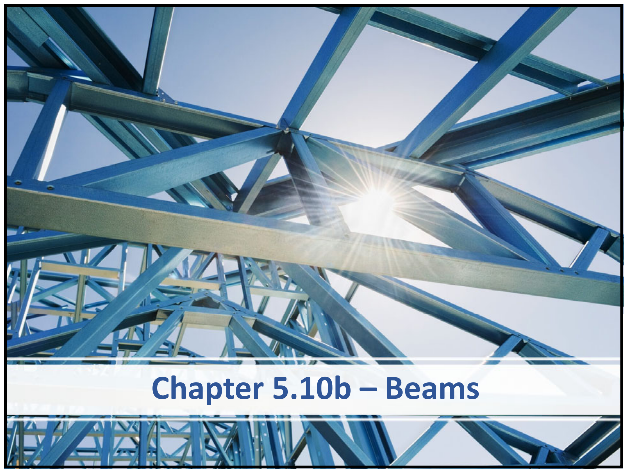


Chapter 5.10b – Beams

Chapter 5 – Design

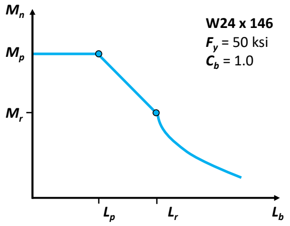
- In **Example 5.10**, it was first assumed that a ***compact*** shape would be used, and then the ***assumption was verified***.
- However, if the search is made based on available strength $\phi_b M_p$ rather than section modulus, it is irrelevant whether the shape is ***compact or noncompact***.
- This is because for noncompact shapes, the tabulated values of $\phi_b M_p$ are based on ***flange local buckling*** and not the ***plastic moment*** (see Section 5.6).
- This means that for laterally supported beams, the Z_x table can be used for design ***without regard*** to whether the shape is ***compact or noncompact***.

Chapter 5 – Beam Design Charts

- Many ***graphs, charts, and tables*** are available for the practicing engineer, and these aids can greatly simplify the ***design process.***
- It is not our purpose in this course to describe all available design aids in detail.
- However, some are worthy of note, particularly the ***curves of moment strength versus unbraced length*** given in Part 3 of the Manual.

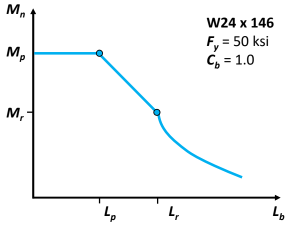
Chapter 5 – Beam Design Charts

- These curves will be described with reference to the figure below.
- This graph shows the ***nominal moment strength*** as a function of unbraced length L_b for a particular compact shape.



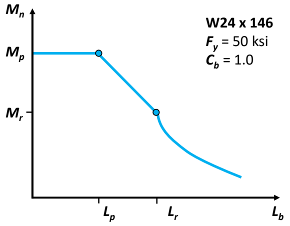
Chapter 5 – Beam Design Charts

- Such a graph can be constructed for any cross-sectional shape and specific values of F_y and C_b by using the appropriate equations for moment strength.



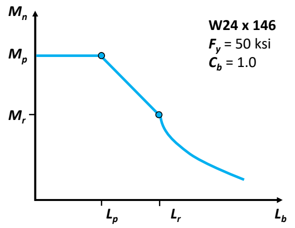
Chapter 5 – Beam Design Charts

- The ***design charts in the Manual*** comprise a family of graphs like the one shown below.
- Two sets of curves are available, one for ***W shapes*** with F_y = 50 *ksi* and one for ***C*** and ***MC*** shapes with F_y = 50 *ksi*.



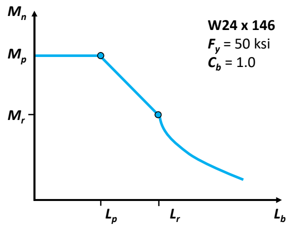
Chapter 5 – Beam Design Charts

- Each graph gives the flexural strength of a standard hot-rolled shape.
- Both the allowable moment strength M_p/Ω_b and the design moment strength $\phi_b M_p$ are given.



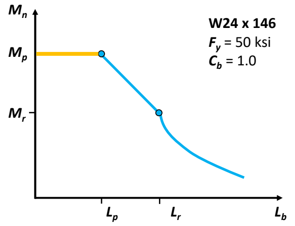
Chapter 5 – Beam Design Charts

- Two scales are shown on the vertical axis—one for M_p/Ω_b and one for $\phi_b M_p$.
- All curves were generated with C_b =1.0; for other values of C_b, multiply the moment from the chart by C_b.



