SPECIAL FOCUS:
NON-BUILDING
STRUCTURES

Singly Symmetric Combination Section Crane Girder Design Aids

PATRICK C. JOHNSON and JEFFREY A. LAMAN

ABSTRACT

Crane runway girders are distinguished by long, unbraced lengths and biaxial bending. Combination sections consisting of a W-shape with a channel cap are typically efficient for these conditions, but time consuming to design due to the iterative process required due to biaxial bending and the complex stability equations provided in the 2005 AISC *Specification*. This paper presents developed Z_x tables and flexural strength graphs and introduces a trial section selection method. Included herein are updated design charts to allow for fast and efficient analysis of the typical combination sections provided in Table 1-19 of the 13th edition AISC *Steel Construction Manual*. Also presented is an overview of crane girder design procedures and an abbreviated design example.

Keywords: biaxial bending, crane runway girders, design, unbraced length.

The design or evaluation procedure for combination sections—a wide flange with a channel cap—is specified in Section F4 of the AISC *Specification for Structural Steel Buildings* (AISC, 2005a), which covers singly symmetric I-shaped members bent about their major axis. Reversal of the specified AISC evaluation process for direct design is not feasible; therefore, design becomes a matter of trial and error. The situation is compounded for a combination section that supports *x*- and *y*-axis moments as in the case of a crane girder, where Chapter H of the 2005 AISC *Specification* must be applied. As a result, design aids are needed to streamline the design process that facilitates rapid selection of the most economical combination section. This paper updates a previously published paper by Laman (1996), presenting new design aids, formatted in the style of familiar AISC tables and figures, including the basis by which the aids are developed and a supporting example. Also presented is a method to determine the equivalent *x*-axis moment required for beams subjected to biaxial moments.

There are many texts and design aids available that address the design of industrial buildings with cranes, such as the design guide by Fisher (2004). While these sources explain the loading and evaluation required for crane runway girders, they do not offer any systematic approach to the selection of trial sections. The problems of a trial-and-error approach are further compounded by the lack of design aids for quickly determining the capacity of the combination sections.

CRANE GIRDER DESIGN BASIS

Crane girders are distinguished by long, unbraced lengths and combined bending about the *x*- and *y*-axis as well as torsion. For typical loading and spans, a wide flange section with a channel cap normally provides an efficient cross-section for the design. Historically, the assumption has been made that the channel and the wide flange top flange resist the horizontal loads and the combination section resists the vertical load. This simplifies the analysis of the actual condition and eliminates the need for an analysis of torsional effects on the combination section (Laman, 1996). Given the complexity of the 2005 AISC *Specification* design equations due to lateral torsional buckling strength determination, design tables and graphs are needed to speed the process. Currently the 13th edition AISC *Steel Construction Manual* (AISC, 2005b) contains design tables and graphs to assist with wide flange and channel design under lateral torsional buckling and serve as a model for the aids presented herein. Based on 2005 AISC *Specification* Section F.4 and the flow chart of Figure 1, design aids presented in Tables 2 and 3 and Figures 2 and 3 have been developed. With the availability of these new design aids, a trial section selection methodology is now possible and is presented here.

M_{ueq} METHOD

Defining the ratio of M_{nx} to M_{ny} as a plastic section modulus ratio, *ZR*:

$$ZR = \frac{M_{nx}}{M_{ny}} = \frac{Z_x F_y}{Z_y F_y} = \frac{Z_x}{Z_y} \tag{1}$$

Patrick C. Johnson, Student, Department of Civil and Environmental Engineering, The Pennsylvania State University, University Park, PA. E-mail: pcjohnson@psu.edu

Jeffrey A. Laman, Ph.D., P.E., Professor, Department of Civil Engineering, The Pennsylvania State University, University Park, PA (corresponding author). E-mail: jlaman@psu.edu

