Rapid Selection of Beam-Columns

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THIS PAPER presents methods for the rapid selection of members in the design of beam-columns. The members may be subject to bending about either or both axes, with or without direct load. Method PM_x converts the direct load and/or the moment about the Y-Y axis into equivalent moments about the X-X axis, reducing the problem to the selection of a beam with bending about the X-X axis only. Method MP converts the moment about the X-X axis and/or the moment about the Y-Y axis into direct loads, reducing the problem to the selection of a column without bending.

ORIGIN OF METHODS

The methods presented herein were born of desperation. The scheduled time for the complete structural design of a large braced power plant was three months (start to finish). This type of structure entails the design of a large number of beam-columns.

It soon became apparent that the excessive time being spent on these members would make it impossible to meet the tight schedule. The design office suffered from a common malady—designer understaffing. The cure required that the designer be relieved of routine tasks. Unfortunately, no routine procedure (as far as was known) was available for the selection of beam-column members. The common "guess" procedure usually required several guesses and resulted in overdesigned or underdesigned sections. When underdesigned, redesign was necessary. Overdesign within about 20 percent was usually tolerated; there just wasn't time to do better.

The development of a simple, rapid procedure became urgent. Since A36 steel with $C_b = 1$ was being used, a method utilizing the allowable moment beam charts on pages 2-48 through 2-53 of the AISC Manual of Steel Construction appeared to offer hope. Could the beam moment be modified to allow for the direct load?

This approach proved successful; its use by a novice resulted in the selection of an efficient section in a short time, even when several loading conditions had to be considered. A modified moment was obtained by converting interaction Formula (7a) as follows:

$$\frac{f_a}{F_a} + \frac{(\mathrm{AF})_{fb} C_m f_b}{F_b} \leq 1.0$$

where

$$(\mathrm{AF})_{fb} = \frac{1}{1 - (f_a/F'_e)}$$

and, solving for F_b,

$$\frac{(\mathrm{AF})_{fb} C_m f_b}{[1 - (f_a/F_a)]} \leq F_b$$

The left hand side of this equation represents an amplified f_b and therefore an amplified M, since $M = f_b S/12$.

A trial section was simply and rapidly checked by this method by finding:

1. $f_a = P/A$
2. F_a (using the higher value of $12K_x l_x/r_x$ and $12K_y l_y/r_y$ from Manual pg. 5-68)
3. f_a/F_a
4. $(\mathrm{AF})_{fb} = 1/[1 - (f_a/F'_e)]$ (Manual pg. 5-69)
5. Modified moment $M' = C_m M \dfrac{(\mathrm{AF})_{fb}}{1 - (f_a/F_a)}$

When the allowable moment in the Manual beam charts was approximately equal to the modified moment, the member was considered satisfactory if:

(a) AISC Specification Formula (7b) was satisfied.
(b) The requirement of Specification Sect. 1.9.2, concerning the maximum allowable ratio of unsupported depth-to-thickness of web, was satisfied.
(c) For $F_b = 24$ ksi, the requirements of Sect. 1.5.1.4.1 concerning compactness for bending, for combined axial load and bending, and for compression flange support were satisfied.

If the member was unsatisfactory, i.e., M_{all} from the beam charts was too high or too low, another trial section was selected, using the modified moment, M', as a guide. Steps 1 through 5 were then repeated. This process was continued until a satisfactory section was found.

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Although the schedule was met with the help of this method, some time-consuming shortcomings were apparent: No guides were available for the selection of reasonable trial members; the section testing was extremely rapid only for A36 steel with $C_b = 1$; the maximum unbraced compression flange length plotted on the beam charts was 25 ft; the checks for compactness for combined axial load and bending (Sect. 1.5.1.4.1) and for the allowable versus actual ratio of unsupported web width T to web thickness t (Sect. 1.9.2) could not be made rapidly.

In addition a member occasionally had to be designed for axial load and bending about both axes, for axial load and bending about the Y-Y axis only, for bending about both axes without axial load, and, in some cases, with A242 steel. The method proved awkward for these cases.

The methods finally developed and presented in this paper overcame all these objections. They are applicable to beams, columns and beam-columns of any steel, and C_b can have any value. A trial section can be selected on a rational basis in a short time. Sections of A36, A440, A441, or A242 steel can be tested rapidly for compliance with all pertinent code requirements. The methods presented are applicable to all other steels; however, in such cases their testing is more time-consuming because necessary design aids are not available. Although the methods described deal only with member selection, they permit rapid preliminary sizing of members and determination of relative stiffness values. Values of P, $C_{mx}M_x$, $C_{my}M_y$, L_{span}, K_xl_x, K_yl_y, l_{yu} and C_b must be known or assumed. Values of P, M_x or M_y may be zero.

DESCRIPTION OF METHODS

Method PM_x converts the direct load and/or the moment about the Y-Y axis into equivalent moments about the X-X axis. This reduces the problem to that of the selection of a beam with bending about the X-X axis only. Method MP converts the moment about the X-X axis and/or the moment about the Y-Y axis into direct loads, reducing the problem to that of the selection of a column without bending. The results from both methods are identical.

Method MP is preferable when a column section (14WF or shallower) would be used, i.e., when P acts in conjunction with M_y only, or when P is relatively high and acts in conjunction with M_x and M_y, or M_x only.

Method PM_x is preferable for all other conditions.

The only conditions for which neither method is advantageous are:

1. Bending about the X-X axis only for A36 steel, $C_b = 1$, $l_{yu} \leq 25$ ft. The Manual beam charts, pgs. 2-48 through 2-53, provide a simple, rapid solution for this case. (Note that the following are not plotted on the charts: WF's heavier than 14 WF 119, all BP's, all I's, and the new 18B through 24B lightweight sections.)

2. Axial load only for A36, A440, A441, and A242 steels. The Manual column tables (pgs. 3-13 through 3-43) adequately provide a simple, rapid solution for this case. (Note that the tables do not include WF's heavier than 14WF426.)

DERIVATION OF FORMULAS

Equivalent Beam Method ($\mathbf{PM_x}$)—The axial load P is converted into an equivalent moment $M_{x\text{-}PM}$ about the X-X axis so that the average fiber stress due to P equals the extreme fiber stress due to $M_{x\text{-}PM}$ as follows (see the Nomenclature in this paper for units):

$$M_{x\text{-}PM} = \frac{f_a S_x}{12} = \frac{(P/A)(2Ar_x^2/d)}{12} = \frac{Pr_x^2}{6d} = C'_{PM}P$$

where $f_a = P_{act}/A = [12(M_{x\text{-}PM})/S_x]$

$$S_x = \frac{I}{c} = \frac{Ar_x^2}{d/2} = \frac{2Ar_x^2}{d} = 12AC'_{PM}$$

where $C'_{PM} = \dfrac{r_x^2}{6d}$

Some other relationships used are:

$$f_{bx} = \frac{12M_x}{S_x}$$

$$F_{bx} = \frac{12M_{x\text{-}all}}{S_x}$$

$$f_{by} = \frac{12M_y}{S_y}$$

$$F_{by} = \frac{12M_{y\text{-}all}}{S_y}$$

For bi-axial bending, Formula (7a) becomes:

$$\frac{f_a}{F_a} + \frac{(\text{AF})_{f_{bx}}C_{mx}f_{bx}}{F_{bx}} + \frac{(\text{AF})_{f_{by}}C_{my}f_{by}}{F_{by}} \lesssim 1$$

This is transformed as follows:

$$\frac{f_a}{F_{bx}}\left(\frac{F_{bx}}{F_a}\right) + \frac{(\text{AF})_{f_{bx}}C_{mx}f_{bx}}{F_{bx}} + \frac{(\text{AF})_{f_{by}}C_{my}f_{by}(F_{bx}/F_{by})}{F_{bx}} \lesssim 1$$

$$\frac{(12M_{x\text{-}PM}/S_x)(F_{bx}/F_a) + (\text{AF})_{f_{bx}}C_{mx}(12M_x/S_x) + (\text{AF})_{f_{by}}C_{my}(12M_y/S_y)(F_{bx}/F_{by})(S_x/S_x)}{12M_{x\text{-}all}/S_x} \lesssim 1$$

$$\frac{M_{x\text{-}PM}(F_{bx}/F_a) + (\text{AF})_{f_{bx}}C_{mx}M_x + (\text{AF})_{f_{by}}C_{my}M_y(S_x/S_y)(F_{bx}/F_{by})}{M_{x\text{-}all}} \lesssim 1$$

$$\frac{C'_{PM}P(F_{bx}/F_a) + (\text{AF})_{f_{bx}}C_{mx}M_x + (\text{AF})_{f_{by}}C_{my}M_y(S_x/S_y)(F_{bx}/F_{by})}{M_{x\text{-}all}} \lesssim 1$$

Thus, multiplying P by $C'_{PM}(F_{bx}/F_a)$ converts P into an equivalent moment about the X-X axis. Multiplying $(\mathrm{AF})_{f_{by}}C_{my}M_y$ by $(S_x/S_y)(F_{bx}/F_{by})$ similarly converts the effective Y-Y axis moment into an equivalent moment about the X-X axis. Adding these to the effective X-X axis moment, $(\mathrm{AF})_{f_{bx}}C_{mx}M_x$ gives an equivalent design moment about the X-X axis. If the member supplied has an allowable moment equal to or greater than this moment, the interaction Formula (7a) is satisfied.

By assuming $F_{bx}/F_{by} = 1$ and using approximate values for $C'_{PM}(F_{bx}/F_a)$ and (S_x/S_y), a trial member can be selected. Better approximate values can then be determined and a revised trial member found. Exact values of $C'_{PM}(F_{bx}/F_a)$, $(\mathrm{AF})_{f_{bx}}$, and $(\mathrm{AF})_{f_{by}}(S_x/S_y)$ (F_{bx}/F_{by}) are then found and an exact equivalent moment determined. A comparison of this with the allowable moment will determine if the trial member is satisfactory or if a new trial member should be chosen.

Equivalent Column Method (MP)—Moments M_x and M_y are converted into equivalent axial loads $P_{x\text{-}eq}$ and $P_{y\text{-}eq}$, respectively, such that the extreme fiber stress due to these moments equal the average fiber stress respectively due to the axial loads.

