	$3.76\sqrt{\frac{E}{F_y}}$	$5.7\sqrt{\frac{E}{F_y}}$



b_f	Flange width
t_f	Flange thickness
h_w	Web height
t_w	Web thickness
d	Total depth
h	Unstiffened web height
k_{des}	Distance from outer surface of flange to depth of fillet radius

Problem. The following beam is W 16× 31 of A992 steel. It supports a reinforced concrete floor slab that provides continuous lateral support of compression flange. The service dead load is 450 lb/ft and service live load is 550 lb/ft. Does the beam has adequate moment strength?



W16X31, A992

DL = 450 lb/ft (excluding self weight)
LL = 550 lb/ft

Flange Check

From Table 1-1, $b_f = 5.53$ in, $t_f = 0.44$ in.

$$\lambda = \frac{b_f}{2t_f} = \frac{5.53}{2\times 0.44} = 6.28$$

$$\lambda_p = 0.38\sqrt{E/F_y} = 0.38\sqrt{29000/50} = 9.15 > 6.28$$

Since, $\lambda < \lambda_p$ for flange, there is no local buckling in flange.

Web Check

From Table 1-1, $d = 15.9$ in, $k_{des} = 0.842$ in and $t_w = 0.275$ in

$$\lambda = \frac{h}{t_w} = \frac{d - 2k_{des}}{t_w} = \frac{15.9 - 2\times 0.842}{0.275} = 51.7$$

$$\lambda_p = 3.76\sqrt{E/F_y} = 3.76\sqrt{29000/50} = 90.5 > 51.7$$

Since, $\lambda < \lambda_p$ for web, there is no local buckling in web either.

Determine Capacity

Since, both flange and web have no local buckling, the section can reach up to plastic moment before failure.
From Table 1-1, $Z_x = 54 \text{ in}^3$.

$$M_p = F_y Z_x = 50\times 54 = 2700 \text{ k-in}$$
$$\phi_b M_n = \phi_b M_p = 0.9\times 2700 \text{ k-in} = 2430 \text{ k-in} 202.5 \text{ k-ft}$$

Determine Demand

The dead load should be increased by self weight (31 lb/ft) of the beam since given dead load (450 lb/ft) is excluded of self weight.

$$w_D = 450 + 31 = 481 \text{ lb/ft}$$
$$w_L = 550 \text{ lb/ft}$$
$$w_u = 1.2 w_D + 1.6 w_L$$
$$= 1.2\times 481 + 1.6\times 550 = 1457 \text{ lb/ft} = 1.46 \text{ k/ft}$$
$$M_u = \frac{w_u L^2}{8} = \frac{1.46\times 30^2}{8} = 164.3 \text{ k-ft} < \phi_b M_n$$

Since, $\phi_b M_n (202.5 \text{ k-ft}) > M_u (164.3 \text{ k-ft})$, the section W 16×31 has adequate moment capacity.

Ans. Yes. The beam has adequate moment strength.

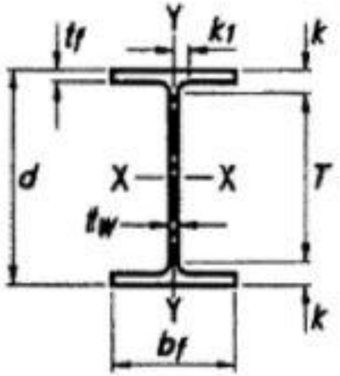


Table 1–1 (continued)
W Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k k_{des}	Distance k k_{det}	k_1	T	Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W16×100	29.5	17.0	17	0.585	9/16	5/16	10.4	10 3/8	0.985	1	1.39	1 7/8	1 1/8	13 1/4	5 1/2
×89	26.2	16.8	16 3/4	0.525	1/2	1/4	10.4	10 3/8	0.875	7/8	1.28	1 3/4	1 1/16		
×77	22.6	16.5	16 1/2	0.455	7/16	1/4	10.3	10 1/4	0.760	3/4	1.16	1 5/8	1 1/16		
×67[c]	19.7	16.3	16 3/8	0.395	3/8	3/16	10.2	10 1/4	0.665	11/16	1.07	1 9/16	1		
W16×57	16.8	16.4	16 3/8	0.430	7/16	1/4	7.12	7 1/8	0.715	11/16	1.12	1 3/8	7/8	13 5/8	3 1/2[g]
×50[c]	14.7	16.3	16 1/4	0.380	3/8	3/16	7.07	7 1/8	0.630	5/8	1.03	1 5/16	13/16		
×45[c]	13.3	16.1	16 1/8	0.345	3/8	3/16	7.04	7	0.565	9/16	0.967	1 1/4	13/16		
×40[c]	11.8	16.0	16	0.305	5/16	3/16	7.00	7	0.505	1/2	0.907	1 3/16	13/16		
×36[c]	10.6	15.9	15 7/8	0.295	5/16	3/16	6.99	7	0.430	7/16	0.832	1 1/8	3/4		
W16×31[c]	9.13	15.9	15 7/8	0.275	1/4	1/8	5.53	5 1/2	0.440	7/16	0.842	1 1/8	3/4	13 5/8	3 1/2
×26[c,v]	7.68	15.7	15 3/4	0.250	1/4	1/8	5.50	5 1/2	0.345	3/8	0.747	1 1/16	3/4	13 5/8	3 1/2
W14×730[h]	215	22.4	22 3/8	3.07	3 1/16	1 9/16	17.9	17 7/8	4.91	4 15/16	5.51	6 3/16	2 3/4	10	3-7 1/2-3[g]
×665[h]	196	21.6	21 5/8	2.83	2 13/16	1 7/16	17.7	17 5/8	4.52	4 1/2	5.12	5 13/16	2 5/8		3-7 1/2-3[g]

Table 1–1 (continued)
W Shapes
Properties

W16 – W14

Nom-inal 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}
100	5.29	24.3	1490	175	7.10	198	186	35.7	2.51	54.9	2.92	16.0	7.73	11900
89	5.92	27.0	1300	155	7.05	175	163	31.4	2.49	48.1	2.88	15.9	5.45	10200
77	6.77	31.2	1110	134	7.00	150	138	26.9	2.47	41.1	2.85	15.8	3.57	8590
67	7.70	35.9	954	117	6.96	130	119	23.2	2.46	35.5	2.82	15.7	2.39	7300
57	4.98	33.0	758	92.2	6.72	105	43.1	12.1	1.60	18.9	1.92	15.7	2.22	2660
50	5.61	37.4	659	81.0	6.68	92.0	37.2	10.5	1.59	16.3	1.89	15.6	1.52	2270
45	6.23	41.1	586	72.7	6.65	82.3	32.8	9.34	1.57	14.5	1.88	15.6	1.11	1990
40	6.93	46.5	518	64.7	6.63	73.0	28.9	8.25	1.57	12.7	1.86	15.5	0.794	1730
36	8.12	48.1	448	56.5	6.51	64.0	24.5	7.00	1.52	10.8	1.83	15.4	0.545	1460
31	6.28	51.6	375	47.2	6.41	54.0	12.4	4.49	1.17	7.03	1.42	15.4	0.461	739
26	7.97	56.8	301	38.4	6.26	44.2	9.59	3.49	1.12	5.48	1.38	15.3	0.262	565
730	1.82	3.71	14300	1280	8.17	1660	4720	527	4.69	816	5.68	17.5	1450	362000
665	1.95	4.03	12400	1150	7.98	1480	4170	472	4.62	730	5.57	17.1	1120	305000