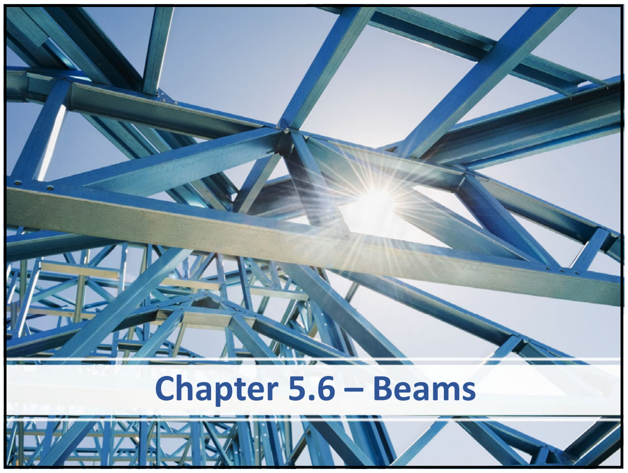
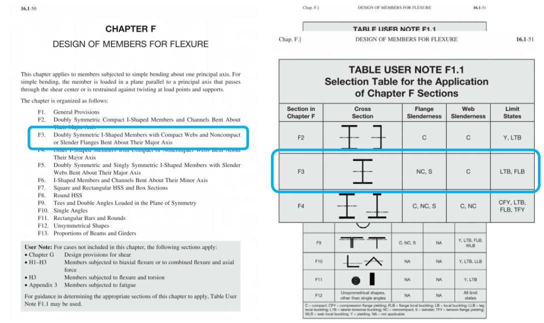


Chapter 5.6 – Beams

1

Chapter 5 – Noncompact Shapes

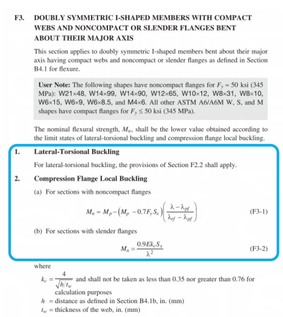
- For flexural members with compact webs and noncompact or slender flanges, refer to **AISC F3**.



2

Chapter 5 – Noncompact Shapes

- For flexural members with compact webs and noncompact or slender flanges, refer to **AISC F3**.



3

Chapter 5 – Noncompact Shapes

- For ***flange local buckling***, if $\lambda_{pf} < \lambda < \lambda_{rf}$, the flange is ***noncompact***, and buckling will be inelastic:

$$M_n = C_b\left[M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}}\right)\right]$$ ***AISC Equation F3-1***

$$\lambda = \frac{b_f}{2t_f} \qquad \lambda_{pf} = 0.38\sqrt{\frac{E}{F_y}} \qquad \lambda_{rf} = 1.0\sqrt{\frac{E}{F_y}}$$ From **Table B4.1b**

- The webs of all hot-rolled shapes in the Manual are ***compact***, so the ***noncompact*** shapes are subject only to the limit states of ***lateral-torsional buckling*** and ***flange local buckling***.

4

Chapter 5 – Noncompact Shapes

- For ***flange local buckling***, if $\lambda_{pf} < \lambda < \lambda_{rf}$, the flange is ***noncompact***, and buckling will be inelastic:

$$M_n = C_b\left[M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}}\right)\right]$$ ***AISC Equation F3-1***

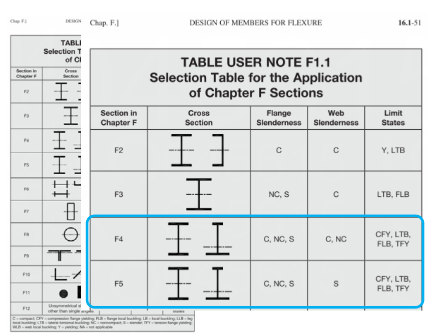
$$\lambda = \frac{b_f}{2t_f} \qquad \lambda_{pf} = 0.38\sqrt{\frac{E}{F_y}} \qquad \lambda_{rf} = 1.0\sqrt{\frac{E}{F_y}}$$ From **Table B4.1b**

- Built-up welded shapes, however, can have ***noncompact*** or ***slender webs*** as well as ***noncompact or slender flanges.***

5

Chapter 5 – Noncompact Shapes

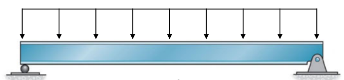
- These cases are covered in **AISC** Sections **F4** and **F5**.