The biaxial bending form of interaction Formula (7a) is transformed as follows:

$$\frac{f_a}{F_a} + \frac{(\mathrm{AF})_{f_{bx}}C_{mx}f_{bx}[1/(F_{bx}/F_a)]}{F_a} + \frac{(\mathrm{AF})_{f_{by}}C_{my}f_{by}[1/(F_{by}/F_a)]}{F_a} \lessgtr 1$$

$$f_a = \frac{P_{act}}{A}$$

$$F_a = \frac{P_{all}}{A}$$

$$f_{bx} = \frac{12M_x}{S_x} = \frac{P_{x\text{-}eq}}{A}$$

$$P_{x\text{-}eq} = \left(\frac{12M_x}{S_x}\right)A = \frac{12M_xA}{(2Ar_x^2/d)} = \frac{M_x}{(r_x^2/6d)} = \frac{M_x}{C'_{PM}}$$

Then,

$$f_{bx} = \frac{(M_x/C'_{PM})}{A}$$

$$f_{by} = \frac{12M_y}{S_y} = \frac{P_{y\text{-}eq}}{A}$$

$$P_{y\text{-}eq} = \left(\frac{12M_y}{S_y}\right)A = \frac{M_y}{M_x}\left(\frac{12M_xA}{S_x}\right)\left(\frac{S_x}{S_y}\right)$$

$$= \frac{M_y}{M_x}\left(\frac{M_x}{C'_{PM}}\right)\left(\frac{S_x}{S_y}\right) = \frac{M_y}{C'_{PM}}\left(\frac{S_x}{S_y}\right)$$

$$f_{by} = \frac{M_y}{C'_{PM}}\left(\frac{S_x}{S_y}\right)\left(\frac{1}{A}\right)$$

Substituting these values in the transformed interaction formula:

$$\frac{(P_{act}/A)}{(P_{all}/A)} + \frac{(\mathrm{AF})_{f_{bx}}C_{mx}(M_x/C'_{PM})(1/A)[1/(F_{bx}/F_a)]}{(P_{all}/A)} + \frac{(\mathrm{AF})_{f_{by}}C_{my}(M_y/C'_{PM})(S_x/S_y)(1/A)[1/(F_{by}/F_a)]}{(P_{all}/A)} \lessgtr 1$$

and

$$\frac{P_{act} + [C_{mx}M_x/(F_{bx}/F_a)][(\mathrm{AF})_{f_{bx}}/C'_{PM}] + C_{my}M_y(\mathrm{AF})_{f_{by}}[(S_x/S_y)/C'_{PM}]F_a/F_{by}}{P_{all}} \lessgtr 1$$

Thus, dividing $(\mathrm{AF})_{f_{bx}}C_{mx}M_x$ by $(F_{bx}/F_a)C'_{PM}$ converts the effective X-X axis moment into an equivalent axial load. Similarly, multiplying $(\mathrm{AF})_{f_{by}}C_{my}M_y$, the effective Y-Y axis moment, by $[(S_x/S_y)/C'_{PM}](F_a/F_{by})$ converts it into an additional equivalent axial load. Adding these to the actual axial load, P_{act}, an equivalent design axial load is obtained. If the member supplied has an allowable axial load equal to or greater than the equivalent design axial load, Formula (7a) is satisfied.

By using approximate values for $C'_{PM}(F_{bx}/F_a)$ and for $(1/C'_{PM})(S_x/S_y)(F_a/F_{by})$ a trial member can be selected. The value of (F_a/F_{by}) can be assumed equal to $1/(F_{bx}/F_a)$ with F_{bx}/F_a obtained from Graph A. Better approximate values can then be determined and a revised trial member found which will be very close to the actual member required. An exact equivalent direct load is then determined. A comparison of this with the allowable direct load will determine whether the trial member is satisfactory or a new trial member should be chosen.

These formulas also apply to Formula (6). In that case, $(\mathrm{AF})_{f_{bx}}$, $(\mathrm{AF})_{f_{by}}$, C_{mx} and C_{my} are simply made equal to 1.

Formula (6) becomes, for Method $\mathrm{PM_x}$:

$$\frac{C'_{PM}\,P(F_{bx}/F_a) + M_x + M_y(S_x/S_y)(F_{bx}/F_{by})}{M_{x\text{-}all}} \lessgtr 1$$

For Method MP, Formula (6) becomes:

$$\frac{P_{act} + \{M_x/[(F_{bx}/F_a)C'_{PM}]\} + (M_y/C'_{PM})(S_x/S_y)(F_a/F_{by})}{P_{all}} \lessgtr 1$$

A refinement, leading to economy in some cases, is the use of a reduced yield point F'_y below the minimum specified yield point F_y. When $l_{yu} < L_c$, $F_b(\max) = 0.60F_y$ when the section is not compact; if the section is compact for F'_y, $F_b(\max) = 0.66F'_y$. The value of F'_y can be obtained using the provisions of Sect. 1.5.1.4.1. The procedures described above are then applicable for F'_y.

DESIGN EXAMPLES AND COMPUTATION FORMS

For maximum efficiency in the use of the PM_x and MP methods, the author has developed a standard computation form for each method. By using these forms, which provide a step-by-step outline for the computations, the designer is required to supply information for the first four lines only; a less-skilled individual can, with minimum supervision, complete the computations by following the instructions on the form. Boxed references such as **Tl**, **GA**, and **L2P** refer to the Tables, Graphs, and computation form lines, respectively.

To illustrate the use of the methods described in this paper, an illustrative example has been worked out on the computation form for each method.

Example 1 (PM_x Method):

Given:

$P = 190$ kips $\quad C_{mx} = C_{my} = 0.85$
$M_x = 450$ kip-ft $\quad l_x = 30.0$ ft
$M_y = 21$ kip-ft $\quad l_y = 20.0$ ft
$L_{span} = 30.0$ ft $\quad l_{yu} = 20.0$ ft
$F_y = 36$ ksi $\quad K_x = K_y = 1$
$C_b = 1$

Solution: See Fig. 1

Example 2 (MP Method):

Given:

$P = 380$ kips $\quad C_{mx} = C_{my} = 0.85$
$M_x = 42$ kip-ft $\quad l_x = 30.0$ ft
$M_y = 21$ kip-ft $\quad l_y = 20.0$ ft
$L_{span} = 30.0$ ft $\quad l_{yu} = 20.0$ ft
$F_y = 36$ ksi $\quad K_x = K_y = 1$
$C_b = 1$

Solution: See Fig. 2.

SUPPLEMENTAL DISCUSSION

General—

Yield Point (F_y)—Since the yield point stress F_y varies for different shapes of A440, A441, and A242 steels (see Manual pgs. 5-155 through 5-157), a trial section for these grades of steel must first be selected before F_y can be entered on the computation form. A subsequent change of section may require a change of F_y.

Wind and Seismic Loads—It is suggested that all axial loads and moments which are considered in conjunction with wind or seismic effects and those due to the wind or seismic effects be reduced to 75 percent of their design values. This permits the use of normal stresses while taking advantage of the Specification provision for increasing allowable stresses by one-third. Quite often it is necessary to consider several loading conditions when selecting a member. Entering the reduced loads and moments as suggested on the computation forms permits a visual comparison of all loading conditions and the elimination of the non-critical ones.

Approximations—In this supplemental discussion, all approximations presented for obtaining trial sections are recommendations by the author. It is intended to make the approximations as broadly applicable as possible; hence, since a large number of parameters are involved, the amount of time saved by using the approximations will vary for different conditions. For any particular application, for instance a light structure using light members, the approximations can be refined.

The testing procedure is precise, however, and includes no approximations. The use of the recommended approximations therefore does not affect the final result. A good approximation saves time; a poor one wastes time.

Design Aids—

Table 3: In a few cases L_u for A440, A441 and A242 steel does not agree with values found in the Steel Construction Manual. The reason is that the author took advantage of the option in a footnote on pg. 5-18: "Where l/r is less than 40 ($12l_{yu}/r_4$ in the author's notation), stress reduction according to Formula (4) may be neglected." Hence, when $L_u = 40r_4/12$ is larger than $L_u = 20{,}000/12(d/A_f)F_y$, the former is included in the table.

Graph A: This graph represents the plot of averaged values obtained from a large number of beam-column designs. Its use should be limited to the selection of trial members.

Graph B: May be used to find values of F_a for all grades of steel when $12Kl/r > 126.1$ (main members) and $12l/r > 120$ (bracing and secondary members).

For steels other than A36, A440, A441 and A242, when $12Kl/r \leq 126.1$, Formulas (1) or (2), Section 1.5.1.3 should be used.

Graph D: The plots of d/t (maximum allowable) vs. f_a/F_a for A36, A242, A440, and A441 steels can be used to check compactness for combined axial force and bending as required by Sect. 1.5.1.4.1. The graph is also of value when calculating reductions in areas to make the section conform to the provisions of Sect. 1.9.2.

Graph E: F_b vs. C_b for various values of $12l_{yu}/r_4$, Formula (4), for $F_y = 36$ ksi.

The graph can also be used for any value of F_y and C_b as follows:

$$F_b = \left[1 - \frac{(12l_{yu}/r_4{}^2)}{2C_c{}^2C_b}\right]0.60F_y \qquad \text{Formula (4)}$$

For $F_y = 36$, this becomes:

$$F_{b\text{-}36} = \left[1 - \frac{(12l_{yu}/r_4{}^2)}{2C^2{}_{c\text{-}36}C_{b\text{-}36}}\right]0.6 \times 36$$

EQUIVALENT BEAM METHOD PM_x

Axial loads – kips ; Moments – ft. kips ; Stresses – ksi ;
Lengths – ft. except r and d which are in.; S – in^3

Boxes: $\boxed{\text{L3}}$ = Line 3 ; $\boxed{\text{GB}}$ = Graph B ; $\boxed{\text{T2}}$ = Table 2 , etc.

P, X or Y following line numbers, denotes line to be used exclusively for P, M_x or M_y respectively.

1	F_y^{ksi} ; C_b			$F_y = 36$; $C_b = 1$
2P	P			190
3X	$C_{mx} M_x$			$0.85 \times 450 = 382$
3Y	$C_{my} M_y$			$0.85 \times 21 = 18$
4	L^{ft}	Span (not for vert. memb.)		30.0
	$K_x \ell_x$			$1 \times 30.0 = 30.0$
	$K_y \ell_y$			$1 \times 20.0 = 20.0$
	ℓ_{yu}	Unbraced l'gth comp. flange		20.0
	d^{in} (min.) = $C_d L$	$\boxed{\text{T1}} \times \boxed{\text{L4}}$ (not for vert. memb.)		$0.54 \times 30.0 = 16.2$
5	d^{in} – try			27
6P	$C_{PM} P (F_{bx}/F_a)_{app}$	$\boxed{\text{T2}} \times \boxed{\text{L2P}} \times \boxed{\text{GA}}$		$(0.76)(190)(1.35) = 195$
7Y	$C_{my} M_y (S_x/S_y)_{app}$	$\boxed{\text{L3Y}} \times \boxed{\text{T2}}$		$(18)(9.3) = 167$
8	$C_{mx} M_x$	$\boxed{\text{L3X}}$		$\underline{382}$
	M_{1x-req}	$\boxed{\text{L6P}} + \boxed{\text{L7Y}} + \boxed{\text{L8}}$		744
9	Member ; M_{x-all}	$\boxed{\text{L10A}}$ or $\boxed{\text{L10B}}$		27 WF 145 740
	S_{x-req} ; S_{x-sup}	$\boxed{\text{T3}}$		403
10A	M_{x-all}	B'm Charts – AISC Manual		740
	$F_{bx} = 12 M_{x-all}/S_x$			$(12)(740)/(403) = 22$
10B	$C_b' = C_{b-act}(36/F_y)$		Use when $F_y \neq 36$ and/or $C_b \neq 1$ and for all other cases for which the AISC Beam Charts are are not applicable.	
	$\ell_{yu} \times 12/r_4^{in}$	$\boxed{\text{L4}} \times 12/\boxed{\text{T3}}$		
	F_{bx4}'	$\boxed{\text{GE}}$		
	$F_{bx4} = F_{bx4}' \left[F_y/36\right]$			
	$F_{bx5} = 1000/\left[\boxed{(d/A_f)\ell_{yu}}\right]$	$1000/\left[\boxed{\text{T3}} \times \boxed{\text{L4}}\right]$		
	For F_{bx} use larger of F_{bx4} or F_{bx5}			
	L_c^{ft} ; L_u^{ft}	$\boxed{\text{T3}}$		
	$M_{x-all} = F_{bx} S_x/12$			

Fig. 1. Computation outline form for Equivalent Beam Method PM_x, including sample computations for Example 1.