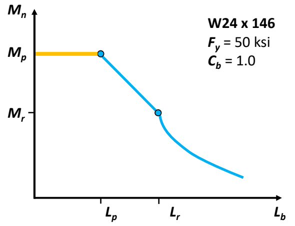
Chapter 5 – Beam Design Charts

- However, the strength can never exceed the value represented by the horizontal line at the left side of the graph.
- For a ***compact*** shape, this represents the strength corresponding to ***yielding*** (reaching the plastic moment M_p).



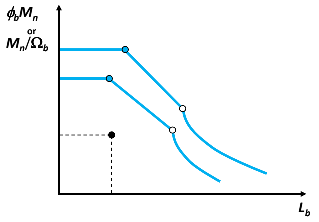
Chapter 5 – Beam Design Charts

- However, the strength can never exceed the value represented by the horizontal line at the left side of the graph.
- If the curve is for a ***noncompact*** shape, the horizontal line represents the ***flange local buckling*** strength.



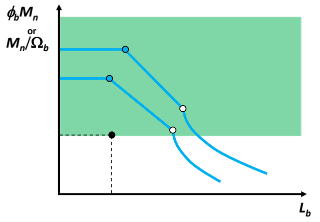
Chapter 5 – Beam Design Charts

- Use of the charts is illustrated below, where two such curves are shown.
- Any point on this graph, such as the intersection of the two dashed lines, represents an available moment strength and an unbraced length.



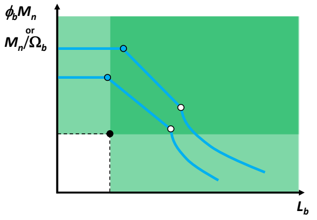
Chapter 5 – Beam Design Charts

- Use of the charts is illustrated below, where two such curves are shown.
- Any point on this graph, such as the intersection of the two dashed lines, represents an available moment strength and an unbraced length.



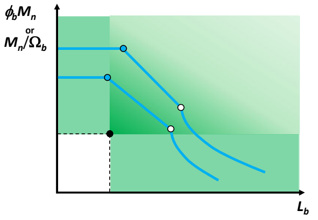
Chapter 5 – Beam Design Charts

- If the moment is a required moment capacity, then any curve ***above*** the point corresponds to a beam with a ***larger moment capacity.***
- Any curve to the ***right*** indicates a beam with ***exactly the required moment capacity***, though for a ***larger unbraced length.***



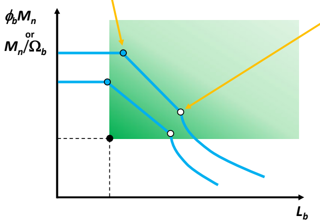
Chapter 5 – Beam Design Charts

- In a design problem, therefore, if the charts are entered with a given ***unbraced length*** and a ***required strength.***
- Curves above and to the right of the point ***correspond to acceptable beams***.



Chapter 5 – Beam Design Charts

- If a dashed portion of a curve is encountered, then a curve for a ***lighter shape lies above or to the right of the dashed curve***.
- A solid circle indicates points on the curves corresponding to L_p an open circle is represented by L_r

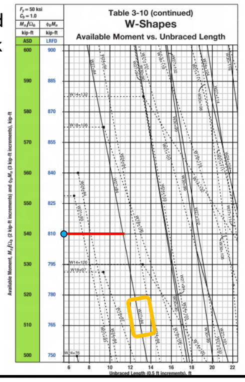


Chapter 5 – Beam Design Charts

- In the ***LRFD*** solution of **Example 5.10**, the required design strength was 810 *k ft*, and there was continuous lateral support.
- For continuous lateral support, L_b can be taken as zero.
- Although L_b = 0 is not on this chart, the smallest value of L_b shown is less than L_p for all shapes on that page.

Chapter 5 – Beam Design Charts

- From the charts, the first solid curve above the 810 *k ft* mark is for a **W24 x 84**,
- Same as **Example 5.10**.