6

Chapter 5 – Noncompact Shapes

- **Example 5.6**: Consider the simply supported beam shown.
- The beam is subjected to a dead load = 0.5 *k/ft* (including the weight of the beam) and live load = 1 *k/ft*.
- If F_y = 50 *ksi*, is a **W12 x 65** adequate?



30 *ft*

7

Chapter 5 – Noncompact Shapes

- **Example 5.6**: Check for compactness.

From Table 1-1 (**1**-26) for a **W12 x 65**

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_{des}	k_{det}	k_1	T	Workable Gage
	in.²	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
×152	44.7	13.7	13¾	0.870	7/8	7/16	12.5	12½	1.40	1⅜	[illegible]	[illegible]	[illegible]		
×136	39.9	13.4	13⅜	0.790	13/16	7/16	12.4	12⅜	1.25	1¼	[illegible]	[illegible]	[illegible]		
×120	35.2	13.1	13⅛	0.710	11/16	3/8	12.3	12⅜	1.11	1⅛	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	0.610	5/8	5/16	12.2	12¼	0.990	1	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	0.550	9/16	5/16	12.2	12⅛	0.900	7/8	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	0.515	1/2	1/4	12.1	12⅛	0.810	13/16	1.41	1 11/16	1 1/16		
×79	23.2	12.4	12⅜	0.470	1/2	1/4	12.1	12⅛	0.735	3/4	1.33	1⅝	1 1/16		
×72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
×65[f]	19.1	12.1	12⅛	0.390	3/8	3/16	12.0	12	0.605	5/8	1.20	1½	1	↓	↓
W12×58	17.0	12.2	12¼	0.360	3/8	3/16	10.0	10	0.640	5/8	1.24	1½	15/16	9¼	5½
×53	15.6	12.1	12	0.345	3/8	3/16	10.0	10	0.575	9/16	1.18	1⅜	15/16	9¼	5½
W12×50	14.6	12.2	12¼	0.370	3/8	3/16	8.08	8⅛	0.640	5/8	1.14	1½	15/16	9¼	5½
×45	13.1	12.1	12	0.335	5/16	3/16	8.05	8	0.575	9/16	1.08	1⅜	15/16	↓	↓
×40	11.7	11.9	12	0.295	5/16	3/16	8.01	8	0.515	1/2	1.02	1⅜	7/8	↓	↓

Section has footnote **f**

[f] Shape exceeds the compact limit for flexure with F_y = 50 ksi.

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Chapter 5 – Noncompact Shapes

- **Example 5.6**: Here, we will ***manually*** check for compactness.

From Table 1-1 (**1**-27) for a **W12 x 65**

Table 1-1 (continued)
W-Shapes
Properties
W14–W12

Nominal 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
87	7.48	18.9	740	118	5.38	132	241	39.7	3.07	60.4	3.46	11.7	5.10	8270
79	8.22	20.7	662	107	5.34	119	216	35.8	3.05	54.3	3.43	11.7	3.84	7330
72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
65	9.92	24.9	533	87.9	5.28	96.8	174	29.1	3.02	44.1	3.38	11.5	2.18	5780
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

$$\frac{b_f}{2t_f} = 9.92$$

$$S_x = 87.9 in^3$$

$$Z_x = 96.8 in^3$$

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Chapter 5 – Noncompact Shapes

- **Example 5.6**: Check for compactness.

From **Table B4.1b**, the limiting width-to-thickness ratios are:

TABLE B4.1b
Width-to-Thickness Ratios: Compression Elements
Members Subjected to Flexure

	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio λ_p (compact/noncompact)	λ_r (noncompact/slender)	Examples
Unstiffened Elements	10	(1) Flanges of rolled I-shaped sections (2) Flanges of channels (3) Flanges of tees	b/t	$0.38\sqrt{\frac{E}{F_y}}$	$1.0\sqrt{\frac{E}{F_y}}$	
	11	Flanges of doubly and singly symmetric I-shaped built-up sections	b/t	$0.38\sqrt{\frac{E}{F_y}}$	$0.95\sqrt{\frac{k_cE}{F_L}}$	
	12	Legs of single angles	b/t	$0.54\sqrt{\frac{E}{F_y}}$	$0.91\sqrt{\frac{E}{F_y}}$	
	13	Flanges of all I-shaped sections and channels in flexure about the minor axis	b/t	$0.38\sqrt{\frac{E}{F_y}}$	$1.0\sqrt{\frac{E}{F_y}}$	
	14	Stems of tees	d/t	$0.84\sqrt{\frac{E}{F_y}}$	$1.52\sqrt{\frac{E}{F_y}}$	

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Chapter 5 – Noncompact Shapes

- **Example 5.6**: Check for compactness.