10Y	F_{by}	$0.66\,F_y$ (compact); $0.60\,F_y$ (non-compact)	24
11P	$f_a = P/(A, A' \text{ or } A'')$	$\boxed{\text{L2P}}/\boxed{\text{T3}}$	190/42.68 = 4.45
12X	$12K_x\,\ell_x/r_x{}^{in}$	$12\,\boxed{\text{L4}}/\boxed{\text{T3}}$	(12)(30.0)/11.26 = 32
12Y	$12K_y\,\ell_y/r_y{}^{in}$	$12\,\boxed{\text{L4}}/\boxed{\text{T3}}$	(12)(20.0)/3.09 = 78
13P	F_a	$\boxed{\text{GB}}$ Use Max. $12K\ell/r$ $\boxed{\text{L12X}}$ or $\boxed{\text{L12Y}}$	15.6
	When F_{bx} $\boxed{\text{L10A}}$ or $\boxed{\text{L10B}} = 0.66F_y$ see Line 13A below.		
14P	$P(F_{bx}/F_a)$	$\boxed{\text{L2}} \times [\boxed{\text{L10A}}$ or $\boxed{\text{L10B}}]/\boxed{\text{L13P}}$	(190)(22)/15.6 = 268
15	C'_{PM}	$\boxed{\text{T3}}$	0.786
16X	$(AF)_{f_{bx}}$	$\boxed{\text{GC}}$ Use $12K_x\,\ell_x/r_x$ $\boxed{\text{L12X}}$	1.03
16Y	$(AF)_{f_{by}}(S_x/S_y)(F_{bx}/F_{by})$	$\boxed{\text{GC}}\ \boxed{\text{T3}}\ [\boxed{\text{L10A}}$ or $\boxed{\text{L10B}}/\boxed{\text{L10Y}}]$	$(1.22)(6.93)\frac{22}{24} = 7.76$
	Use $12K_y\,\ell_y/r_y$ $\boxed{\text{L12Y}}$ for $(AF)_{f_{by}}$		
17	$C'_{PM}P(F_{bx}/F_a)$	$\boxed{\text{L15}}\ \boxed{\text{L14P}}$	(0.786)(268) = 210
	$+C_{my}M_y(AF)_{f_{by}}(S_x/S_y)(F_{bx}/F_{by})$	$\boxed{\text{L3Y}}\ \boxed{\text{L16Y}}$	+(18)(7.76) = 140
	$+C_{mx}M_x(AF)_{f_{bx}}$	$\boxed{\text{L3X}}\ \boxed{\text{L16X}}$	+(382)(1.03) = 393
	$= M_{2x\text{-}req}$		743
18	$\frac{f_a}{0.6F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1$	At points braced in plane of bending	$\frac{4.45}{22} + \frac{\frac{(12)(450)}{(403)}}{22} + \frac{\frac{(12)(21)}{(58.3)}}{24} = 0.20+0.61+0.18=0.99$
13A	f_a/F_a	$\boxed{\text{L11P}}/\boxed{\text{L13P}}$ — If there is no entry in d/t col. in $\boxed{\text{T3}}$ $F_{b\text{-}max} = 0.66F_y$	
	d/t (actual)	$\boxed{\text{T3}}$	
	d/t (allowable)	$\boxed{\text{GD}}$	
	If d/t (actual) > d/t (all.), F_{bx}(max.) = $0.6F_y$; Revise Lines 9 and 10A or 10B.		
Compare $M_{2x\text{-}req}$ $\boxed{\text{L17}}$ with $M_{x\text{-}all.}$ $\boxed{\text{L9}}$; if unsatisfactory, select new member.			

Fig. 7. (*Continued.*)

EQUIVALENT COLUMN METHOD MP

Axial loads – kips ; Moments – ft. kips ; Stresses – ksi ;
Lengths – ft. except r and d which are in.; S – in^3

Boxes: $\boxed{L3}$ = Line 3 ; $\boxed{GB}$ = Graph B ; $\boxed{T2}$ = Table 2 , etc.

P, X or Y following line numbers, denotes line to be used exclusively for P, M_x or M_y respectively.

Line	Item		Reference	Computation
1	F_y^{ksi} ; C_b			$F_y = 36$; $C_b = 1$
2P	P			380
3X	$C_{mx} M_x$			$0.85 \times 42 = 36$
3Y	$C_{my} M_y$			$0.85 \times 21 = 18$
4	L^{ft}		Span (not for vert. memb.)	
	$K_x \ell_x$			$1 \times 30.0 = 30.0$
	$K_y \ell_y$			$1 \times 20.0 = 20.0$
	ℓ_{yu}		Unbraced lgth. comp. flange	20.0
	d^{in} (min.) = $C_d L$		$\boxed{T1} \times \boxed{L4}$ (not for vert. memb.)	
5	d^{in} – try			14
6X	$C_{mx}M_x/[C_{PM}(F_{bx}/F_a)_{app}]$		$\boxed{L3X}/[\boxed{T2}\ \boxed{GA}]$	$36/[(0.44)(1.42)] = 58$
7Y	$\dfrac{C_{my} M_y (S_x/S_y)_{app}}{C_{PM}(F_{bx}/F_a)_{app}}$		$\dfrac{\boxed{L3Y}\ \boxed{T2}}{\boxed{T2}\ \boxed{GA}}$	$\dfrac{(18)(4.3)}{(0.44)(1.42)} = 124$
8	P		$\boxed{L2P}$	380
	P_{1x} – req		$\boxed{L6X} + \boxed{L7Y} + \boxed{L8}$	562
9	Member	P_{all}	Col. Tables - AISC Man'l* or $\boxed{L9A}$	14 WF 119 — 596
	A_{req}	A, A' or A''$_{sup.}$	$\boxed{T3}$	34.99
9A	$P_{all} = F_a \times (A, A' \text{ or } A'')$		$\boxed{L13P} \times \boxed{T3}$	
10A	L_c^{ft} ; L_u^{ft}		$\boxed{T3}$	$L_c = 15.9$; $L_u = 42.9$
	$F_{bx} = 0.66 F_y$ for compact sect. with $\ell_{yu} \lesssim L_c$ and Line 13A satisfied.			
	$F_{bx} = 0.60 F_y$ if above not satisfied or for $L_c \lesssim \ell_{yu} \lesssim L_u$			22
10B	$C'_b = C_{b-act}(36/F_y)$		Computation req. only when F_{bx} is not obtained on Line 10 A	
	$\ell_{yu} \times 12/r_4^{in}$		$\boxed{L4} \times 12/\boxed{T3}$	
	F'_{bx4}		$\boxed{GE}$	
	$F_{bx4} = F'_{bx4}(F_Y/36)$			
	$F_{bx5} = 1000/[(d/A_f)\ell_{yu}]$		$1000/(\boxed{T3} \times \boxed{L4})$	

Fig. 2. Computation outline form for Equivalent Column Method MP, including sample computations for Example 2.

10X	F_{bx} - use	$\boxed{L10A}$ or larger value of $\boxed{L10B}$	22
10Y	F_{by}	$0.66\,F_y$ (compact); $0.60\,F_y$ (non-compact)	24
11P	$f_a = P/(A, A'$ or $A'')$	$\boxed{L2P}$ / $\boxed{T3}$	380/34.99 = 10.9
12X	$12K_x\,\ell_x/r_x{}^{in}$	12 $\boxed{L4}$ / $\boxed{T3}$	12×30/6.26 = 57.5
12Y	$12K_y\,\ell_y/r_y{}^{in}$	12 $\boxed{L4}$ / $\boxed{T3}$	12×20/3.75 = 64
13P	F_a	$\boxed{GB}$ Use Max. $12K\ell/r$ $\boxed{L12X}$ or $\boxed{L12Y}$	17.1
	When F_{bx} $\boxed{L10X}$ $= 0.66\,F_y$, see Line 13A below		
14X	$C_{mx}M_x/[F_{bx}/F_a]$	$\boxed{L3X}$ / [$\boxed{L10X}$ / $\boxed{L13P}$]	36/[22/17.1] = 28.0
15	C'_{PM}	$\boxed{T3}$	0.451
16X	$(AF)_{f_{bx}}$	$\boxed{GC}$ Use $12K_x\,\ell_x/r_x$ $\boxed{L12X}$	1.32
16Y	$(AF)_{f_{by}}(S_x/S_y)\,\dfrac{F_a}{C'_{PM}\,F_{by}}$	$\boxed{GC}$ $\boxed{T3}$ $\boxed{L13P}$ $\boxed{L15}$ $\boxed{L10Y}$ [Use $12K_y\ell_y/r_y$ $\boxed{L12Y}$ for $(AF)_{f_{by}}$]	$\dfrac{(1.41)(2.82)(17.1)}{(0.451)(24)} = 6.26$
17	P	$\boxed{L2P}$	380
	$+\dfrac{C_{my}M_y(AF)_{f_{by}}(S_x/S_y)F_a}{C'_{PM}\,F_{by}}$	$\boxed{L3Y}$ $\boxed{L16Y}$	+(18)(6.26) = 113
	$+\dfrac{C_{mx}M_x}{(F_{bx}/F_a)}\,\dfrac{(AF)_{f_{bx}}}{C'_{PM}}$	$\boxed{L14X} \times \dfrac{\boxed{L16X}}{\boxed{L15}}$	$+(28.0)\dfrac{(1.32)}{(0.451)} = 82$
	$= P_{2-req}$		575
18	$\dfrac{f_a}{0.6F_y} + \dfrac{f_{bx}}{F_{bx}} + \dfrac{f_{by}}{F_{by}} \lesssim 1$	At points braced in plane of bending	$\dfrac{10.9}{22} + \dfrac{(12)(42)/(189)}{22} + \dfrac{(12)(21)/(67.1)}{24} =$ 0.50+0.12+0.16 = 0.78
13A	f_a/F_a	$\boxed{L11P}$ / $\boxed{L13P}$ — If there is no entry in d/t col. in $\boxed{T3}$ $F_b(max) = 0.66F_y$	
	d/t (actual)	$\boxed{T3}$	
	d/t (allowable)	$\boxed{GD}$	
	If d/t (actual) > d/t (all.), F_{bx} (max.) $= 0.60\,F_y$; Revise Line 10X.		
Compare P_{2-req} $\boxed{L17}$ with P_{all} $\boxed{L9}$; If unsatisfactory, select new member.			
* Select preliminary section using effective length $K_y\ell_y$. Calculate equivalent effective length $K_x\,\ell_x/(r_x/r_y)$. Find new P_{all} for this equivalent effective length if it exceeds $K_y\ell_y$. If new P_{all} is inadequate, select new section and repeat process.			