Table 1. *b* and *m* Values for Typical Combination Sections

	Channel Cap	L_b (ft)	10	20	30	40	50	60	70	80	90	100
Fy = 50 ksi	MC18×42.7	***b***	1.5	1.4	1.3	1.1	1.1	0.75	0.6	0.5	0.4	0.4
		m ($\times10^3$)	1.9	1.9	1.9	1.9	1.6	1.7	1.7	1.7	1.7	1.6
	C15×33.9	***b***	1.1	1.0	0.9	0.9	0.8	0.6	0.5	0.4	0.4	
		m ($\times10^3$)	3.0	3.0	3.0	2.8	2.6	2.5	2.5	2.5	2.3	
	C12×20.7	***b***	0.7	0.7	0.6	0.7	0.5	0.4	0.4	0.4		
		m ($\times10^3$)	6.3	6.0	6.0	5.1	5.0	5.0	4.6	4.2		
	C10×15.3	***b***	0.2	0.2	0.2	0.1	0.2	0.1				
		m ($\times10^3$)	13	12	12	11	11	11				
Fy = 36 ksi	**Channel Cap**	**L_b (ft)**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
	MC18×42.7	***b***	1.4	1.5	1.4	1.3	1.3	1.1	0.85	0.7	0.6	0.5
		m ($\times10^3$)	2.7	2.6	2.6	2.6	2.5	2.3	2.3	2.3	2.3	2.4
	C15×33.9	***b***	1.1	1.0	1.0	0.9	0.9	0.9	0.7	0.6	0.6	0.6
		m ($\times10^3$)	4.1	4.1	4.1	4.1	3.9	3.5	3.4	3.4	3.1	3.0
	C12×20.7	***b***	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.5		
		m ($\times10^3$)	8.4	8.4	8.0	8.0	7.3	7.3	6.7	6.2		
	C10×15.3	***b***	0.2	0.2	0.2	0.2	0.2	0.2				
		m ($\times10^3$)	17	17	17	17	16	16				

and observing that a nearly linear relationship between *ZR* and ϕM_{nx} exists for each channel section used as a cap, Equation H1-1b can be rearranged into an explicit function for ϕM_{nx}:

$$\frac{M_{ux}}{\phi M_{nx}} + \frac{M_{uy}}{\phi M_{ny}} \leq 1 \tag{2}$$

Now substituting *ZR* for the moment ratio into Equation 2,

$$\frac{M_{ux}}{\phi M_{nx}} + \frac{M_{uy}}{\phi M_{nx}/ZR} \leq 1 \tag{3}$$

Rearranging Equation 3:

$$\frac{M_{ux}}{\phi M_{nx}} + \frac{\left(ZR\right)\left(M_{uy}\right)}{\phi M_{nx}} \leq 1 \tag{4}$$

Rearranging Equation 4:

$$M_{ux} + \left(ZR\right)\left(M_{uy}\right) \leq \phi M_{nx} \tag{5}$$

Equation 5 is an approximation based on the near-linear relationship (0.98 correlation) between *ZR* and M_{nx} for combination sections of this study. Because ϕM_{nx} is not initially known, an equivalent moment, M_{ueq}, is substituted for ϕM_n in Equation 5 to form Equation 6:

$$M_{ueq} \geq M_{ux} + \left(ZR\right)\left(M_{uy}\right) \tag{6}$$

For a trial channel cap selection, *ZR* is replaced with a linear function of M_{ueq} and solved for M_{ueq}:

$$M_{ueq} \geq M_{ux} + \left(mM_{ueq} + b\right)M_{uy} \tag{7}$$

where the coefficients *m* ([kip-ft]$^{-1}$) and *b* (unitless) represent the straight-line slope and intercept for the near-linear relationship. Distributing terms gives the following:

$$M_{ueq} \geq M_{ux} + mM_{ueq}M_{uy} + bM_{uy} \tag{8}$$

Collecting the terms of Equation 8 results in the following:

$$\left(1 - mM_{uy}\right)M_{ueq} \geq M_{ux} + bM_{uy} \tag{9}$$

Solving for M_{ueq} results in Equation 10 for load and resistance factor design (LRFD):

$$M_{ueq} \geq \frac{M_{ux} + bM_{uy}}{1 - mM_{uy}} \tag{10}$$

Table 2. Z_x Design Selection Table for Typical Combination Sections ($F_y = 36$ ksi)

