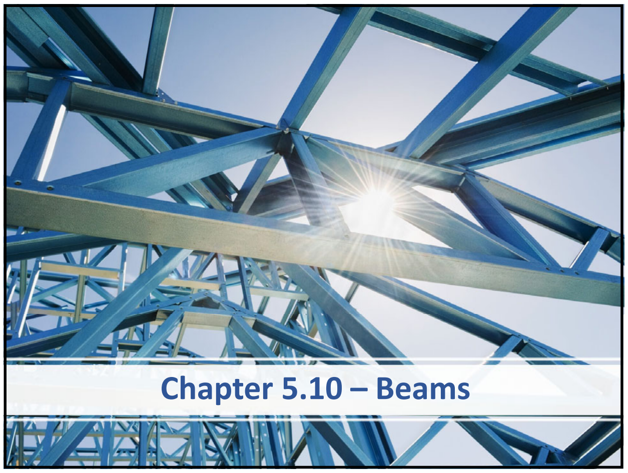


1

Chapter 5 – Design

- ***Beam design*** entails the ***selection of a cross-sectional shape*** that will have ***enough strength*** and that will meet ***serviceability requirements***.
- As far as strength is concerned, ***flexure*** is almost always more critical than ***shear***, so the usual practice is to ***design for flexure and then check shear***.

2

Chapter 5 – Design

- The ***design process*** can be outlined as follows:
  1. Compute the required moment strength (i.e., the factored load moment M_u for ***LRFD***.

     The ***weight of the beam*** is part of the dead load but is unknown at this point.

     Because the ***beam weight*** is usually a small part of the total load, it is ignored at the beginning of a design problem.

     The selected shape will usually be ***satisfactory*** when the moment is recomputed with beam weight.

3

Chapter 5 – Design

- The ***design process*** can be outlined as follows:
  2. Compute the ***moment of inertia required*** to meet the ***deflection limit***.

     Use the **service load** for this computation.
  3. Select a ***shape that meets the strength requirement***, then check the moment of inertia. Select a different shape if necessary.

4

Chapter 5 – Design

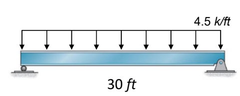
- The ***design process*** can be outlined as follows:
  4. Compute the required moment strength and moment of inertia using the ***actual beam weight***.

     If necessary, select a different shape.
  5. Check the ***shear strength***.
- The trial shape can be easily selected in only a ***limited*** number of situations.
- In most cases, ***design aids***, such as the ***beam design charts*** in **Part 3 of the Manual**, can be used.

5

Chapter 5 – Design

- **Example 5.10**: Select a standard hot-rolled shape of **A992** steel (**F_y** = 50 *ksi*; ***F*** = 65 *ksi*) for the beam shown. The beam has continuous lateral support and must support a uniform service live load of 4.5 *kips/ft*. The maximum permissible live load deflection is ***L/240***.



LRFD Solution

Initially, ignore the beam weight.

$$w_u = 1.2w_D + 1.6w_L = 1.2(0) + 1.6(4.5k/ft) = 7.2k\,ft$$

$$M_u = \frac{w_u L^2}{8} = \frac{7.2k/ft(30\,ft)^2}{8} = 810.0k\,ft = \phi_b M_n$$

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Chapter 5 – Design

➢ **Example 5.10**: The maximum permissible live load deflection is:

$$\frac{L}{240} = \frac{360in}{240} = 1.5in \leq \frac{5wL^4}{384EI}$$

$$\therefore\ I = \frac{5wL^4}{384E\Delta} = \frac{5(4.5k/ft)(1ft/12in)(360in)^4}{384(29{,}000ksi)(1.5in)} = 1{,}885.4in^4$$

Assume that the shape will be ***compact***. For a compact shape with full lateral support:

$$M_n = M_p = F_y Z_x \qquad \phi_b M_n > M_u \qquad \therefore\ \phi_b F_y Z_x > M_u$$

$$Z_x > \frac{M_u}{\phi_b F_y} = \frac{810.0kft(12in/ft)}{0.90(50ksi)} = 216in^3$$

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Chapter 5 – Design

➢ **Example 5.10**: The ***Z_x*** table lists hot-rolled shapes commonly used as beams, ordered by ***decreasing plastic section modulus***.