Fig. 2. (*Continued.*)

For any other value of F_y, say $F_{y\text{-}act}$,

$$F_{b\text{-}act} = \left[1 - \frac{(12l_{yu}/r_4)^2}{2C^2_{c\text{-}act}\, C_{b\text{-}act}}\right] 0.6 \times F_{y\text{-}act}$$

$$C_c^2 \propto \frac{1}{F_y}$$

Therefore, $C^2_{c\text{-}act} = C^2_{c\text{-}36}(36/F_{y\text{-}act})$

and $C^2_{c\text{-}act}C_{b\text{-}act} = C^2_{c\text{-}36}\,\dfrac{36}{F_{y\text{-}act}}\,C_{b\text{-}act}$

$$F_{b\text{-}act} = \left[1 - \frac{(12l_{yu}/r_4)^2}{2C^2_{c\text{-}36}C_{b\text{-}act}(36/F_{y\text{-}act})}\right] 0.6 \times F_{y\text{-}act} \times \frac{36}{36}$$

Let $C'_b = C_{b\text{-}act}(36/F_{y\text{-}act})$

$$F_{b\text{-}act} = \left(\left[1 - \frac{(12l_{yu}/r_4)^2}{2C^2_{c\text{-}36}C'_b}\right] 0.6 \times 36\right)\frac{F_{y\text{-}act}}{36}$$

Let $F'_b = \left[1 - \dfrac{(12l_{yu}/r_4)^2}{2C^2_{c\text{-}36}C'_b}\right] 0.6 \times 36$

F'_b is in exactly the same form as $F_{b\text{-}36}$ above. Hence, Graph E can be used to find F'_b using $12l_{yu}/r_4$ and C'_b.

$$F_{b\text{-}act} = F'_b\,\frac{F_{y\text{-}act}}{36}$$

When $F_y \neq 36$ ksi, the procedure is as follows:

1. Find $C'_b = C_{b\text{-}act}(36/F_{y\text{-}act})$
2. Using C'_b as abscissa, enter Graph E and obtain F_{bx4} as ordinate.
3. Calculate $F_{bx4\text{-}act} = F_{bx4} \times F_{y\text{-}act}/36$

Equivalent Beam Method (PM_x)—

Trial Depth—A reasonable trial depth, d, may be obtained by computing a "ballpark" preliminary equivalent moment, $M_{eq} = 0.5P + 10C_{my}M_y + C_{mx}M_x$. The allowable moment beam charts in the Manual (for A36) can then be used to rapidly obtain a trial value of d. Also by calculating $S_x = 12M_{eq}/0.55F_y$ (assume F_y = 50 ksi for A440, A441 and A242 steel), the use of the Elastic Section Modulus Table (AISC Manual) or Table 3 will result in a reasonable trial value of d for any steel. It should be realized, of course, that the trial depth may be fixed by functional considerations. Table 1 provides suggested minimum depths when the member is used as a beam. Although any trial depth may be arbitrarily assumed, a poor assumption may require additional computations.

Trial Member—Using $M_{1x\text{-}req}$ and l_{yu}, the value of $M_{x\text{-}all}$ for a trial member may be obtained from the Manual allowable moment charts for $l_{yu} \leq 25$ ft, $C_b = 1$, and A36 steel. For A36 steel and $C_b \neq 1$, a trial member may be selected from the Manual allowable moment charts using $M_{1x\text{-}req}$ and l_{yu}. For any steel, with C_b equal to any value, a trial member may be selected from the Elastic Section Modulus Table or Table 3, using $S_{x\text{-}req} = 12M_{1x\text{-}req}/0.55F_y$.

The suitability of a trial member with $M_{all} \geqq M_{1x\text{-}req}$ can be accurately and rapidly determined by completing the necessary computations. If the trial section is found to be unsuitable, a good approximation of the required properties of a suitable member is indicated and in many cases a new satisfactory member can be selected without further computations.

Excessive refinement at the stage of arriving at a trial member is not warranted, since F_{bx}/F_a is a rough approximation, $C_{mx}M_x$ should be multiplied by $(AF)_{f_{bx}}$, and $C_{my}M_y$ should be multiplied by $(AF)_{f_{by}}$ and S_x/S_y. The futility of refinement at this stage can be highlighted by the observation that S_x/S_y can vary by 50 percent for members of the same depth.

Finding F_{bx}—When $L_c < l_{yu} \leq L_u$, $F_{bx} = 0.60F_y$. When $L_c \geq l_{yu}$ **and** the section is compact for bending **and** the section is compact for combined axial force and bending (Sect. 1.5.1.4.1), $F_{bx} = 0.66F_y$. If **any** of the aforementioned three requirements are **not** satisfied, $F_{bx\text{-}max} = 0.60F_y$. When $L_u < l_{yu}$, $F_{bx} = 12M_{x\text{-}all}/S_x$. For A36 steel with $C_b = 1$ and $l_{yu} \leq 25$ ft, $M_{x\text{-}all}$ can be obtained from the allowable moment charts. For all other cases, F_{bx} can be obtained as shown on Line 10B of the computation form (Fig. 1), using the larger value of F_{bx4} or F_{bx5} with a maximum of $0.60F_y$.

Compactness—Sections not compact for bending for A36, A440, A441 and A242 steels are indicated by the symbol †, and sections not compact for A440, A441, and A242 steels are indicated by the symbol ‡, on the left side of Table 3.

When $F_{bx} = 0.66F_y$, the section must be checked for compactness for axial force and bending moment as required by Sect. 1.5.1.4.1. If there is no entry in the d/t column in Table 3 under the appropriate F_y value, the section is compact as required and $F_{bx} = 0.66F_y$ can be used if $l_{yu} < L_c$ and the section is compact for bending. If there is an entry, and if d/t (actual) $\leq d/t$ (allowable), $F_{bx\text{-}max} = 0.66F_y$, providing the other requirements are met. Otherwise, use $F_{bx\text{-}max} = 0.60F_y$.

Finding F_{by}—If the section is compact for bending, $F_{by} = 0.66F_y$. Otherwise, $F_{by} = 0.60F_y$. The provisions of Sect. 1.5.1.4.1 regarding lateral support and combined axial force and bending, do **not** apply.

Reduced Section Areas—Use the actual sectional area A unless it is necessary to reduce the area because of an excessive b_f/t_f ratio (Sect. 1.9.1) or T/t ratio (Sect. 1.9.2). Where such reductions are necessary, the reduced areas A′ (A36) and A′′ (A242, A440, and A441) are shown in Table 3.

Reduced area A''' is required for other steels when:

1. $b_f > \frac{6000}{\sqrt{F_y}} t_f$ (Sect. 1.9.1)

   The required reduction in area is

   $\Delta A_{9.1} = t_f[2b_f - (12000\ t_f/\sqrt{F_y})]$

2. $T > \frac{8000}{\sqrt{F_y}} t$ (Sect. 1.9.2)

   The required reduction in area is

   $\Delta A_{9.2} = t[T - (8000/\sqrt{F_y})t]$

   (See discussion below, *re* Sect. 1.5.1.4.1.)

Other section properties have not been revised for the above area reductions.

Sect. 1.9.1 reductions affect only the 14BP73 ($\pm 5\%$) and the 12BP53 ($\pm 2\%$) in A440, A441, and A242 steel. It was felt that section property revisions were not warranted since these sections are rarely used in structures, and when used as piles, loads and support conditions are not accurately known. The use of the listed section properties for these members when used as columns or beam-columns is unconservative; the section properties should be revised when warranted.

Higher strength steels have not been examined; more sections will probably be affected by Sect. 1.9.1. It is also probable that section properties will have to be revised for the affected sections.

Sect. 1.9.2 reductions mainly affect r values; the effects on other section properties are negligible. It was felt that revision of the r values was not warranted because: (1) the criteria of Sect. 1.9.2 represents a rough approximation and (2) the use of the unrevised r value is conservative.

A Sect. 1.5.1.4.1 provision regarding an additional requirement for compactness when a member is subjected to combined axial force and bending moment provides a more liberal rule under certain conditions than Sect. 1.9.2 for the maximum allowable T/t ratios. It is logical to use this more liberal rule for non-compact members also.

An examination of the section property pages in the AISC Manual, pgs. **1**-6 through **1**-25, will show that, for members having excessive T/t values,

$$T = \frac{d}{1.13 \pm 0.02} \qquad \left(T = \frac{d}{1.13} \text{ is used by the author}\right)$$

Sect. 1.9.2 controls and no reduction in area is necessary when $T/t \lessgtr 8000/\sqrt{F_y}$ or $d/t \lessgtr 9040/\sqrt{F_y}$, using the author's value for T.

Sect. 1.5.1.4.1 ($d/t \lessgtr 13{,}300\ [1 - 1.43(f_a/F_a)]/\sqrt{F_y}$) controls when $d/t > 9040/\sqrt{F_y}$ or $f_a/F_a < 0.224$.

The reduction in area required is then

$$\Delta A_{1\text{-}5} = t\left[d - \frac{13{,}300}{\sqrt{F_y}}\ (1 - 1.43f_a/F_a)t\right]$$

For A36, A440, A441, and A242 steels, the reduction required can be found as follows:

1. Find d/t (allowable) from Graph D.
2. $d_{all} = (t)d/t$ (allowable)
3. $\Delta A_{1\text{-}5} = (d_{act} - d_{all})t$

The required reductions in area may be reduced or eliminated in some cases by reducing the effective F_y' value, thus permitting increased allowable d/t and T/t values. The new effective F_y value should then be used throughout the computations.

The conservative Sect. 1.9.2 provision (without any decrease in the effective F_y) has been used in this procedure because of its simplicity.

Guides—When it is possible to use the allowable moment charts ($F_y = 36$, $C_b = 1$) or the column tables (column sections in A36, A242, A440 and A441 steels with $C_b = 1$) from the Manual, the first trial section is usually satisfactory; a maximum of two trial sections will almost always result in the most economical section. When these Manual design aids cannot be used, there are usually lighter sections that should be examined. Some guides useful in the selection of likely sections are:

1. $M_{x\text{-}all}$ increases with an increase in r_4 if Formula (4) controls.
2. $M_{x\text{-}all}$ increases with a decrease in d/A_f if Formula (5) controls.
3. The S_x/S_y ratio is very important when there is an M_y acting. The ratio can amplify M_y as much as $12\frac{1}{2}$ times. High concurrent P values with accompanying high f_a values can further increase this amplified M_y value by more than 50 percent.
4. The C'_{PM} values require examination when the P value is relatively high.

Considering the large number of parameters entering into the selection of satisfactory economical sections, a detailed comparative analysis of possible sections will generally be found more time consuming than the testing of several likely sections. The guides outlined above are useful for rapid comparisons of likely trial members.

The Elastic Section Modulus Table and/or Table 3 should be examined for possible lighter members with $S_{x\text{-}req} = 12M_{2x\text{-}req}/F_{bx\text{-}max}$.

Equivalent Column Method (**MP**)—Much of the previous discussion under the heading "Equivalent Beam Method (PM_x)" is also applicable to the MP Method. The following are additional comments on the latter method:

Trial Section—A reasonable trial section may be obtained by first computing a "ballpark" preliminary equivalent axial load, $P_{eq} = P + 1.7C_{mx}M_x + 8C_{my}M_y$ and then utilizing the column tables in the Manual (for A36, A440, A441 and A242 steels).

For steels other than A36, A440, A441 and A242, with any value of C_b, an approximate required section area $A_{req} = P_{eq}/0.45F_y$ may be computed and a suitable trial section selected from Table 3. The characteristics of this section may then be used to select a better trial section or the preliminary trial section can be tested without further refinement.

Allowable Axial Load, P_{all}—The value of $P_{all} = F_a \times (A, A', \text{or } A'')$ must be found when the Manual column tables cannot be used.