Chapter 5 – Beam Design Charts

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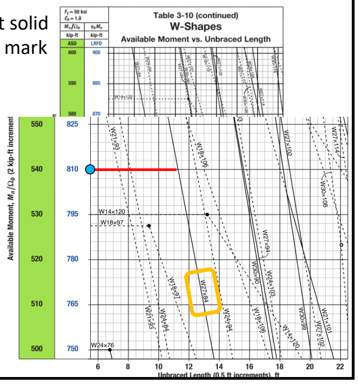
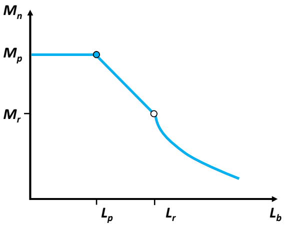
- Same as **Example 5.10**.



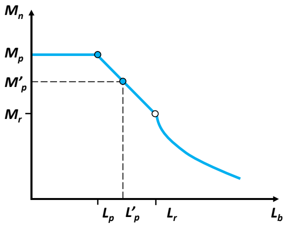
Chapter 5 – Beam Design Charts

- The beam curve shown below is for a ***compact shape***, so the value of M_n for sufficiently small values of L_b is M_p.
- As discussed in Section 5.6, if the shape is ***noncompact***, the maximum value of M_n will be based on ***flange local buckling***.



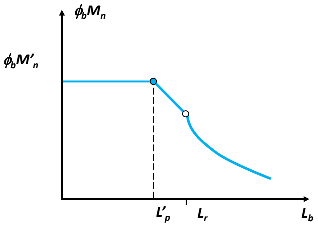
Chapter 5 – Beam Design Charts

- Consider the moment strength of ***noncompact*** shapes.
- The maximum nominal strength is denoted M'_p, and the maximum unbraced length for which this strength is valid is denoted L'_p.



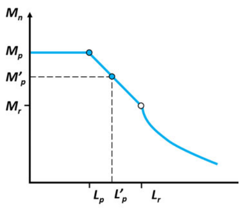
Chapter 5 – Beam Design Charts

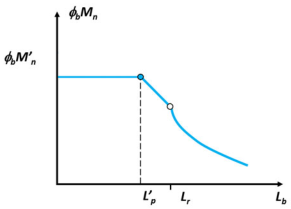
- Although the charts for ***compact*** and ***noncompact*** shapes are similar in appearance, M_p and L_p are used for ***compact*** shapes, whereas M'_p and L'_p are used for ***noncompact*** shapes



Chapter 5 – Beam Design Charts

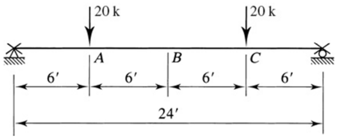
- This notation is ***not used*** in the charts or in any of the other design aids in the Manual.
- Whether a shape is ***compact*** or ***noncompact*** is irrelevant to the use of the charts.





Chapter 5 – Beam Design Charts

- **Example 5.11:** The beam shown below must support two concentrated live loads of 20 *k* each at the quarter points. The maximum live load deflection must not exceed ***L/240***. Lateral support is provided at the ends of the beam. Use **A992** steel and select a **W** shape.

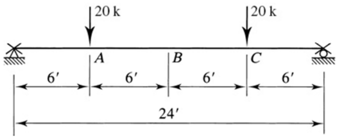


- If the weight of the beam is neglected, the central half of the beam is subjected to a uniform moment.

$$M_A = M_B = M_C = M_{Max}$$

Chapter 5 – Beam Design Charts

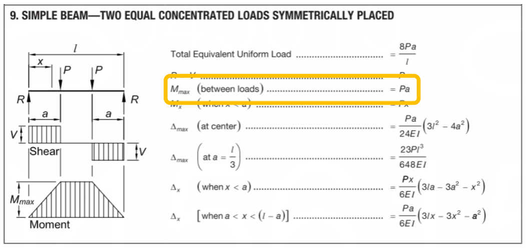
- **Example 5.11:** The beam shown below must support two concentrated live loads of 20 *k* each at the quarter points. The maximum live load deflection must not exceed ***L/240***. Lateral support is provided at the ends of the beam. Use **A992** steel and select a **W** shape.



- Even if the weight is included, it will be negligible compared to the concentrated loads, and C_b can still be taken as 1.0, permitting the charts to be used without modification.