$\Phi = 0.90$
$\Omega = 1.67$

W-Shapes with Cap Channels

F_y = 36 ksi

Shape	Z_x	M_{px}/Ω	ΦM_{px}	M_{rx}/Ω	ΦM_{rx}	BF		L_p	L_r	I_x	M_{ny}/Ω	ΦM_{ny}
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kip-ft	kip-ft
	in.^{3}	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.^{4}	ASD	LRFD
W36×150 + MC18×42.7	738	1330	1990	993	1490	9.57	14.4	12.2	47.0	12000	196	294
W36×150 + C15×33.9	716	1290	1930	961	1440	10.6	15.9	11.2	42.1	11500	152	229
W33×141 + MC18×42.7	652	1170	1760	880	1320	8.11	12.2	12.2	48.1	10000	192	288
W33×141 + C15×33.9	635	1140	1710	866	1300	8.76	13.2	11.2	42.5	9580	148	223
W33×118 + MC18×42.7	544	977	1470	719	1080	6.95	10.4	12.6	49.8	8280	179	269
W33×118 + C15×33.9	529	950	1430	710	1070	7.47	11.2	11.6	43.8	7900	135	203
W30×116 + MC18×42.7	492	884	1330	656	986	5.96	8.95	12.4	50.7	6900	177	266
W30×116 + C15×33.9	480	862	1300	647	972	6.53	9.81	11.3	44.4	6590	133	200
W30×99 + MC18×42.7	412	740	1110	546	821	4.87	7.32	12.7	52.6	5830	168	253
W30×99 + C15×33.9	408	733	1100	539	810	5.65	8.5	11.7	46.0	5550	124	187
W27×94 + C15×33.9	357	641	964	481	724	4.49	6.75	11.6	47.2	4530	125	187
W27×84 + C15×33.9	316	568	853	426	640	3.87	5.81	11.8	48.6	4050	120	180
W24×84 + C15×33.9	286	514	772	390	586	3.25	4.88	11.6	49.7	3340	119	179
W24×84 + C12×20.7	275	494	743	379	570	4.39	6.60	9.09	35.3	3030	74.1	111
W24×68 + C15×33.9	232	417	626	311	467	2.62	3.94	12.1	52.5	2710	112	169
W24×68 + C12×20.7	224	402	605	302	454	3.72	5.59	9.42	36.5	2440	67.1	101
W21×68 + C15×33.9	207	372	559	280	421	2.15	3.24	11.9	54.4	2180	112	169
W21×68 + C12×20.7	200	359	540	273	410	3.06	4.59	9.23	37.4	1970	67	101
W21×62 + C15×33.9	189	340	510	255	383	1.94	2.92	12.1	55.6	2000	110	165
W21×62 + C12×20.7	183	329	494	248	373	2.83	4.25	9.38	38.0	1800	64.7	97.3
W18×50 + C15×33.9	133	239	359	190	285	1.03	1.55	12.4	60.1	1250	106	159
W18×50 + C12×20.7	127	228	343	175	263	1.68	2.53	9.55	41.2	1120	60.4	90.8
W16×36 + C15×33.9	86.8	156	234	144	216	0.244	0.367	12.9	62.9	748	101	151
W16×36 + C12×20.7	83.2	149	225	113	170	1.01	1.52	10.0	46.2	670	55.4	83.3
W14×30 + C12×20.7	62.0	111	167	88.1	132	0.599	0.900	10.2	49.0	447	53.8	80.9
W14×30 + C10×15.3	60.3	108	163	82.6	124	0.882	1.33	8.36	37.5	420	36.4	54.7
W12×26 + C12×20.7	48.2	86.6	130	73.7	111	0.314	0.472	10.3	51.2	318	53.2	79.9
W12×26 + C10×15.3	47.0	84.4	127	65.2	98.0	0.605	0.909	8.44	40.2	299	35.8	53.7

Table 3. Z_x Design Selection Table for Typical Combination Sections ($F_y = 50$ ksi)

$\Phi = 0.90$
$\Omega = 1.67$

W-Shapes with Cap Channels

F_y = 50 ksi

Shape	Z_x	M_{px}/Ω	ΦM_{px}	M_{rx}/Ω	ΦM_{rx}	BF		L_p	L_r	I_x	M_{ny}/Ω	ΦM_{ny}
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kip-ft	kip-ft
	in.^{3}	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.^{4}	ASD	LRFD
W36×150 + MC18×42.7	738	1840	2770	1380	2070	16.2	24.4	10.4	38.9	12000	272	409
W36×150 + C15×33.9	716	1790	2690	1330	2010	17.9	26.9	9.53	34.8	11500	211	317
W33×141 + MC18×42.7	652	1630	2450	1220	1840	13.8	20.8	10.4	39.6	10000	267	401
W33×141 + C15×33.9	635	1580	2380	1200	1810	14.9	22.4	9.50	35.0	9580	206	310
W33×118 + MC18×42.7	544	1360	2040	998	1500	11.7	17.6	10.7	41.3	8280	248	373
W33×118 + C15×33.9	529	1320	1980	986	1480	12.6	18.9	9.80	36.4	7900	188	282
W30×116 + MC18×42.7	492	1230	1850	911	1370	10.2	15.3	10.5	41.7	6900	246	369
W30×116 + C15×33.9	480	1200	1800	898	1350	11.1	16.7	9.61	36.5	6590	185	278
W30×99 + MC18×42.7	412	1030	1550	758	1140	8.23	12.4	10.8	43.6	5830	233	351
W30×99 + C15×33.9	408	1020	1530	749	1130	9.55	14.4	9.91	38.1	5550	173	260
W27×94 + C15×33.9	357	891	1340	669	1010	7.66	11.5	9.84	38.8	4530	173	260
W27×84 + C15×33.9	316	788	1190	591	889	6.55	9.85	10.0	40.1	4050	167	251
W24×84 + C15×33.9	286	714	1070	541	814	5.60	8.42	9.85	40.6	3340	166	249
W24×84 + C12×20.7	275	686	1030	526	791	7.53	11.3	7.71	28.9	3030	103	155
W24×68 + C15×33.9	232	579	870	432	649	4.47	6.72	10.2	43.2	2710	156	235
W24×68 + C12×20.7	224	559	840	419	630	6.29	9.46	7.99	30.2	2440	93.2	140
W21×68 + C15×33.9	207	516	776	389	585	3.74	5.62	10.1	44.1	2180	156	234
W21×68 + C12×20.7	200	499	750	379	570	5.26	7.91	7.83	30.6	1970	93.1	140
W21×62 + C15×33.9	189	472	709	354	533	3.35	5.04	10.3	45.2	2000	153	230
W21×62 + C12×20.7	183	457	686	344	518	4.83	7.26	7.96	31.2	1800	89.9	135
W18×50 + C15×33.9	133	332	499	263	396	1.81	2.71	10.5	48.5	1250	147	221
W18×50 + C12×20.7	127	317	476	243	365	2.90	4.37	8.11	33.6	1120	83.9	126
W16×36 + C15×33.9	86.8	217	326	200	300	0.427	0.641	10.9	50.7	748	140	210
W16×36 + C12×20.7	83.2	208	312	157	236	1.74	2.62	8.49	37.7	670	77.0	116
W14×30 + C12×20.7	62.0	155	233	122	184	1.04	1.56	8.66	39.7	447	74.7	112
W14×30 + C10×15.3	60.3	150	226	115	173	1.52	2.29	7.10	30.6	420	50.5	76.0
W12×26 + C12×20.7	48.2	120	181	102	154	0.551	0.829	8.74	41.1	318	73.9	111
W12×26 + C10×15.3	47.0	117	176	90.6	136	1.05	1.58	7.16	32.5	299	49.7	74.6