NOMENCLATURE

Terms not defined below are given in the *AISC Manual of Steel Construction, Sixth Edition.*

A' = Reduced effective cross-sectional area for A36 members, sq in.

A'' = Reduced effective cross-sectional area for A242, A440, and A441 members, sq in.

A''' = Reduced effective cross-sectional area for steels other than A36, A242, A440, and A441

$(AF)_{f_{bx}}$ = Amplification factor in Formula (7a) $= 1/[1 - (f_a/F'_{ex})]$

$(AF)_{f_{by}}$ = Amplification factor in Formula (7a) $= 1/[1 - (f_a/F'_{ey})]$

C_{PM} = $r_x^2/6d$ (average)ft

C'_{PM} = $r_x^2/6d$ (exact)ft

F_{bx4} = Bending stress permitted in absence of axial force, from Formula (4)

F_{bx5} = Bending stress permitted in absence of axial force, from Formula (5)

l = Actual unsupported length of member, ft

l_b = Actual unsupported length of member in plane of bending, ft

l_{yu} = Unsupported length of compression flange, ft

M_{all} = Allowable bending moment if bending moment alone existed, kip-ft

M_{eq} = Total equivalent external beam moment, kip-ft

M_x = External beam moment about X-X axis, kip-ft

$M_{x\text{-}PM}$ = Equivalent external beam moment about the X-X axis inducing an extreme fiber stress equal to the average stress induced by the direct load, kip-ft

M_y = External beam moment about Y-Y axis, kip-ft

P_{eq} = Axial load inducing an average stress equal to the extreme fiber stress induced by the external beam moment, kips

r_4 = Radius of gyration of the compression flange plus one-sixth the web area about an axis in the plane of the web, used in Formula (4), in.

r_x (average) = Weighted average radius of gyration about X-X axis for members of the same nominal depth (by author), in.

r_x (exact) = Actual radius of gyration about X-X axis, in.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Stone and Webster Engineering Corporation, Garden City, N. Y. The methods described were developed by the author while Structural Department Manager at that firm.

Also, thanks are due to Samuel H. Marcus, AISC Regional Engineer, for his sincere efforts and helpful suggestions in the review of this paper.

Table 1 [a] Values of $C_{d\text{-}min}$ for Use in Equation d_{min} (in.) $= C_{d\text{-}min} \times L_{span}$ (ft)

Members	$C_{d\text{-}min}$
1. Subject to shock or vibration (in large partitionless open areas with long spans of light construction) in typical office and residential buildings[b]	$\frac{1}{1.67}$
2. Subject to shock and vibration (heavy duty handling, industrial building, etc.)[c]	$\frac{F_y}{54.2}$
3. Floors (not subject to shock and vibration)[c]	$\frac{F_y}{66.7}$
4. Roofs with slope <3/12[c]	$\frac{F_y}{83.3}$
5. Flat roofs, simple or continuous[d]	$\frac{F_b}{50}$

[a] The values listed, except for Item 5, are recommended by AISC as guides for beams and girders without axial load. However, they can also be used as guides for beams and girders with axial load.
[b] See AISC Engineering Journal, Oct. 1965, pg. 145.
[c] For fully stressed members, see AISC Manual, p. 5–125.
[d] Mandatory as per AISC Specification, Sect. 1.13.
Note: For plastered ceilings, see AISC Specification Sect. 1.13.

Table 2

d (in.)	C_{PM} (approx.)	(S_x/S_y) (approx.)
36	0.98	10.6
33	0.91	10.3
30	0.82	10.3
27	0.76	9.3
24	0.71	8.8
21	0.60	8.8
18	0.52	7.8
16	0.46	7.8
14	0.44	4.3
12	0.38	5.0
10	0.31	4.3
8	0.24	4.6

Table 3

Member	X-X Axis		Y-Y Axis							A36				A242		A440	A441	
	S_x (in.³)	r_x (in.)	S_y (in.³)	r_y (in.)	r_4 (in.)	d/A_f (1/in.)	A (in.²)	C'_{PM} (ft)	S_x/S_y	A' (in.²)	d/t	L_c (ft)	L_u (ft)	F_y (ksi)	A'' (in.²)	d/t	L_c (ft)	L_u (ft)
36WF 300	1105	15.17	147.1	3.73	4.27	1.31	88.17	1.044	7.51	—	—	18.0	34.7	46	—	38.80	16.0	27.7
280	1031	15.12	135.9	3.70	4.24	1.40	82.32	1.044	7.61	—	—	18.0	32.5	46	—	41.20	15.9	25.9
260	951	15.00	123.3	3.65	4.20	1.52	76.56	1.035	7.71	—	43.10	17.9	29.9	46	—	43.10	15.9	23.8
245	893	14.95	114.4	3.62	4.17	1.62	72.03	1.033	7.81	—	44.90	17.9	28.1	46	71.06	44.90	15.8	22.4
230	836	14.88	105.7	3.59	4.14	1.73	67.73	1.028	7.90	—	46.90	17.8	26.3	46	65.57	46.90	15.8	21.0
194	664	14.56	58.7	2.49	2.99	2.39	57.11	0.968	11.30	—	47.25	13.1	19.0	50	53.61	47.25	11.1	13.9
182	621	14.52	54.3	2.47	2.97	2.55	53.54	0.967	11.41	52.32	50.01	13.1	17.8	50	49.08	50.01	11.1	13.1
170	579	14.47	50.0	2.45	2.95	2.73	49.98	0.965	11.59	47.55	53.10	13.0	16.7	50	44.71	53.10	11.0	12.2
160	541	14.38	45.9	2.42	2.92	2.94	47.09	0.957	11.79	44.01	55.20	13.0	15.5	50	41.38	55.20	11.0	11.3
150	503	14.29	41.8	2.38	2.89	3.19	44.16	0.950	12.00	40.47	57.40	13.0	14.2	50	38.08	57.40	10.4	10.4
‡135	439	14.01	34.7	2.28	2.81	3.75	39.70	0.920	12.65	35.49	59.50	12.1	12.1	50	33.27	—	—	9.3
33WF 240	811	13.88	110.2	3.52	4.04	1.51	70.52	0.958	7.36	—	—	17.2	30.1	46	—	40.40	15.2	24.0
220	741	13.79	99.0	3.48	4.00	1.65	64.73	0.953	7.49	—	42.90	17.1	27.5	46	—	42.90	15.2	22.0
200	670	13.71	87.8	3.43	3.96	1.82	58.79	0.950	7.61	—	46.20	17.1	25.0	46	57.27	46.20	15.1	19.9
152	486	13.50	44.3	2.39	2.85	2.74	44.71	0.907	11.00	42.82	52.80	12.5	16.6	50	40.33	52.80	10.6	12.2
141	447	13.39	39.8	2.35	2.82	3.01	41.51	0.897	11.20	38.94	55.00	12.5	15.1	50	36.69	55.00	10.6	11.1
130	405	13.23	35.0	2.29	2.77	3.36	38.26	0.881	11.60	35.19	57.10	12.5	13.5	50	33.09	57.10	9.9	9.9
‡118	358	13.02	29.7	2.22	2.71	3.88	34.71	0.860	12.05	31.17	59.40	11.7	11.7	50	29.27	—	—	9.0
30WF 210	650	12.64	93.7	3.38	3.86	1.53	61.78	0.876	6.92	—	—	16.4	29.7	50	—	39.15	13.9	21.8
190	586	12.57	83.1	3.34	3.82	1.69	55.90	0.874	7.06	—	42.40	16.3	26.9	50	55.79	42.40	13.8	19.7
172	528	12.48	73.4	3.30	3.78	1.87	50.65	0.869	7.21	—	45.60	16.2	24.3	50	49.24	45.60	13.7	17.8
132	380	12.17	35.1	2.18	2.60	2.87	38.83	0.814	10.83	38.25	49.30	11.4	15.8	50	35.89	49.30	9.7	11.6
124	355	12.11	32.3	2.16	2.58	3.08	36.45	0.810	11.00	35.16	51.55	11.4	14.8	50	33.07	51.55	9.6	10.8
116	328	12.00	29.2	2.12	2.55	3.36	34.13	0.800	11.23	32.38	53.20	11.4	13.5	50	30.43	53.20	9.6	9.9
108	299	11.85	25.8	2.06	2.51	3.74	31.77	0.785	11.60	29.70	54.40	11.4	12.2	50	27.84	54.40	8.9	8.9
‡ 99	269	11.70	22.4	2.00	2.46	4.23	29.11	0.769	12.01	26.57	56.75	10.7	10.7	50	24.89	—	—	8.2
27WF 177	493	11.36	73.7	3.16	3.60	1.63	52.10	0.790	6.70	—	—	15.3	27.9	50	—	37.70	12.9	20.4
160	445	11.31	65.3	3.12	3.56	1.80	47.04	0.788	6.82	—	—	15.2	25.3	50	—	41.20	12.9	18.5
145	403	11.26	58.3	3.09	3.53	1.97	42.68	0.786	6.93	—	44.80	15.1	23.1	50	41.64	44.80	12.8	16.9
114	299	11.03	29.7	2.11	2.50	2.91	33.53	0.743	10.07	—	47.90	10.9	15.6	50	31.54	47.90	9.2	11.5
102	266	10.96	25.9	2.08	2.47	3.27	30.01	0.740	10.30	28.89	52.30	10.9	13.9	50	27.24	52.30	9.2	10.2
94	243	10.87	23.0	2.04	2.44	3.61	27.65	0.732	10.55	26.01	54.90	10.8	12.6	50	24.54	54.90	9.2	9.2
‡ 84	212	10.69	19.2	1.97	2.38	4.21	24.71	0.714	11.00	22.64	57.70	10.8	10.8	50	21.30	—	—	7.9
24WF 160	414	10.42	69.9	3.23	3.64	1.55	47.04	0.732	5.93	—	—	15.3	29.3	50	—	37.70	12.9	21.5
145	373	10.34	61.8	3.19	3.60	1.71	42.62	0.728	6.03	—	—	15.2	26.6	50	—	40.30	12.9	19.5
‡130	331	10.24	53.6	3.13	3.55	1.93	38.21	0.720	6.19	—	42.85	15.2	23.6	50	37.91	—	—	17.3
120	299	10.15	42.0	2.68	3.07	2.16	35.29	0.706	7.12	—	43.70	13.1	21.0	50	34.80	43.70	11.1	15.4
110	274	10.12	38.0	2.66	3.04	2.34	32.36	0.706	7.24	—	47.35	13.0	19.4	50	31.07	47.35	11.0	14.2
‡100	249	10.08	33.9	2.63	3.01	2.58	29.43	0.705	7.35	28.90	51.25	13.0	17.6	50	27.54	—	—	12.9

Table 3 (continued)