Chapter 5 – Beam Design Charts

- **Example 5.11:** From **Table 3-22**, the maximum deflection (at midspan) for two equal and symmetrically placed loads is:


9. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS SYMMETRICALLY PLACED

Total Equivalent Uniform Load = $\frac{8Pa}{l}$

M_{max} (between loads) = Pa

Δ_{max} (at center) = $\frac{Pa}{24EI}(3l^2 - 4a^2)$

Δ_{max} $\left(\text{at } a = \frac{l}{3}\right)$ = $\frac{23Pl^3}{648EI}$

Δ_x (when $x < a$) = $\frac{Px}{6EI}(3la - 3a^2 - x^2)$

Δ_x [when $a < x < (l - a)$] = $\frac{Pa}{6EI}(3lx - 3x^2 - a^2)$

$$M_u = Pa = 1.6(20k)6ft = 192kft$$

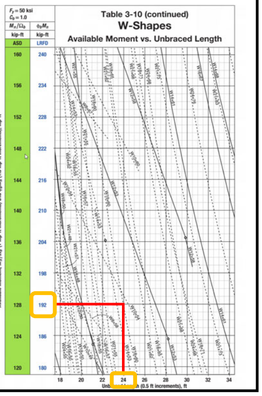
Chapter 5 – Beam Design Charts

- **Example 5.11:** ***LRFD*** Solution

Temporarily ignoring the beam weight, the factored-load moment is:

$M_u = 192kft$

$L_b = 24\,ft$



Chapter 5 – Beam Design Charts

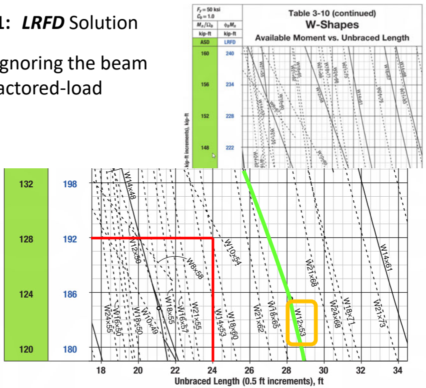
- **Example 5.11:** ***LRFD*** Solution

Temporarily ignoring the beam weight, the factored-load moment is:

$M_u = 192kft$

$L_b = 24\,ft$

W12 x 53



Chapter 5 – Beam Design Charts

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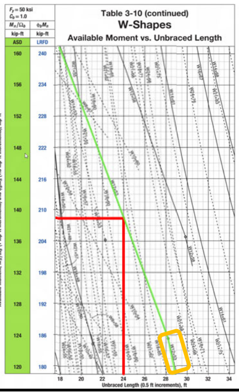


Chapter 5 – Beam Design Charts

- **Example 5.11:** ***LRFD*** Solution

Temporarily ignoring the beam weight, the factored-load moment is:

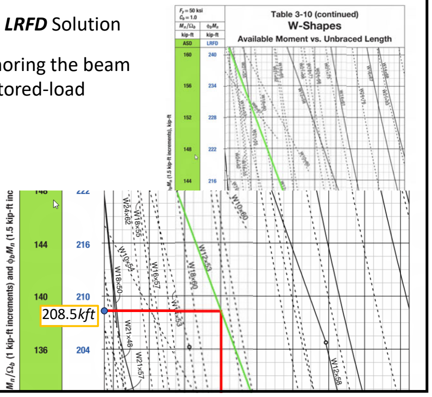
$M_u = 192kft$

$L_b = 24\,ft$

W12 x 53

$\phi_b M_n = 208.5kft$
$> 192kft$

O.K.



Chapter 5 – Beam Design Charts

- **Example 5.11:** ***LRFD*** Solution

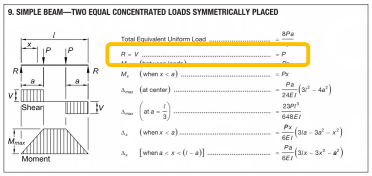
Addition moment from the factored beam weight

Accounting for the beam weight:

$$M_u = 192kft + \frac{wL^2}{8} = 192kft + \frac{1.2(0.053k/ft)(24ft)^2}{8}$$

$$= 196.6kft < 208.5kft$$ **O.K.**

Check for shear


9. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS SYMMETRICALLY PLACED

Total Equivalent Uniform Load = $\frac{8Pa}{l}$

$R = V$ = P

M_x (when $x < a$) = Px

Δ_{max} (at center) = $\frac{Pa}{24EI}(3l^2 - 4a^2)$

Δ_{max} $\left(\text{at } a = \frac{l}{3}\right)$ = $\frac{23Pl^3}{648EI}$

Δ_x (when $x < a$) = $\frac{Px}{6EI}(3la - 3a^2 - x^2)$

Δ_x [when $a < x < (l - a)$] = $\frac{Pa}{6EI}(3lx - 3x^2 - a^2)$

Chapter 5 – Beam Design Charts

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$$M_u = 192kft + \frac{wL^2}{8} = 192kft + \frac{1.2(0.053k/ft)(24ft)^2}{8}$$