The derivation for allowable stress design (ASD) is similar and results in the following equation:

$$M_{aeq} = \frac{M_{ax} + bM_{ay}}{1 - 1.5mM_{ay}} \tag{11}$$

The coefficients m and b have been determined based on a regression analysis of all values for applicable channel caps for spans in 10 ft increments up to 100 ft and are provided in Table 1. The resulting equivalent moment determined from Equation 10 (LRFD) or Equation 11 (ASD) is then used to select a trial section from Z_x tables presented in Table 2 (F_y = 36 ksi) or Table 3 (F_y = 50 ksi) or from design graphs presented in Figures 1 and 2 to select a trial section. For unbraced lengths greater than the limiting length for yielding ($L_b > L_p$), the strong axis moment, M_{ux} or M_{ax}, should be divided by the C_b for a more accurate selection.

$$M_{aeq} = \frac{M_{ax}/C_b + bM_{ay}}{1 - 1.5mM_{ay}} \tag{12}$$

$$M_{ueq} = \frac{M_{ux}/C_b + bM_{uy}}{1 - mM_{uy}} \tag{13}$$

M_{ueq} is then used in the design graphs presented in Figure 2 (F_y = 36 ksi) or Figure 3 (F_y = 50 ksi) to select a trial section. The use of these graphs is identical to the widely used and familiar beam design moment graphs already provided in Part 3 of the 13th edition AISC *Steel Construction Manual* (AISC, 2005b).

SINGLY SYMMETRIC CRANE GIRDER DESIGN PROCEDURE

1. Determine deflection limits and stiffness requirements. Vertical deflection is typically limited to *L*/600 for light and medium cranes and *L*/1000 for heavy cranes. Horizontal deflection is typically limited to *L*/400 for all cranes. In addition, I_x is based on the full combination section, while I_y is based only on the channel and the top flange of the W-shape.
2. Determine the applied loads, including crane manufacturer specified maximum wheel loads, rail weight and runway girder weight. Maximum wheel loads are increased by 25% for cab or remotely operated bridge cranes and 10% for pendant operated bridge cranes.