Member	X-X Axis		Y-Y Axis							A36				A242		A440	A441	
	S_x (in.³)	r_x (in.)	S_y (in.³)	r_y (in.)	r_4 (in.)	d/A_f (1/in.)	A (in.²)	C'_{PM} (ft)	S_x/S_y	A' (in.²)	d/t	L_c (ft)	L_u (ft)	F_y (ksi)	A'' (in.²)	d/t	L_c (ft)	L_u (ft)
24WF 94	221	9.85	22.6	1.92	2.27	3.07	27.63	0.666	9.78	—	47.10	9.8	14.8	50	26.17	47.10	8.3	10.9
84	196	9.78	19.6	1.89	2.24	3.47	24.71	0.662	10.00	23.98	51.30	9.8	13.1	50	22.58	51.30	8.3	9.6
76	175	9.68	17.0	1.85	2.20	3.90	22.37	0.653	10.30	21.13	54.40	9.7	11.7	50	19.94	54.40	8.2	8.5
‡ 68	153	9.53	14.2	1.79	2.15	4.55	20.00	0.639	10.80	18.40	57.00	9.7	10.0	50	17.33	—	—	7.3
21WF 142	317	9.03	58.8	3.04	3.40	1.49	41.76	0.633	5.40	—	—	14.2	30.5	50	—	—	12.0	22.4
127	284	8.99	51.8	3.01	3.37	1.65	37.34	0.634	5.50	—	—	14.1	27.5	50	—	36.15	12.0	20.2
‡112	250	8.92	44.6	2.96	3.33	1.87	32.93	0.631	5.60	—	—	14.1	24.3	50	—	—	—	17.8
96	198	8.60	24.2	1.97	2.29	2.50	28.21	0.583	8.15	—	—	9.8	18.2	50	—	36.80	8.3	13.3
82	168	8.53	20.0	1.93	2.25	2.93	24.10	0.580	8.40	—	—	9.7	15.5	50	24.03	41.80	8.2	11.4
73	151	8.64	16.0	1.76	2.07	3.46	21.46	0.586	9.41	—	46.70	9.0	13.1	50	20.42	46.70	7.6	9.6
68	140	8.59	14.6	1.74	2.05	3.73	20.02	0.582	9.58	19.81	49.15	9.0	12.2	50	18.67	49.15	7.6	8.9
62	126	8.53	12.9	1.71	2.02	4.15	18.23	0.578	9.80	17.53	52.40	8.9	11.0	50	16.54	52.40	7.6	8.0
‡ 55	110	8.40	10.7	1.65	1.98	4.85	16.18	0.565	10.25	15.12	55.50	8.9	9.4	50	14.26	—	—	6.9
18WF 114	220	7.79	43.2	2.76	3.08	1.58	33.51	0.547	5.10	—	—	12.8	28.8	50	—	—	10.8	21.1
105	202	7.75	39.2	2.73	3.05	1.71	30.86	0.546	5.15	—	—	12.8	26.6	50	—	—	10.8	19.5
96	184	7.70	35.2	2.71	3.02	1.86	28.22	0.543	5.23	—	—	12.7	24.4	50	—	—	10.8	17.9
85	156	7.57	22.5	2.00	2.27	2.28	24.97	0.522	6.94	—	—	9.6	19.9	50	—	—	8.1	14.6
77	142	7.54	20.2	1.98	2.25	2.49	22.63	0.522	7.01	—	—	9.5	18.3	50	—	38.20	8.1	13.4
70	128	7.49	17.9	1.95	2.23	2.74	20.56	0.520	7.16	—	—	9.5	16.6	50	—	41.10	8.0	12.2
64	117	7.46	16.1	1.93	2.21	2.99	18.80	0.519	7.26	—	44.30	9.4	15.2	50	18.45	44.30	8.0	11.1
60	108	7.47	12.5	1.63	1.90	3.48	17.64	0.511	8.62	—	43.90	8.2	13.1	50	17.27	43.90	6.9	9.6
55	98	7.41	11.1	1.61	1.88	3.82	16.19	0.504	8.85	—	46.50	8.2	11.9	50	15.48	46.50	6.9	8.7
50	89	7.38	9.9	1.59	1.86	4.22	14.71	0.504	9.00	14.43	50.25	8.1	10.8	50	13.64	50.25	6.9	7.9
‡ 45	79	7.30	8.5	1.55	1.83	4.79	13.24	0.497	9.29	12.65	53.25	8.1	9.5	50	11.97	—	—	7.0
16WF 96	166	6.93	35.9	2.71	3.00	1.62	28.22	0.491	4.63	—	—	12.5	28.1	50	—	—	10.6	20.6
88	151	6.87	32.2	2.67	2.97	1.77	25.87	0.488	4.68	—	—	12.5	25.7	50	—	—	10.5	18.8
78	128	6.74	20.4	1.95	2.22	2.17	22.92	0.464	6.26	—	—	9.3	20.9	50	—	—	7.9	15.4
71	116	6.70	18.2	1.93	2.20	2.38	20.86	0.463	6.36	—	—	9.3	19.1	50	—	—	7.8	14.0
64	104	6.66	16.1	1.91	2.17	2.63	18.80	0.462	6.51	—	—	9.2	17.3	50	—	37.00	7.8	12.7
58	94	6.62	14.3	1.88	2.15	2.91	17.04	0.460	6.59	—	—	9.2	15.6	50	—	39.00	7.8	11.5
50	81	6.68	9.8	1.54	1.79	3.66	14.70	0.458	8.27	—	42.75	7.7	12.4	50	14.55	42.75	6.5	9.1
45	72	6.64	8.7	1.52	1.76	4.07	13.24	0.457	8.28	—	46.60	7.6	11.2	50	12.70	46.60	6.5	8.2
40	64	6.62	7.6	1.50	1.74	4.54	11.77	0.456	8.43	11.45	52.10	7.6	10.0	50	10.87	52.10	6.4	7.3
‡ 36	56	6.49	6.3	1.45	1.70	5.30	10.59	0.442	8.89	10.17	53.00	7.6	8.6	50	9.63	—	—	6.3
14WF 730	1281	8.18	527.3	4.69	4.99	0.256	214.7	0.497	2.43	—	—	19.4	177.6	42	—	—	17.9	156.0
665	1152	7.99	472.2	4.62	4.92	0.272	195.5	0.491	2.44	—	—	19.1	167.1	42	—	—	17.6	147.0
605	1036	7.81	422.7	4.55	4.85	0.289	177.9	0.487	2.45	—	—	18.9	157.3	42	—	—	17.4	138.3
550	932	7.64	378.6	4.49	4.79	0.308	161.8	0.480	2.47	—	—	18.6	147.6	42	—	—	17.2	129.9
500	839	7.48	339.0	4.43	4.73	0.330	147.0	0.475	2.48	—	—	18.4	137.8	42	—	—	17.0	121.2

Table 3 (continued)

	X-X Axis		Y-Y Axis							A36				A242		A440	A441	
Member	S_x (in.^{3})	r_x (in.)	S_y (in.^{3})	r_y (in.)	r_4 (in.)	d/A_f (1/in.)	A (in.^{2})	C'_{PM} (ft)	S_x/S_y	A' (in.^{2})	d/t	L_c (ft)	L_u (ft)	F_y (ksi)	A'' (in.^{2})	d/t	L_c (ft)	L_u (ft)
14WF 455	757	7.35	304.4	4.38	4.68	0.352	133.7	0.473	2.49	—	—	18.2	129.1	42	—	—	16.8	113.7
426	707	7.26	282.7	4.34	4.64	0.369	125.3	0.471	2.50	—	—	18.1	123.2	42	—	—	16.7	107.5
398	657	7.17	261.6	4.31	4.61	0.388	117.0	0.467	2.51	—	—	18.0	117.2	42	—	—	16.6	102.2
370	608	7.08	241.1	4.27	4.57	0.410	108.8	0.466	2.53	—	—	17.8	110.9	42	—	—	16.5	96.7
342	559	6.99	220.8	4.24	4.54	0.435	100.6	0.463	2.53	—	—	17.7	104.5	42	—	—	16.4	91.2
314	512	6.90	201.0	4.20	4.50	0.464	92.30	0.462	2.55	—	—	17.6	98.0	42	—	—	16.2	85.5
287	465	6.81	181.8	4.17	4.47	0.498	84.37	0.460	2.56	—	—	17.5	91.3	42	—	—	16.1	79.7
264	427	6.74	166.1	4.14	4.44	0.531	77.63	0.460	2.57	—	—	17.4	85.6	42	—	—	16.0	74.7
246	397	6.68	153.9	4.12	4.42	0.562	72.33	0.458	2.58	—	—	17.3	80.9	42	—	—	15.9	70.6
237	382	6.65	147.7	4.11	4.40	0.580	69.69	0.458	2.58	—	—	17.2	78.4	42	—	—	15.9	68.4
228	368	6.62	141.8	4.10	4.39	0.597	67.06	0.457	2.60	—	—	17.2	76.1	42	—	—	15.9	66.4
219	353	6.59	135.6	4.08	4.38	0.618	64.36	0.456	2.60	—	—	17.1	73.6	42	—	—	15.8	64.2
211	339	6.56	130.2	4.07	4.37	0.638	62.07	0.456	2.60	—	—	17.1	71.2	46	—	—	15.1	56.8
202	325	6.54	124.4	4.06	4.36	0.660	59.39	0.456	2.61	—	—	17.1	68.9	46	—	—	15.1	54.9
193	310	6.51	118.4	4.05	4.35	0.686	56.73	0.456	2.62	—	—	17.0	66.3	46	—	—	15.1	52.8
184	296	6.49	112.7	4.04	4.33	0.713	54.07	0.456	2.63	—	—	17.0	63.8	46	—	—	15.0	50.8
176	282	6.45	107.1	4.02	4.32	0.743	51.73	0.455	2.64	—	—	16.9	61.2	46	—	—	15.0	48.8
167	267	6.42	101.3	4.01	4.31	0.777	49.09	0.454	2.64	—	—	16.9	58.5	46	—	—	14.9	46.7
158	253	6.40	95.8	4.00	4.30	0.812	46.47	0.455	2.65	—	—	16.8	56.0	46	—	—	14.9	44.6
150	240	6.37	90.6	3.99	4.29	0.850	44.08	0.454	2.66	—	—	16.8	53.5	46	—	—	14.9	42.6
142	227	6.32	85.2	3.97	4.27	0.895	41.85	0.452	2.67	—	—	16.8	50.8	46	—	—	14.9	40.5
320	493	6.63	195.7	4.17	4.57	0.481	94.12	0.437	2.52	—	—	18.1	94.5	42	—	—	16.7	82.5
136	216	6.31	77.0	3.77	4.06	0.941	39.98	0.450	2.80	—	—	16.0	48.3	50	—	—	13.5	35.4
127	202	6.29	71.8	3.76	4.05	0.997	37.33	0.451	2.81	—	—	15.9	45.6	50	—	—	13.5	33.4
‡119	189	6.26	67.1	3.75	4.04	1.06	34.99	0.451	2.82	—	—	15.9	42.9	50	—	—	—	31.4
‡111	176	6.23	62.2	3.73	4.02	1.13	32.65	0.451	2.84	—	—	15.8	40.2	50	—	—	—	29.5
†103	164	6.21	57.6	3.72	4.01	1.20	30.26	0.451	2.85	—	—	—	37.9	50	—	—	—	27.8
† 95	151	6.17	52.8	3.71	4.00	1.30	27.94	0.450	2.85	—	—	—	35.0	50	—	—	—	25.6
† 87	138	6.15	48.2	3.70	3.98	1.40	25.56	0.451	2.86	—	—	—	32.5	50	—	—	—	23.8
‡ 84	131	6.13	37.5	3.02	3.28	1.52	24.71	0.442	3.49	—	—	13.0	29.9	50	—	—	—	21.9
‡ 78	121	6.09	34.5	3.00	3.27	1.63	22.94	0.439	3.51	—	—	13.0	27.9	50	—	—	—	20.4
74	112	6.05	26.5	2.48	2.72	1.80	21.76	0.431	4.24	—	—	10.9	25.3	50	—	—	9.2	18.5
68	103	6.02	24.1	2.46	2.71	1.95	20.00	0.429	4.27	—	—	10.9	23.3	50	—	—	9.2	17.1
‡ 61	92.2	5.98	21.5	2.45	2.70	2.16	17.94	0.429	4.29	—	—	10.8	21.0	50	—	—	—	15.4
53	77.8	5.90	14.3	1.92	2.15	2.63	15.59	0.417	5.45	—	—	8.7	17.3	50	—	37.70	7.4	12.7
48	70.2	5.86	12.8	1.91	2.13	2.90	14.11	0.415	5.50	—	—	8.7	15.7	50	—	40.80	7.4	11.5
‡ 43	62.7	5.82	11.3	1.89	2.12	3.24	12.65	0.412	5.56	—	44.40	8.7	14.0	50	12.56	—	—	10.3
38	54.6	5.87	7.3	1.49	1.71	4.06	11.17	0.408	7.50	—	45.10	7.3	11.2	50	10.84	45.10	6.2	8.2
‡ 34	48.5	5.83	6.3	1.46	1.69	4.58	10.00	0.404	7.70	—	48.80	7.3	9.9	50	9.49	—	—	7.3
‡ 30	41.8	5.73	5.2	1.41	1.65	5.37	8.81	0.395	8.05	8.61	51.35	7.3	8.5	50	8.16	—	—	6.2