From **Table B4.1b**, the limiting width-to-thickness ratios are:

$$\lambda_{pf} = 0.38\sqrt{\frac{E}{F_y}} = 0.38\sqrt{\frac{29{,}000ksi}{50ksi}} = 9.15$$

$$\lambda_{rf} = 1.0\sqrt{\frac{E}{F_y}} = 1.0\sqrt{\frac{29{,}000ksi}{50ksi}} = 24.08$$

$$\lambda = \frac{b_f}{2t_f} = 9.92$$

Since $\lambda_{pf} < \lambda < \lambda_{rf}$, this shape is: ***noncompact***

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Chapter 5 – Noncompact Shapes

- **Example 5.6**: Check the capacity based on the limit state of ***flange local buckling***:

$$M_n = \left[M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}}\right)\right]$$ ***AISC Equation F3-1***

$$M_p = F_yZ_x = 50ksi\left(96.8in^3\right) = 4{,}840k\,in$$

$$0.7F_yS_x = 0.7\left(50ksi\right)\left(87.9in^3\right) = 3{,}076.5k\,in$$

$$M_n = \left[4{,}840k\,in - \left(4{,}840kin - 3{,}076.5k\,in\right)\left(\frac{9.92 - 9.15}{24.08 - 9.15}\right)\right]$$

$$= 4{,}749.25k\,in \le M_p = 4{,}840k\,in$$

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Chapter 5 – Noncompact Shapes

- **Example 5.6**: Check the capacity based on the ***lateral-torsional buckling limit state***. From the $\boldsymbol{Z_x}$ table, Table 3-2 (**3**-25):

F_y = 50 ksi — Table 3-2 (continued) **W-Shapes** Selection by Z_x — Z_x

Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF/Ω_b	$\phi_b BF$	L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.^{3}	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.^{4}	ASD	LRFD
W21×50	**110**	**274**	**413**	**165**	**248**	**12.1**	**18.3**	**4.59**	**13.6**	**984**	**158**	**237**
W12×72	108	269	405	170	256	3.69	5.56	10.7	37.5	597	106	159
W21×48[f]	**107**	**265**	**398**	**162**	**244**	**9.89**	**14.8**	**6.09**	**16.5**	**959**	**144**	**216**
W16×57	105	262	394	161	242	7.98	12.0	5.65	18.3	758	141	212
W14×61	102	254	383	161	242	4.93	7.48	8.65	27.5	640	104	156
W18×50	101	252	379	155	233	8.76	13.2	5.83	16.9	800	128	192
W12×65[f]	96.8	237	356	154	231	3.58	5.39	11.9	35.1	533	94.4	142
W21×44	**95.4**	**238**	**358**	**143**	**214**	**11.1**	**16.8**	**4.45**	**13.0**	**843**	**145**	**217**
W16×50	92.0	230	345	141	213	7.69	11.4	5.62	17.2	659	124	186

$L_p = 11.9\,ft$

$L_r = 35.1\,ft$

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Chapter 5 – Noncompact Shapes

- **Example 5.6**: Check the capacity based on the ***lateral-torsional buckling limit state***. From the $\boldsymbol{Z_x}$ table, Table 3-2 (**3**-25):

$L_b = 30\,ft \qquad L_p < L_b < L_r \qquad \therefore$ Failure is by ***inelastic LTB***