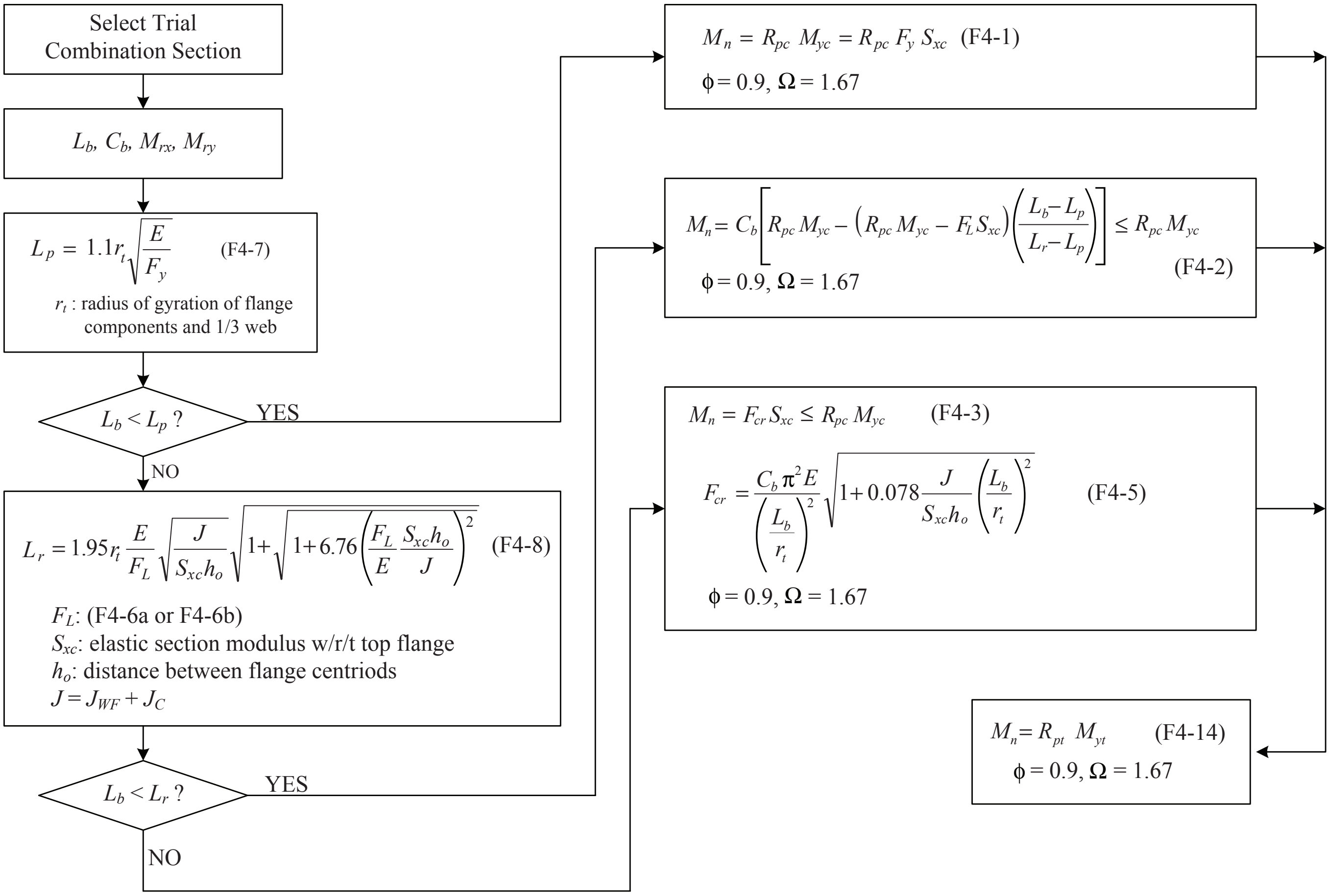

Fig. 1. Flow chart of the 2005 AISC Specification *Chapter F.4 evaluation process.*

3. Calculate the *x*- and *y*-axis bending moments and shear forces, applying suitable load combinations and determine the equivalent moment from Equation 10 (LRFD) or Equation 11 (ASD), or Equations 12 or 13 if C_b is applied.
4. Using the equivalent moment, select a trial section using either or Figure 2 or 3 or Table 2 or 3. Long spans supporting light cranes are normally controlled by deflection; therefore, trial section selection may be based on moment of inertia.
5. Evaluate the trial section for flexural and shear capacity based on 2005 AISC *Specification* Chapter F.4 following the flow chart in Figure 1, Chapter G, and Chapter H. Flexural capacity can also be determined with the assistance of Table 2 or 3. All singly symmetric, W and C combination sections listed in Table 1-19 of the 13th edition AISC *Steel Construction Manual* meet the compact web criteria of Table B4.1; therefore, the web plastification factors, R_{pc} and R_{pt}, are the ratio of the plastic moment to the compression and tension flange yield moments, respectively. Thus, $R_{pc}\,M_{yc} = M_p$ and $R_{pt}\,M_{yt} = M_p$, which can be substituted into Equation F4-2 of the 2005 AISC *Specification*:

$$M_{nx} = C_b\left[M_{px} - \left(M_{px} - F_L S_{xc}\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right]$$