Table 3 (continued)

Member	X-X Axis		Y-Y Axis							A36				A242		A440	A441	
	S_x (in.³)	r_x (in.)	S_y (in.³)	r_y (in.)	r_4 (in.)	d/A_f (1/in.)	A (in.²)	C'_{PM} (ft)	S_x/S_y	A' (in.²)	d/t	L_c (ft)	L_u (ft)	F_y (ksi)	A'' (in.²)	d/t	L_c (ft)	L_u (ft)
12WF 190	263	5.82	93.1	3.25	3.50	0.654	55.86	0.393	2.82	—	—	13.7	69.5	46	—	—	12.1	55.4
161	222	5.70	77.7	3.20	3.45	0.746	47.38	0.390	2.86	—	—	13.6	60.9	46	—	—	12.0	48.6
133	182	5.59	63.1	3.16	3.40	0.875	39.11	0.389	2.89	—	—	13.4	51.9	46	—	—	11.8	41.4
120	163	5.51	56.0	3.13	3.38	0.963	35.31	0.386	2.92	—	—	13.3	47.2	46	—	—	11.8	37.6
106	144	5.46	49.2	3.11	3.36	1.07	31.19	0.386	2.94	—	—	13.2	42.5	50	—	—	11.2	31.2
99	135	5.43	45.7	3.09	3.34	1.14	29.09	0.385	2.94	—	—	13.2	39.9	50	—	—	11.2	29.2
92	125	5.40	42.2	3.08	3.33	1.21	27.06	0.385	2.96	—	—	13.2	37.6	50	—	—	11.1	27.5
‡ 85	116	5.38	38.9	3.07	3.32	1.29	24.98	0.386	2.98	—	—	13.1	35.2	50	—	—	—	25.8
‡ 79	107	5.34	35.8	3.05	3.31	1.39	23.22	0.384	2.99	—	—	13.1	32.7	50	—	—	—	24.0
† 72	97.5	5.31	32.4	3.04	3.29	1.52	21.16	0.384	3.00	—	—	—	29.9	50	—	—	—	21.9
† 65	88.0	5.28	29.1	3.02	3.28	1.67	19.11	0.383	3.02	—	—	—	27.2	50	—	—	—	20.0
‡ 58	78.1	5.28	21.4	2.51	2.73	1.90	17.06	0.382	3.65	—	—	10.8	23.9	50	—	—	—	17.5
‡ 53	70.7	5.23	19.2	2.48	2.71	2.09	15.59	0.378	3.68	—	—	10.8	21.7	50	—	—	—	15.9
50	64.7	5.18	14.0	1.96	2.17	2.35	14.71	0.367	4.64	—	—	8.8	19.3	50	—	—	7.4	14.2
45	58.2	5.15	12.4	1.94	2.15	2.60	13.24	0.367	4.70	—	—	8.7	17.5	50	—	35.9	7.4	12.8
‡ 40	51.9	5.13	11.0	1.94	2.14	2.89	11.77	0.367	4.72	—	—	8.7	15.7	50	—	—	—	11.5
36	45.9	5.15	7.2	1.50	1.69	3.45	10.59	0.361	6.37	—	—	7.1	13.2	50	—	40.20	6.0	9.7
31	39.4	5.11	6.1	1.47	1.66	3.98	9.12	0.360	6.46	—	45.60	7.1	11.4	50	8.90	45.60	6.0	8.4
‡ 27	34.1	5.06	5.1	1.44	1.64	4.60	7.97	0.357	6.69	7.91	49.80	7.0	9.9	50	7.55	—	—	7.2
10WF 112	126	4.67	45.2	2.67	2.88	0.876	32.92	0.320	2.80	—	—	11.3	51.9	50	—	—	9.5	38.1
100	112	4.61	39.9	2.65	2.85	0.961	29.43	0.319	2.82	—	—	11.2	47.3	50	—	—	9.5	34.7
89	99.7	4.55	35.2	2.63	2.83	1.06	26.19	0.317	2.83	—	—	11.1	42.9	50	—	—	9.4	31.4
77	86.1	4.49	30.1	2.60	2.80	1.20	22.67	0.316	2.86	—	—	11.0	37.9	50	—	—	9.3	27.8
72	80.1	4.46	27.9	2.59	2.79	1.28	21.18	0.316	2.88	—	—	11.0	35.5	50	—	—	9.3	26.0
66	73.7	4.44	25.5	2.58	2.78	1.37	19.41	0.316	2.89	—	—	11.0	33.2	50	—	—	9.3	24.3
‡ 60	67.1	4.41	23.1	2.57	2.77	1.49	17.66	0.316	2.90	—	—	10.9	30.5	50	—	—	—	22.4
‡ 54	60.4	4.39	20.7	2.56	2.75	1.63	15.88	0.317	2.92	—	—	10.9	27.9	50	—	—	—	20.4
† 49	54.6	4.35	18.6	2.54	2.74	1.79	14.40	0.316	2.94	—	—	—	25.4	50	—	—	—	18.6
45	49.1	4.33	13.3	2.00	2.18	2.04	13.24	0.309	3.69	—	—	8.7	22.3	50	—	—	7.4	16.3
‡ 39	42.2	4.27	11.2	1.98	2.16	2.36	11.48	0.306	3.77	—	—	8.7	19.3	50	—	—	—	14.1
† 33	35.0	4.20	9.2	1.94	2.14	2.83	9.71	0.302	3.81	—	—	—	16.1	50	—	—	—	11.8
29	30.8	4.29	5.2	1.34	1.50	3.52	8.53	0.300	5.92	—	—	6.3	12.9	50	—	—	5.3	9.5
25	26.4	4.26	4.4	1.31	1.48	4.08	7.35	0.300	6.00	—	—	6.2	11.1	50	—	40.00	5.3	8.2
‡ 21	21.5	4.14	3.4	1.25	1.43	5.07	6.19	0.290	6.32	—	—	6.2	9.0	50	—	—	—	6.6

Table 3 (continued)