F_y = 50 ksi — Table 3-2 (continued) **W-Shapes** Selection by Z_x — Z_x

Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF/Ω_b	$\phi_b BF$	L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.^{3}	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.^{4}	ASD	LRFD
W21×50	**110**	**274**	**413**	**165**	**248**	**12.1**	**18.3**	**4.59**	**13.6**	**984**	**158**	**237**
W12×72	108	269	405	170	256	3.69	5.56	10.7	37.5	597	106	159
W21×48[f]	**107**	**265**	**398**	**162**	**244**	**9.89**	**14.8**	**6.09**	**16.5**	**959**	**144**	**216**
W16×57	105	262	394	161	242	7.98	12.0	5.65	18.3	758	141	212
W14×61	102	254	383	161	242	4.93	7.48	8.65	27.5	640	104	156
W18×50	101	252	379	155	233	8.76	13.2	5.83	16.9	800	128	192
W12×65[f]	96.8	237	356	154	231	3.58	5.39	11.9	35.1	533	94.4	142
W21×44	**95.4**	**238**	**358**	**143**	**214**	**11.1**	**16.8**	**4.45**	**13.0**	**843**	**145**	**217**
W16×50	92.0	230	345	141	213	7.69	11.4	5.62	17.2	659	124	186

$L_p = 11.9\,ft$

$L_r = 35.1\,ft$

14

Chapter 5 – Noncompact Shapes

- **Example 5.6**: Check the capacity based on the ***lateral-torsional buckling limit state***. From the $\boldsymbol{Z_x}$ table, Table 3-2 (**3**-25):

$L_b = 30\,ft \qquad L_p < L_b < L_r \qquad \therefore$ Failure is by ***inelastic LTB***

$$M_n = C_b\left[M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right]$$ ***AISC Equation F3-1***

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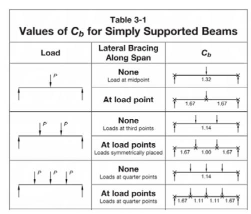
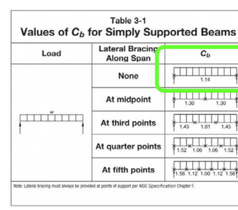
Chapter 5 – Noncompact Shapes

- **Example 5.6**: Values of $\boldsymbol{C_b}$ for other cases are available in **Table 3-1** of **Part 3 of the Manual**.





For a uniformly loaded, simply supported beam with lateral support at the ends, $\boldsymbol{C_b}$ = 1.14

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Chapter 5 – Noncompact Shapes

- **Example 5.6**: ***AISC Equation F2-2*** gives:

$$M_n = C_b\left[M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right]$$

$$= 1.14\left[4{,}840\,k\,in - \left(4{,}840\,k\,in - 3{,}076.5\,k\,in\right)\left(\frac{30ft - 11.9ft}{35.15ft - 11.9ft}\right)\right]$$

$$= \boxed{3{,}929.83\,k\,in} \; < \; M_p = 4{,}840\,k\,in$$

FLB: $M_n = 4{,}749.25\,k\,in$

Inelastic LTB: $M_n = 3{,}929.83\,k\,in$ **Controls**

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Chapter 5 – Noncompact Shapes

- **Example 5.6**: The smaller moment strength controls, in this case, lateral-torsional buckling, $\boldsymbol{M_n}$ = 3,929.83 *k in*.

The ***LRFD*** design strength is:

$$\phi_b M_n = 0.9\left(3{,}929.83\,k\,in\right) = 3{,}536.85\,k\,in = \boxed{294.74\,k\,ft}$$

The factored load and moment are:

$$w_u = 1.2w_D + 1.6w_L = 1.2\left(0.5\,k/ft\right) + 1.6\left(1.0\,k/ft\right)$$

$$= 2.20\,k/ft$$

$$M_u = \frac{w_uL^2}{8} = \frac{\left(2.20\,k/ft\right)\left(30\,ft\right)^2}{8} = 247.50\,k\,ft \; < \; 294.74\,k\,ft$$

O.K.

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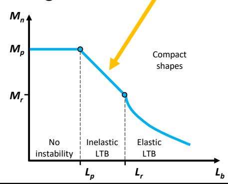
Chapter 5 – Noncompact Shapes

- Noncompact shapes are identified in the Z_x table by an "f".
- Noncompact shapes are also treated differently in the Z_x table in the following way.
- The tabulated value of L_p is the unbraced length at which the nominal strength based on ***inelastic lateral-torsional buckling*** equals ***flange local buckling*** strength.



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Chapter 5 – Noncompact Shapes

- This is the ***maximum unbraced length*** for which the nominal strength can be taken as the strength based on ***flange local buckling***.
- Recall that L_p for ***compact*** shapes is the maximum unbraced length for which the nominal strength can be taken as the ***plastic moment***.