F_y = 50 ksi — **Table 3-2** — **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
W36×925[h]	4130	10300	15500	5920	8900	47.6	71.7	15.0	107	73000	2600	3900
W36×853[h]	3920	9780	14700	5680	8530	48.3	72.7	15.1	100	70000	2170	3260
W36×802[h]	3660	9130	13700	5310	7980	48.0	71.9	14.9	94.5	64800	2030	3040
W36×723[h]	3270	8160	12300	4790	7190	47.6	72.2	14.7	85.5	57300	1810	2720
W40×655[h]	3080	7680	11600	4520	6800	56.1	85.3	13.6	69.9	56500	1720	2580
W36×652[h]	2910	7260	10900	4300	6460	46.8	70.3	14.5	77.7	50600	1620	2430
W40×593[h]	2760	6890	10400	4090	6140	55.4	84.4	13.4	63.9	50400	1540	2310
W36×529[h]	2330	5810	8740	3480	5220	46.4	70.1	14.1	64.3	39600	1280	1920
W40×503[h]	2320	5790	8700	3460	5200	55.3	83.1	13.1	55.2	41600	1300	1950
W36×487[h]	2130	5310	7990	3200	4800	46.0	69.5	14.0	59.9	36000	1180	1770
W14×873[h]	2030	5060	7610	2670	4020	7.67	11.5	17.3	329	18100	1860	2790

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➢ **Example 5.10**: Also, they are grouped so that the shape at the top of each group (**in bold type**) is the lightest one that has enough section modulus to satisfy a required section modulus that falls within the group.

F_y = 50 ksi — **Table 3-2** — **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
W36×925[h]	4130	10300	15500	5920	8900	47.6	71.7	15.0	107	73000	2600	3900
W36×853[h]	3920	9780	14700	5680	8530	48.3	72.7	15.1	100	70000	2170	3260
W36×802[h]	3660	9130	13700	5310	7980	48.0	71.9	14.9	94.5	64800	2030	3040
W36×723[h]	3270	8160	12300	4790	7190	47.6	72.2	14.7	85.5	57300	1810	2720
W40×655[h]	3080	7680	11600	4520	6800	56.1	85.3	13.6	69.9	56500	1720	2580
W36×652[h]	2910	7260	10900	4300	6460	46.8	70.3	14.5	77.7	50600	1620	2430
W40×593[h]	2760	6890	10400	4090	6140	55.4	84.4	13.4	63.9	50400	1540	2310
W36×529[h]	2330	5810	8740	3480	5220	46.4	70.1	14.1	64.3	39600	1280	1920
W40×503[h]	2320	5790	8700	3460	5200	55.3	83.1	13.1	55.2	41600	1300	1950
W36×487[h]	2130	5310	7990	3200	4800	46.0	69.5	14.0	59.9	36000	1180	1770
W14×873[h]	2030	5060	7610	2670	4020	7.67	11.5	17.3	329	18100	1860	2790

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Chapter 5 – Design

➢ **Example 5.10**: In this example, the shape that comes closest to meeting the section modulus requirement is **W21 x 93**

$$Z_x = 216in^3$$

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

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
W21×93	221	551	829	335	504	14.6	22.0	6.50	21.3	2070	251	376
W14×120	212	529	795	332	499	5.09	7.65	13.2	51.9	1380	171	257
W18×97	211	526	791	328	494	9.41	14.1	9.36	30.4	1750	199	299
W24×76	**200**	**499**	**750**	**307**	**462**	**15.1**	**22.6**	**6.78**	**19.5**	**2100**	**210**	**315**
W16×100	198	494	743	306	459	7.86	11.9	8.87	32.8	1490	199	298
W21×83	196	489	735	299	449	13.8	20.8	6.46	20.2	1830	220	331
W14×109	192	479	720	302	454	5.01	7.54	13.2	48.5	1240	150	225
W18×86	186	464	698	290	436	9.01	13.6	9.29	28.6	1530	177	265
W12×120	186	464	698	285	428	3.94	5.95	11.1	56.5	1070	186	279

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Chapter 5 – Design

➢ **Example 5.10**: However, there is one lighter.