$$\le M_{px} \qquad (14)$$

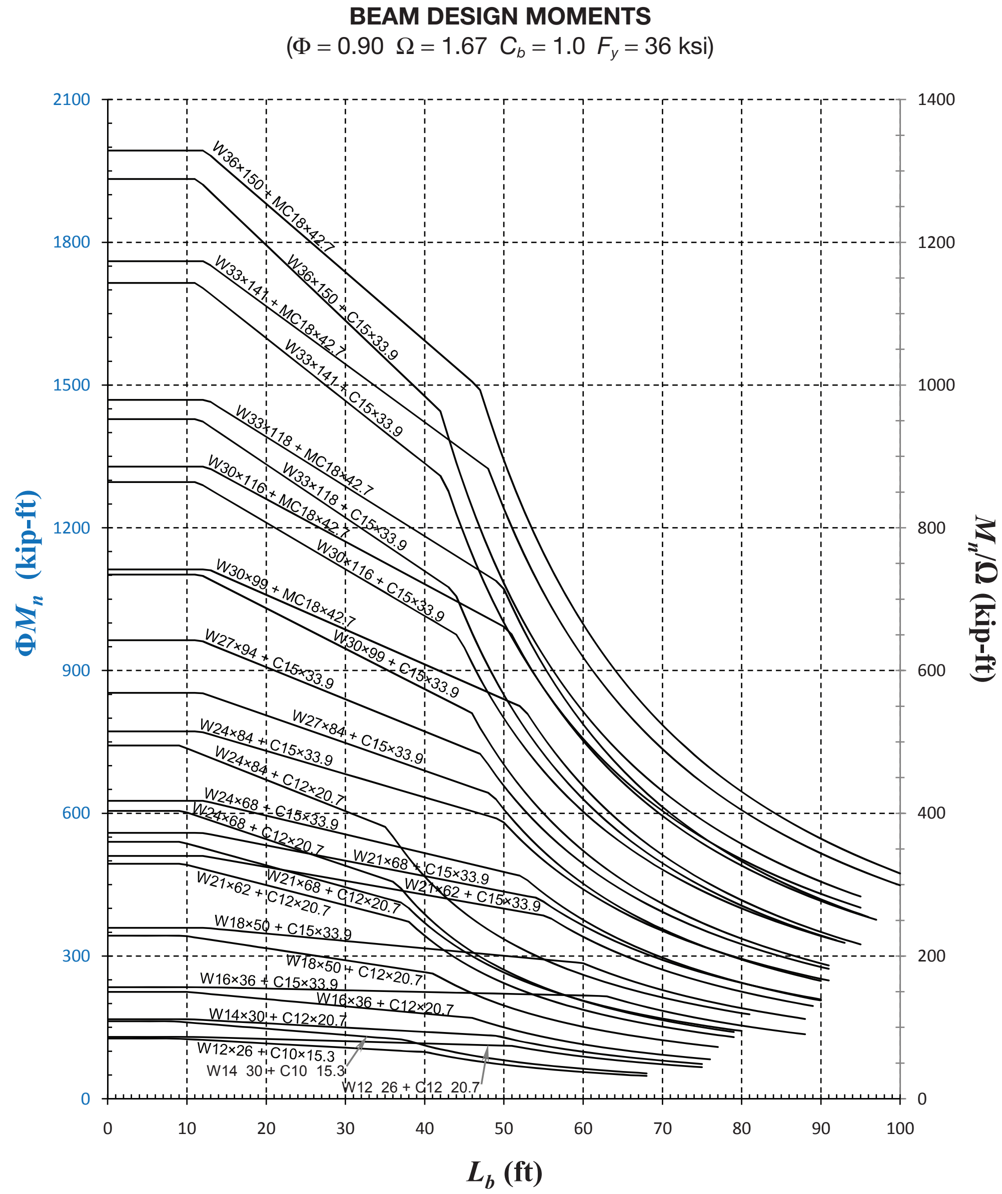

Fig. 2. Combination section design moment diagram (F_y = *36 ksi).*

BF is then defined as:

$$BF = \phi\left(\frac{M_{px} - F_L S_{xc}}{L_r - L_p}\right) \tag{15}$$

Substituting Equation 15 into Equation 14:

$$\phi M_{nx} = C_b\left[\phi M_{px} - BF\left(L_b - L_p\right)\right] \le \phi M_{px} \tag{16}$$

M_{ny} is calculated as the *y*-axis plastic bending strength of the wide flange top flange and the channel for combination sections:

$$M_{ny} = \left(Z_{W\text{ top flange}} + Z_{x\text{ channel}}\right)F_y = \left(\frac{t_f b_f^2}{4} + Z_{x\text{ channel}}\right)F_y \tag{17}$$

6. Check concentrated load criteria in 2005 AISC *Specification* Section J10.
7. Evaluate fatigue provisions of 2005 AISC *Specification* Appendix 3.