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Chapter 5 – Noncompact Shapes

- For the shape in **Example 5.6**, equate the nominal strength based on ***FLB*** to the strength based on ***inelastic LTB*** (AISC ***Equation F2-2***), with C_b = 1.0.

$$M_n = M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{L_b - L_p}{L_r - L_p}\right) \qquad \textbf{\textit{AISC Equation F2-2}}$$

The value of L_r given in **Example 5.6** is unchanged.

The value of L_p is computed using ***AISC Equation F2-5***:

$$L_p = 1.76r_y\sqrt{\frac{E}{F_y}} = 1.76(3.02in)\sqrt{\frac{29{,}000ksi}{50ksi}} = 128.01in = 10.67ft$$

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Chapter 5 – Noncompact Shapes

- Returning to ***AISC Equation F2-2*** gives:

$$M_n = M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{L_b - L_p}{L_r - L_p}\right) \qquad \textbf{\textit{FLB}}: M_n = 4{,}749.25k\,in \quad M_p = 4{,}840k\,in$$

$$4{,}749.25k\,in = \left[4{,}840k\,in - \left(4{,}840k\,in - 3{,}076.5k\,in\right)\left(\frac{L_b - 10.67ft}{35.1ft - 10.67ft}\right)\right]$$

$$\therefore\ L_p = 11.93ft$$

- In the Z_x table, L_p = 11.9 *ft* for a **W12 x 65** with F_y = 50 *ksi*.
- In addition, the available strength values, $\phi_b M_{px}$ are based on ***flange local buckling*** rather than the ***plastic moment***.

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Chapter 5 – Moment Strength

- Let's present a summary of the procedure for the computation of ***nominal moment strength*** for ***I*** and ***C***-shaped sections bent about the ***x***-axis.
- All terms in the following equations have been previously defined.
- To safe space, the **AISC** equation numbers will not be shown.
- This summary is for ***compact*** and ***noncompact*** shapes only.
- ***Slender*** shapes are not included.

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Chapter 5 – Moment Strength

1. Determine whether the shape is ***compact***.
2. If the shape is ***compact***, check for ***lateral-torsional buckling*** as follows.

For $L_b \le L_p$ there is no ***LTB***, and $M_n = M_p$

For $L_p < L_b \le L_r$ compute inelastic ***LTB***

$$M_n = C_b\left[M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right] \le M_p$$

For $L_b > L_r$ compute elastic ***LTB*** $M_n = F_{cr}S_x \le M_p$

$$F_{cr} = \frac{C_b\pi^2E}{\left(L_b/r_{ts}\right)^2}\sqrt{1 + 0.078\frac{Jc}{S_xh_0}\left(\frac{L_b}{r_{ts}}\right)^2}$$

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Chapter 5 – Moment Strength

3. If the shape is ***noncompact*** because of the ***flange***, the nominal strength will be:

$$\min\begin{cases} \textit{flange local buckling (FLB)} \\ \textit{lateral-torsional buckling (LTB)} \end{cases}$$

a. Flange local buckling:

If $\lambda \leq \lambda_{pf}$ there is no ***FLB***, and

If $\lambda_{pf} < \lambda \leq \lambda_{rf}$ the flange is ***noncompact***, and

$$M_n = C_b\left[M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}}\right)\right]$$

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Chapter 5 – Moment Strength

3. If the shape is ***noncompact*** because of the ***flange***, the nominal strength will be:

$$\min\begin{cases} \textit{flange local buckling (FLB)} \\ \textit{lateral-torsional buckling (LTB)} \end{cases}$$

b. Lateral-torsional buckling:

If $L_b \leq L_p$ there is no ***LTB***, and

If $L_p < L_b \leq L_r$ there is inelastic ***LTB***, and

$$M_n = C_b\left[M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right] \leq M_p$$

If $L_b > L_r$ there is elastic ***LTB***, and $M_n = F_{cr}S_x \leq M_p$

$$F_{cr} = \frac{C_b\pi^2E}{\left(L_b/r_{ts}\right)^2}\sqrt{1 + 0.078\frac{Jc}{S_xh_0}\left(\frac{L_b}{r_{ts}}\right)^2}$$

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Chapter 5 – Beams

Any questions?

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