$$Z_x = 216in^3$$

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

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
W21×93	221	551	829	335	504	14.6	22.0	6.50	21.3	2070	251	376
W14×120	212	529	795	332	499	5.09	7.65	13.2	51.9	1380	171	257
W18×97	211	526	791	328	494	9.41	14.1	9.36	30.4	1750	199	299
W24×76	**200**	**499**	**750**	**307**	**462**	**15.1**	**22.6**	**6.78**	**19.5**	**2100**	**210**	**315**
W16×100	198	494	743	306	459	7.86	11.9	8.87	32.8	1490	199	298
W21×83	196	489	735	299	449	13.8	20.8	6.46	20.2	1830	220	331
W14×109	192	479	720	302	454	5.01	7.54	13.2	48.5	1240	150	225
W18×86	186	464	698	290	436	9.01	13.6	9.29	28.6	1530	177	265
W12×120	186	464	698	285	428	3.94	5.95	11.1	56.5	1070	186	279

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Chapter 5 – Design

➢ **Example 5.10**: However, there is one lighter. **W24 x 84**

$$Z_x = 216in^3$$

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

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
W24×84	**224**	**559**	**840**	**342**	**515**	**16.2**	**24.2**	**6.89**	**20.3**	**2370**	**227**	**340**
W12×136	214	534	803	325	488	4.02	6.06	11.2	63.2	1240	212	318
W14×120	212	529	795	332	499	5.09	7.65	13.2	51.9	1380	171	257
W18×97	211	526	791	328	494	9.41	14.1	9.36	30.4	1750	199	299
W24×76	**200**	**499**	**750**	**307**	**462**	**15.1**	**22.6**	**6.78**	**19.5**	**2100**	**210**	**315**
W16×100	198	494	743	306	459	7.86	11.9	8.87	32.8	1490	199	298
W21×83	196	489	735	299	449	13.8	20.8	6.46	20.2	1830	220	331
W14×109	192	479	720	302	454	5.01	7.54	13.2	48.5	1240	150	225
W18×86	186	464	698	290	436	9.01	13.6	9.29	28.6	1530	177	265
W12×120	186	464	698	285	428	3.94	5.95	11.1	56.5	1070	186	279

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Chapter 5 – Design

- **Example 5.10**: Try a **W24 x 84**: This shape is ***compact***, as assumed (noncompact shapes are marked as such in the table); therefore $M_n = M_p$, as assumed.

From Table 1-1 (**1**-20): $I_x = 2{,}370\,in^4 > 1{,}885\,in^4$ **O.K.**

Account for the weight of the beam:

$$w_u = 1.2w_D + 1.6w_L = 1.2(0.084\,k/ft) + 1.6(4.5\,k/ft) = 7.301\,k\,ft$$

$$M_u = \frac{w_u L^2}{8} = \frac{7.301\,k/ft\,(30\,ft)^2}{8} = 821.4\,k\,ft$$

$$Z_x > \frac{M_u}{\phi_b F_y} = \frac{821.4\,kft\,(12\,in/ft)}{0.90(50\,ksi)} = 219.04\,in^3 < 224\,in^3$$ **O.K.**

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Chapter 5 – Design

- **Example 5.10**: Instead of basing the search on the required section modulus, the design strength $\phi_b M_p$ could be used, because it is directly proportional to Z_x and is also tabulated.

$$\phi_b M_n = 810.0\,k\,ft$$

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

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
W24×84	**224**	**559**	**840**	**342**	**515**	**16.2**	**24.2**	**6.89**	**20.3**	**2370**	**227**	**340**
W12×136	214	534	803	325	488	4.02	6.06	11.2	63.2	1240	212	318
W14×120	212	529	795	332	499	5.09	7.65	13.2	51.9	1380	171	257
W18×97	211	526	791	328	494	9.41	14.1	9.36	30.4	1750	199	299
W24×76	**200**	**499**	**750**	**307**	**462**	**15.1**	**22.6**	**6.78**	**19.5**	**2100**	**210**	**315**
W16×100	198	494	743	306	459	7.86	11.9	8.87	32.8	1490	199	298
W21×83	196	489	735	299	449	13.8	20.8	6.46	20.2	1830	220	331
W14×109	192	479	720	302	454	5.01	7.54	13.2	48.5	1240	150	225
W18×86	186	464	698	290	436	9.01	13.6	9.29	28.6	1530	177	265
W12×120	186	464	698	285	428	3.94	5.95	11.1	56.5	1070	186	279

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Chapter 5 – Design

Let's work on some problems

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Chapter 5 – Beams

Any questions?

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