EXAMPLE USING LRFD

Crane capacity = 20 tons
Bridge span = 70 ft
Cab-operated
Bridge weight = 57.2 kips
Trolley weight = 10.6 kips
Max wheel load = 38.1 kips (no impact included)

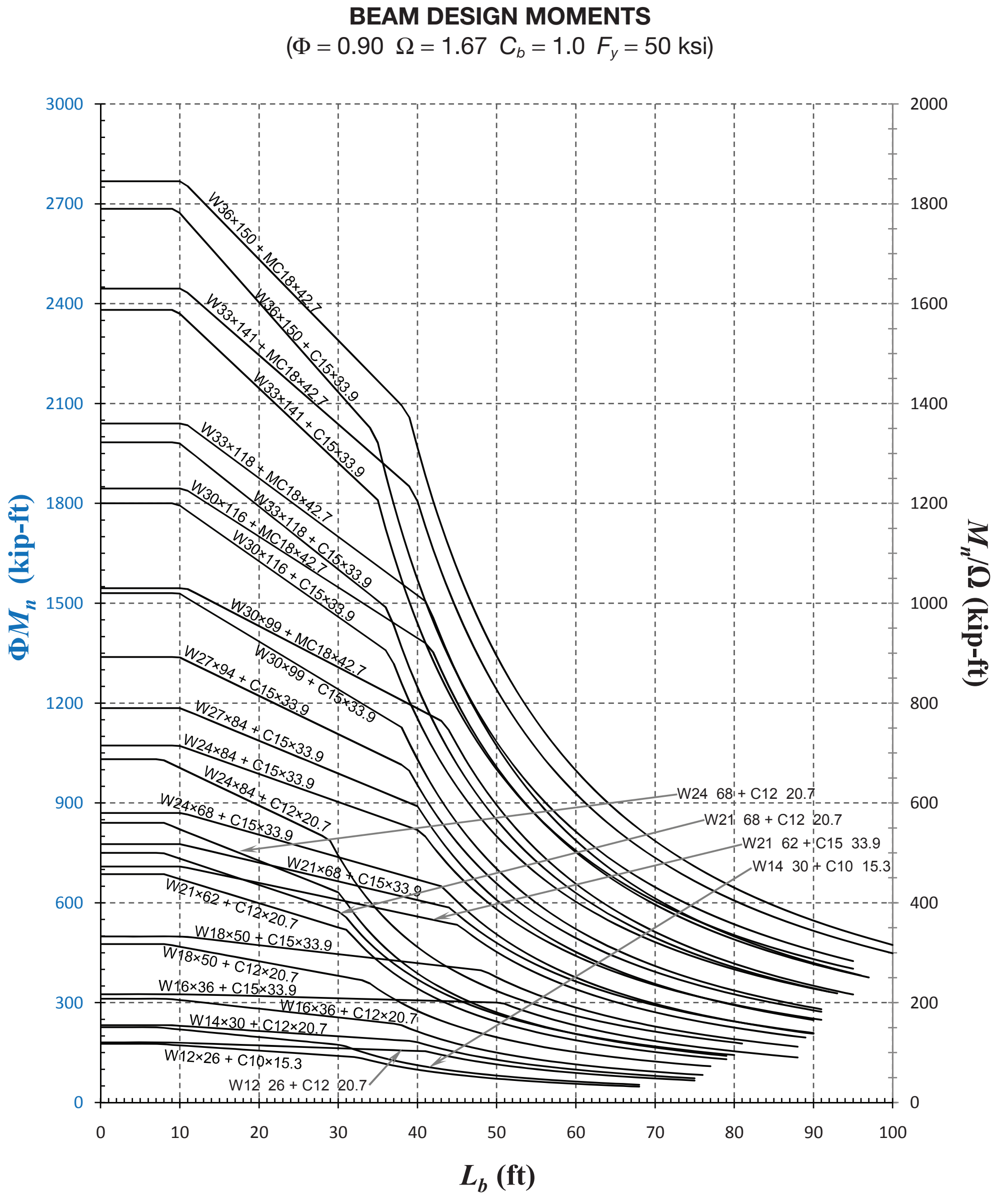

Fig. 3. Combination section design moment diagram (F_y = *50 ksi).*

Wheel spacing = 12 ft
Runway girder span = $L_b = 30$ ft, $F_y = 50$ ksi

1. Calculate the maximum factored moments and shears:

   $P_{u\,vert}$ per wheel = 55.2 kips (assuming $\lambda = 1.6$ for lifted and trolley weight)

   $P_{u\,horz}$ per wheel = 4.05 kips

   w_u (self weight of girder and rail)

   $$= 0.19 \text{ kips/ft}$$

   $$M_{ux} = 683 \text{ kip-ft},\ C_b = 1.19$$

   $$M_{uy} = 39 \text{ kip-ft}$$

   $$V_{uy} = 119 \text{ kips}$$

   $$V = 6.5 \text{ kips}$$

   Girder analysis details for this crane loading are provided in Fisher (2004).