$$= 196.6kft < 208.5kft \quad \boxed{\text{O.K.}}$$

Check for shear

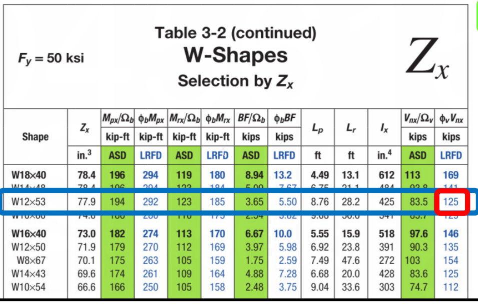
$$V_u = 1.6(20k) + \frac{1.2(0.053k/ft)(24ft)}{2} = 32.8k$$

Chapter 5 – Beam Design Charts

- **Example 5.11:** ***LRFD*** Solution

From the “$\boldsymbol{Z_x}$ table” – Table 3-2 (**3**-25) $\phi_v V_n = 125k > 32.8k$

O.K.



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
W18×40	**78.4**	**196**	**294**	**119**	**180**	**8.94**	**13.2**	**4.49**	**13.1**	**612**	**113**	**169**
W12×53	77.9	194	292	123	185	3.65	5.50	8.76	28.2	425	83.5	125
W16×40	**73.0**	**182**	**274**	**113**	**170**	**6.67**	**10.0**	**5.55**	**15.9**	**518**	**97.6**	**146**
W12×50	71.9	179	270	112	169	3.97	5.98	6.92	23.8	391	90.3	135
W8×67	70.1	175	263	105	159	1.75	2.59	7.49	47.6	272	103	154
W14×43	69.6	174	261	109	164	4.88	7.28	6.68	20.0	428	83.6	125
W10×54	66.6	166	250	105	158	2.48	3.75	9.04	33.6	303	74.7	112

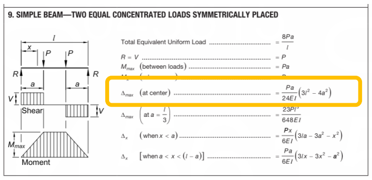
Chapter 5 – Beam Design Charts

- **Example 5.11:** ***LRFD*** Solution

The maximum permissible live load deflection is:

$$\frac{L}{240} = \frac{24\,ft(12in/ft)}{240} = 1.20in$$

From **Table 3-22**, the maximum deflection (at midspan) for two equal and symmetrically placed loads is:



9. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS SYMMETRICALLY PLACED

Total Equivalent Uniform Load .... $= \frac{8Pa}{l}$

$R = V$ .... $= P$

M_{max} (between loads) .... $= Pa$

Δ_{max} (at center) .... $= \frac{Pa}{24EI}(3l^2 - 4a^2)$

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Δ_x (when $x < a$) .... $= \frac{Px}{6EI}(3la - 3a^2 - x^2)$

Δ_x [when $a < x < (l - a)$] .... $= \frac{Pa}{6EI}(3lx - 3x^2 - a^2)$

Chapter 5 – Beam Design Charts

- **Example 5.11:** ***LRFD*** Solution

The maximum permissible live load deflection is:

$$\frac{L}{240} = \frac{24\,ft(12in/ft)}{240} = 1.20in$$

From **Table 3-22**, the maximum deflection (at midspan) for two equal and symmetrically placed loads is:

$$\Delta_{max} = \frac{Pa}{24EI}(3L^2 - 4a^2)$$

$$= \frac{20k(72in)}{24(29{,}000ksi)(425in^4)}\left(3(288in)^2 - 4(72)^2\right)$$

$$= 1.11in < 1.20in \quad \boxed{\text{O.K.}}$$

Chapter 5 – Beam Design Charts

- Although the charts are based on $\boldsymbol{C_b}$ = 1.0, they can easily be used for design when $\boldsymbol{C_b}$ is not 1.0.
- To use the design aids, divide the required strength by $\boldsymbol{C_b}$ before entering the charts.