2. Determine M_{ueq}:

   Expect a C15×33.9 channel cap. From Table 1, with $L_b = 30$ ft and $F_y = 50$ ksi:

   $$b = 0.9$$

   $$m = 3.0\times10^{-3}$$

   $$M_{ueq} = \frac{M_{ux}/C_b + bM_{uy}}{1 - mM_{uy}}$$

   $$= \frac{(683 \text{ kip-ft})/1.19 + 0.9(39 \text{ kip-ft})}{1 - \left(3.0\times10^{-3}\right)(39 \text{ kip-ft})}$$

   $$= 690 \text{ kip-ft}$$

3. Select first trial section:

   From Figure 3, with M_{ueq} = 690 kip-ft and L_b = 30 ft, select a W24×68 + C15×33.9. For this trial section, the following values are taken from Table 3:

   $$\phi M_{px} = 870 \text{ kip-ft}$$

   $$L_p = 10.2 \text{ ft}$$

   $$L_r = 43.2 \text{ ft}$$

   $$I_x = 2710 \text{ in}^4$$

   $$I_y = 385 \text{ in}^4$$

   $$BF = 6.72$$

4. Evaluate M_{cx} and M_{cy}:

   $$L_p = 10.2 \text{ ft} < L_p = 30 \text{ ft} < L_r = 43.2 \text{ ft}$$

   $$M_{cx} = \phi M_{nx} = C_b\left[\phi M_{px} - BF\left(L_b - L_p\right)\right] \le \phi M_{px}$$

   $$\phi M_{nx} = 1.19\left[870 \text{ kip-ft} - 6.72(30 \text{ ft} - 10.2 \text{ ft})\right]$$

   $$= 877 \text{ kip-ft}$$

   However, M_{cx} is limited by $\phi M_{px} = 870$ kip-ft. Therefore,

   $$M_{cx} = \phi M_{nx} = \phi M_{px} = 870 \text{ kip-ft}$$

   $$\phi M_{ny} = \phi F_y\left(\frac{t_f b_f^2}{4} + Z_{x\text{ channel}}\right)$$

   $$= \frac{(0.9)50 \text{ ksi}}{12 \text{ in./ft}}\left(\frac{0.585 \text{ in.}(8.97 \text{ in.})^2}{4} + 50.8 \text{ in.}^3\right)$$

   $$= 235 \text{ kip-ft}$$

5. Evaluate Chapter H interaction (Equation H1-1b):

   $$\frac{P_r}{2P_c} + \frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}$$

   $$= 0 + \frac{683 \text{ kip-ft}}{870 \text{ kip-ft}} + \frac{39 \text{ kip-ft}}{235 \text{ kip-ft}}$$

   $$= 0.785 + 0.166$$

   $$= 0.95 \le 1.0$$

6. Calculate $I_{required}$ based on strategic location of the crane P_{vert} and P_{horiz} for maximum deflection:

   $$\Delta_{\text{vert max}} \le \frac{L}{600} = \frac{360 \text{ in.}}{600} = 0.6 \text{ in.}$$

   therefore $Ix \ge 3{,}372$ in.^{4}

   $$\Delta_{\text{horiz max}} \le \frac{L}{400} = \frac{360 \text{ in.}}{400} = 0.9 \text{ in.}$$

   therefore $I_y \ge 140$ in.^{4}

The W24×68 + C15×33.9 trial section efficiently meets all 2005 AISC *Specification* strength requirements; however, the section does not meet generally accepted vertical deflection requirements. A W27×84 + C15×33.9 does meet both AISC strength and generally accepted deflection requirements.

CONCLUSION

A simplified design procedure is discussed for the crane girders listed as combination sections in Table 1-19 of the 13th edition AISC *Steel Construction Manual*. An equivalent moment method is presented for accurate selection of a combination section subjected to biaxial bending. Beam design moment graphs are presented to allow rapid selection of trial sections and tables are provided for efficient analysis of typical combination sections.

REFERENCES

AISC (2005a), *Specification for Structural Steel Buildings*, AISC 360-05, American Institute of Steel Construction, Chicago, IL.

AISC (2005b), *Steel Construction Manual*, 13th ed., American Institute of Steel Construction, Chicago, IL.

Fisher, J.M. (2004), *Design Guide 7: Industrial Buildings—Roofs to Anchor Rods*, 2nd ed., American Institute of Steel Construction, Chicago, IL.

Laman, J.A. (1996), "LRFD Crane Girder Design and Aids," *Engineering Journal*, American Institute of Steel Construction, Vol. 33, No. 4, 1996, pp. 153–158.