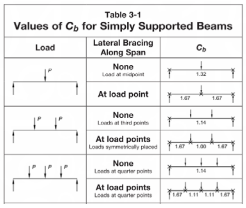


Table 3-1

Values of C_b for Simply Supported Beams

Load	Lateral Bracing Along Span	C_b
P at midpoint	**None** Load at midpoint	1.32
	At load point	1.67, 1.67
P, P	**None** Loads at third points	1.14
	At load points Loads symmetrically placed	1.67, 1.00, 1.67
P, P, P	**None** Loads at quarter points	1.14
	At load points Loads at quarter points	1.67, 1.11, 1.11, 1.67

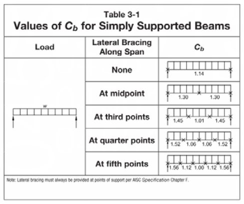


Table 3-1

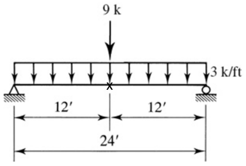
Values of C_b for Simply Supported Beams

Load	Lateral Bracing Along Span	C_b
w	**None**	1.14
	At midpoint	1.30, 1.30
	At third points	1.45, 1.01, 1.45
	At quarter points	1.52, 1.06, 1.06, 1.52
	At fifth points	1.56, 1.12, 1.00, 1.12, 1.56

Note: Lateral bracing must always be provided at points of support per AISC *Specification* Chapter F.

Chapter 5 – Beam Design Charts

- **Example 5.12**: Use **A992** steel ($\boldsymbol{F_y}$ = 50 *ksi*; $\boldsymbol{F_u}$ = 65 *ksi*) and select a rolled shape for the beam shown below.
- The concentrated load is a service live load, and the uniform load is 30% dead load and 70% live load.
- Lateral bracing is provided at the ends and at midspan. There is no restriction on deflection.



$$w_D = 0.3(3k/ft) = 0.9k/ft$$

$$w_L = 0.7(3k/ft) = 2.1k/ft$$

Chapter 5 – Beam Design Charts

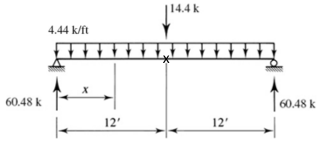
- **Example 5.12**: ***LRFD*** Solution

$$w_u = 1.2w_D + 1.6w_L = 1.2(0.9k/ft) + 1.6(2.1k/ft) = 4.44k/ft$$

$$P_u = 1.6(9k) = 14.4k$$

The factored loads and reactions are shown below.

Next, determine the moments required for the computation of C_b.



Chapter 5 – Beam Design Charts

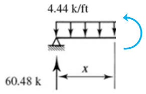
- **Example 5.12**: ***LRFD*** Solution

$$w_u = 1.2w_D + 1.6w_L = 1.2(0.9k/ft) + 1.6(2.1k/ft) = 4.44k/ft$$

$$P_u = 1.6(9k) = 14.4k$$

For $0 \le x \le 12\ ft$, the bending moment is:

$$M = 60.48x - 4.44x(x/2)$$



Chapter 5 – Beam Design Charts

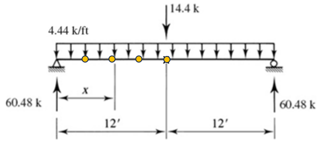
- **Example 5.12**: ***LRFD*** Solution

$$M_A(x = 3\,ft) = 60.48(3\,ft) - 2.22(3\,ft)^2 = 161.5kft$$

$$M_B(x = 6\,ft) = 60.48(6\,ft) - 2.22(6\,ft)^2 = 283.0kft$$

$$M_C(x = 9\,ft) = 60.48(9\,ft) - 2.22(9\,ft)^2 = 364.5kft$$

$$M_{Max}(x = 12\,ft) = 60.48(12\,ft) - 2.22(12\,ft)^2 = \boxed{406.1\,kft}$$



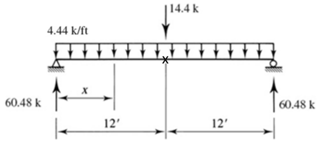
Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

$$C_b = \frac{12.5M_{\max}}{2.5M_{\max} + 3M_A + 4M_B + 3M_C}$$

$$= \frac{12.5(406.1kft)}{2.5(406.1kft) + 3(161.5kft) + 4(283.0kft) + 3(364.5kft)}$$

$$= 1.36$$



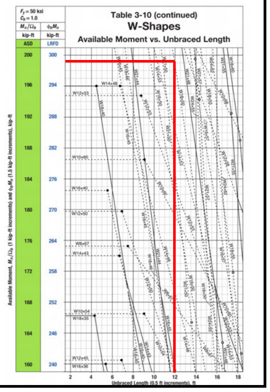
Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

Temporarily ignoring the beam weight, the factored-load moment is:

$$\frac{M_u}{C_b} = \frac{406.1\,kft}{1.36} = 299kft$$

$$L_b = 12\,ft$$



Chapter 5 – Beam Design Charts

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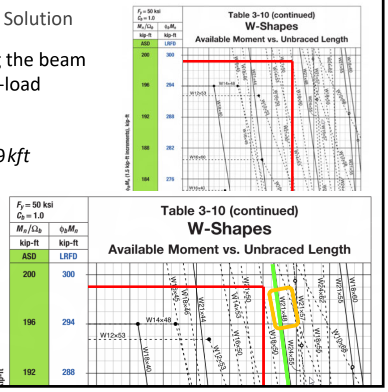
<u>**W21 x 48**</u>



Chapter 5 – Beam Design Charts

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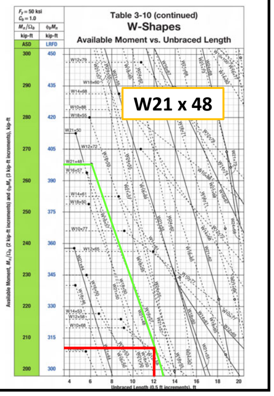
W21 x 48



Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

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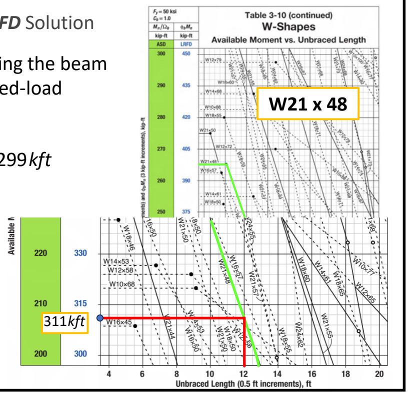
$$\frac{M_u}{C_b} = \frac{406.1\ kft}{1.36} = 299\,kft$$

$$L_b = 12\,ft$$

W21 x 48

$$\phi_b M_n = 311\ kft$$



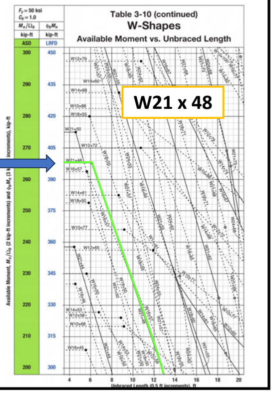
Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

Since C_b = 1.36, the actual design strength is:

$$\phi_b M_n = 1.36(311\ kft)$$

$$= 423\,kft$$



Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

Since C_b = 1.36, the actual design strength is:

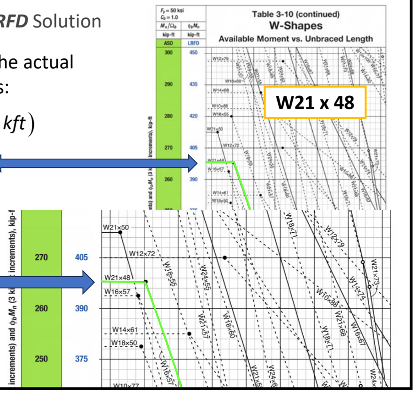
$$\phi_b M_n = 1.36(311\ kft)$$

$$= 423\,kft$$

$$\phi_b M_n \approx 398\,kft$$

$$\phi_b M_n < 406.1\,kft$$

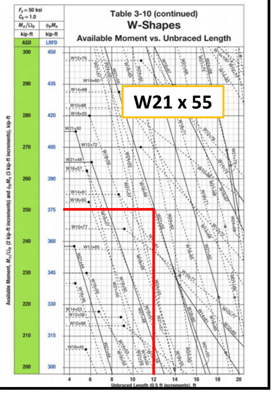
N.G.



Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

For the next shape, move up in the charts to the next solid curve



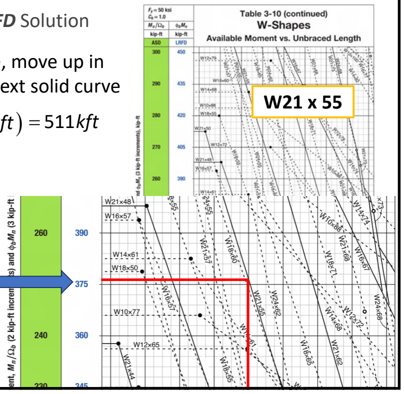
Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

For the next shape, move up in the charts to the next solid curve

$$\phi_b M_n = 1.36(376\ kft) = 511\,kft$$

$$\phi_b M_n \approx 376\,kft$$

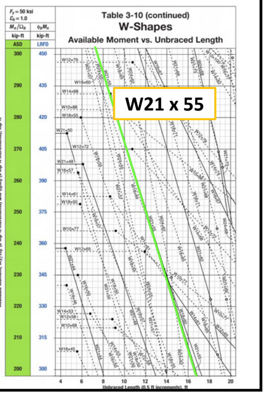


Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

For the next shape, move up in the charts to the next solid curve

$\phi_b M_n = 1.36(376\ kft) = 511 kft$

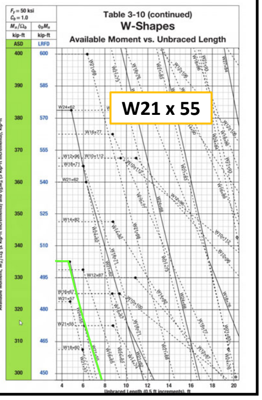


Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

For the next shape, move up in the charts to the next solid curve

$\phi_b M_n = 1.36(376\ kft) = 511 kft$



Chapter 5 – Beam Design Charts

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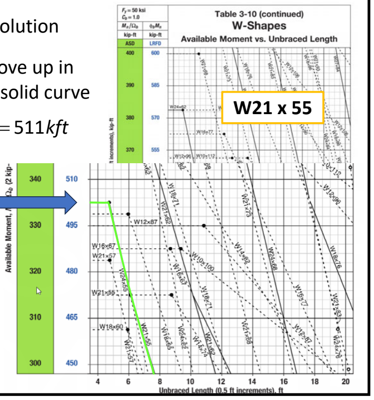
For the next shape, move up in the charts to the next solid curve

$\phi_b M_n = 1.36(376\ kft) = 511 kft$



$\phi_b M_n \approx 502.5 kft$

$\phi_b M_n > 406.1 kft$

O.K.

Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

Addition moment from the factored beam weight

Accounting for the beam weight:

$$M_u = 406.1kft + \frac{wL^2}{8} = 406.1kft + \frac{1.2(0.055k/ft)(24ft)^2}{8}$$

$$= 410.9kft < 502.5kft$$ **O.K.**

Check for shear

$$V_u = 60.48k + \frac{1.2(0.055k/ft)(24ft)}{2} = 61.3k$$

Reaction

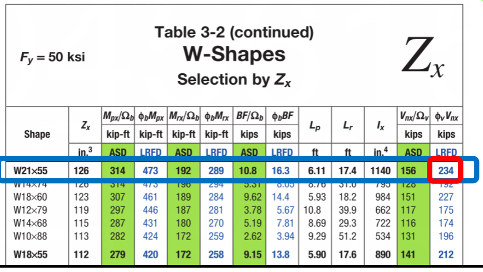
Addition reaction from factored beam weight

Chapter 5 – Beam Design Charts

- **Example 5.12**: ***LRFD*** Solution

From the "Z_x table" – Table 3-2 (**3**-25) $\phi_v V_n = 234k > 32.8k$

O.K.



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
W21×55	**126**	**314**	**473**	**192**	**289**	**10.8**	**16.3**	**6.11**	**17.4**	**1140**	**156**	**234**
W14×74	126	314	473	196	294	5.31	8.05	8.76	31.0	795	128	192
W18×60	123	307	461	189	284	9.62	14.4	5.93	18.2	984	151	227
W12×79	119	297	446	187	281	3.78	5.67	10.8	39.9	662	117	175
W14×68	115	287	431	180	270	5.19	7.81	8.69	29.3	722	116	174
W10×88	113	282	424	172	259	2.62	3.94	9.29	51.2	534	131	196
W18×55	**112**	**279**	**420**	**172**	**258**	**9.15**	**13.8**	**5.90**	**17.6**	**890**	**141**	**212**

Chapter 5 – Beam Design Charts

Let's work on some problems

Chapter 5 – Beams

Any questions?