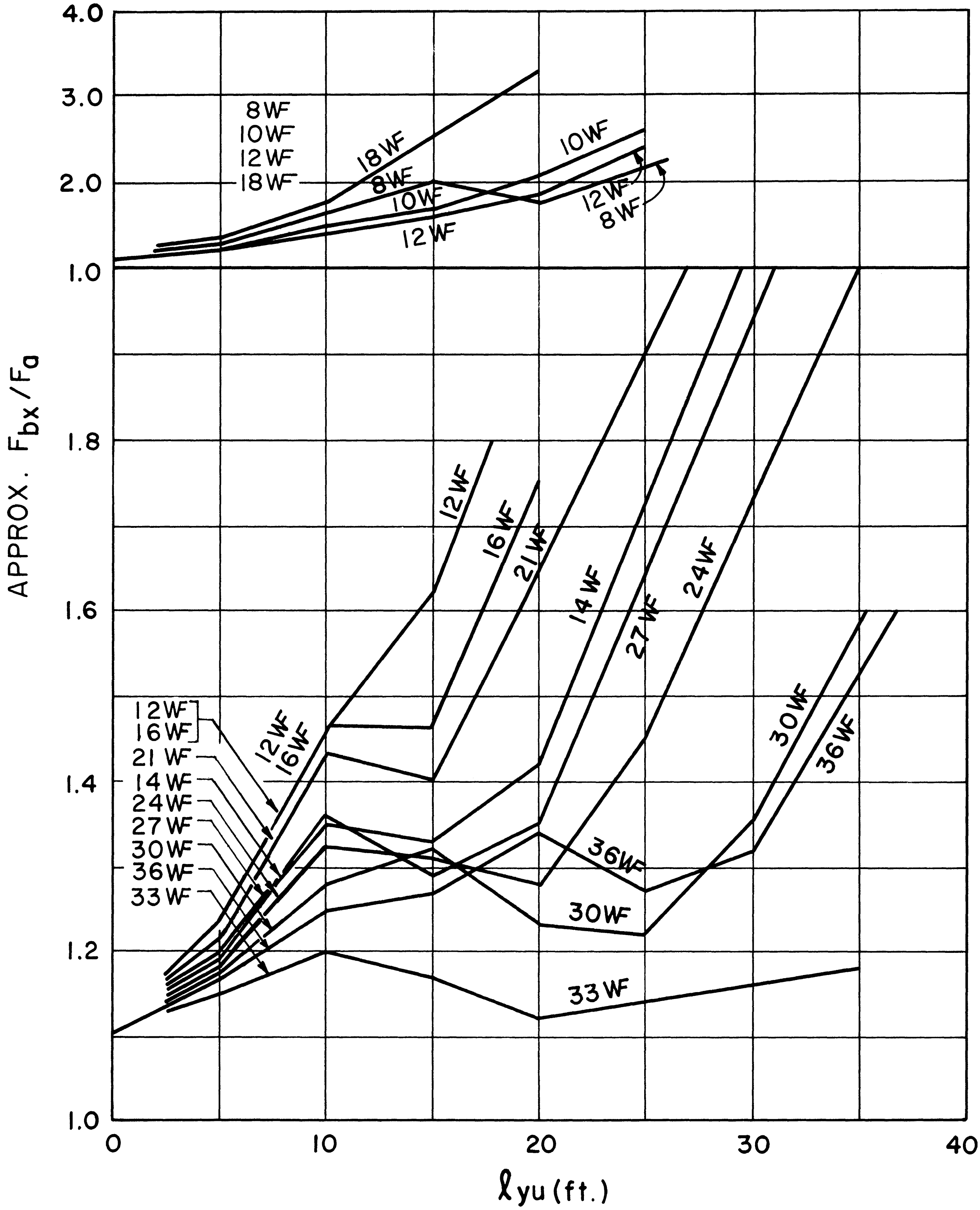
Member	X-X Axis S_x (in.³)	X-X Axis r_x (in.)	Y-Y Axis S_y (in.³)	Y-Y Axis r_y (in.)	r_4 (in.)	d/A_f (1/in.)	A (in.²)	C'_{PM} (ft)	S_x/S_y	A36 A' (in.²)	A36 d/t	A36 L_c (ft)	A36 L_u (ft)	A242 F_y (ksi)	A242 A'' (in.²)	A440 d/t	A441 L_c (ft)	A441 L_u (ft)
8WF 67	60.4	3.71	21.4	2.12	2.28	1.16	19.70	0.255	2.82	—	—	9.0	39.2	50	—	—	7.6	28.7
58	52.0	3.65	18.2	2.10	2.26	1.32	17.06	0.254	2.86	—	—	8.9	34.4	50	—	—	7.5	25.3
48	43.2	3.61	15.0	2.08	2.24	1.53	14.11	0.255	2.88	—	—	8.8	29.7	50	—	—	7.4	21.8
40	35.5	3.53	12.1	2.04	2.21	1.83	11.76	0.252	2.93	—	—	8.8	24.8	50	—	—	7.4	18.2
‡ 35	31.1	3.50	10.6	2.03	2.20	2.05	10.30	0.251	2.94	—	—	8.7	22.2	50	—	—	—	16.3
† 31	27.4	3.47	9.2	2.01	2.18	2.31	9.12	0.251	2.98	—	—	—	19.7	50	—	—	—	14.4
28	24.3	3.45	6.6	1.62	1.77	2.66	8.23	0.246	3.68	—	—	7.1	17.1	50	—	—	6.0	12.5
‡ 24	20.8	3.42	5.6	1.61	1.76	3.07	7.06	0.246	3.72	—	—	7.0	14.8	50	—	—	—	10.9
20	17.0	3.43	3.2	1.20	1.35	4.08	5.88	0.241	5.32	—	—	5.7	11.1	50	—	—	4.8	8.2
‡ 17	14.1	3.36	2.6	1.16	1.32	4.95	5.00	0.235	5.42	—	—	5.7	9.2	50	—	—	—	6.7
H BEARING PILES																		
†14BP 117	173	5.97	59.5	3.59	4.05	1.19	34.44	0.417	2.92	—	—	—	38.2	50	—	—	—	28.0
† 102	150	5.93	51.3	3.56	3.98	1.35	30.01	0.417	2.93	—	—	—	33.7	50	—	—	—	24.7
† 89	131	5.89	44.4	3.53	3.95	1.53	26.19	0.416	2.96	—	—	—	29.7	50	—	—	—	21.8
† 73	108	5.85	35.9	3.49	3.91	1.85	21.46	0.418	3.00	—	—	—	24.6	50	20.44	—	—	16.8
†12BP 74	93.5	5.10	30.2	2.91	3.27	1.63	21.76	0.358	3.10	—	—	—	27.9	50	—	—	—	20.4
† 53	67.0	5.03	21.2	2.86	3.21	2.24	15.58	0.359	3.16	—	—	—	20.3	50	15.28	—	—	14.4
†10BP 57	58.9	4.19	19.7	2.45	2.74	1.74	16.76	0.291	2.98	—	—	—	26.1	50	—	—	—	19.2
† 42	43.4	4.13	14.2	2.40	2.70	2.31	12.35	0.292	3.05	—	—	—	19.7	50	—	—	—	14.4
† 8BP 36	29.9	3.36	9.9	1.95	2.19	2.21	10.60	0.234	3.02	—	—	—	20.6	50	—	—	—	15.1
LIGHT WF AND MISCELLANEOUS COLUMNS																		
‡8M 34.3	28.9	3.40	8.8	1.87	2.06	2.18	10.09	0.241	3.28	—	—	8.7	20.9	50	—	—	—	15.3
‡ 32.6	28.2	3.45	8.6	1.90	2.07	2.20	9.59	0.248	3.28	—	—	8.6	20.7	50	—	—	—	15.2
6WF 25.0	16.8	2.69	5.6	1.52	1.64	2.30	7.37	0.189	3.00	—	—	6.6	19.8	50	—	—	5.6	14.5
6M 25.0	15.7	2.53	5.0	1.43	1.54	2.10	7.35	0.178	3.14	—	—	6.4	21.6	50	—	—	5.4	15.9
‡ 22.5	13.7	2.49	4.0	1.36	1.52	2.60	6.62	0.172	3.43	—	—	6.6	17.5	50	—	—	—	12.8
‡6WF 20.0	13.4	2.66	4.4	1.50	1.64	2.81	5.90	0.190	3.05	—	—	6.5	16.2	50	—	—	—	11.9
‡6M 20.0	12.9	2.57	3.8	1.39	1.51	2.66	5.88	0.183	3.40	—	—	6.4	17.1	50	—	—	—	12.5
†6WF 15.5	10.1	2.56	3.2	1.45	1.61	3.72	4.62	0.182	3.16	—	—	—	12.2	50	—	—	—	9.0
5M 18.9	9.5	2.08	3.1	1.20	1.29	2.40	5.56	0.144	3.06	—	—	5.4	18.9	50	—	—	4.6	13.9
5WF 18.5	9.94	2.16	3.5	1.28	1.38	2.43	5.45	0.152	2.84	—	—	5.4	18.7	50	—	—	4.6	13.7
16.0	8.53	2.13	3.0	1.26	1.37	2.78	4.70	0.151	2.84	—	—	5.4	16.4	50	—	—	4.6	12.0
4WF 13.0	5.45	1.72	1.9	0.99	1.01	2.97	3.82	0.119	2.86	—	—	4.4	15.3	50	—	—	3.7	11.2
4M 13.0	5.20	1.65	1.7	0.94	1.02	2.73	3.82	0.113	3.06	—	—	4.3	16.7	50	—	—	3.6	12.2

Table 3 (continued)

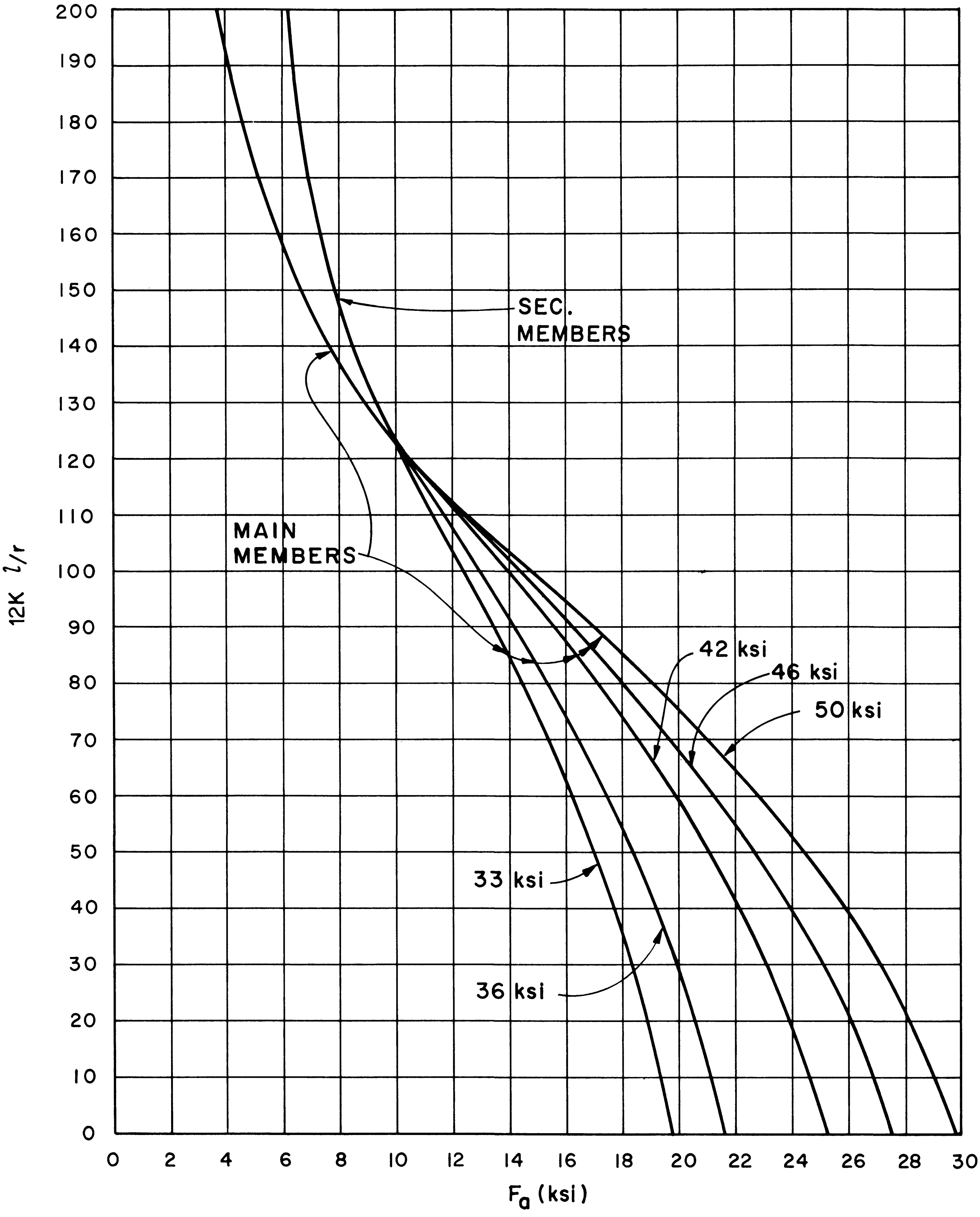
Member	X-X Axis S_x (in.³)	X-X Axis r_x (in.)	Y-Y Axis S_y (in.³)	Y-Y Axis r_y (in.)	r_4 (in.)	d/A_f (1/in.)	A (in.²)	C'_{PM} (ft)	S_x/S_y	A36 A' (in.²)	A36 d/t	A36 L_c (ft)	A36 L_u (ft)	A242 F_y (ksi)	A242 A'' (in.²)	A440 d/t	A441 L_c (ft)	A441 L_u (ft)
MISCELLANEOUS SHAPES (M) & LIGHT BEAMS (B)																		
24B 61	129.5	9.25	9.69	1.38	1.71	5.71	17.95	0.602	13.40	16.33	56.60	7.6	8.0	50	15.21	56.60	5.8	5.8
55	113.7	9.10	8.19	1.33	1.68	6.69	16.17	0.585	13.90	14.26	59.50	6.8	6.8	50	13.25	59.50	5.0	5.6
21B 49	93.2	8.20	7.52	1.30	1.60	6.00	14.42	0.538	12.40	13.28	56.70	7.1	7.6	50	12.37	56.70	5.6	5.6
44	81.5	8.06	6.33	1.26	1.58	7.05	12.95	0.525	12.89	11.55	59.50	6.5	6.5	50	10.76	59.50	4.7	5.3
18B 40	68.3	7.21	6.30	1.27	1.53	5.68	11.76	0.484	10.85	10.94	56.60	6.5	8.0	50	10.26	56.60	5.5	5.9
35	57.9	7.05	5.12	1.22	1.49	6.88	10.30	0.468	11.33	9.30	59.50	6.5	6.6	50	8.69	59.50	4.8	4.8
16B 31	47.0	6.39	4.19	1.13	1.35	6.49	9.12	0.428	11.20	8.46	57.60	6.0	7.0	50	7.99	57.60	5.1	5.1
‡ 26	38.1	6.24	3.17	1.07	1.30	8.25	7.65	0.414	12.00	6.79	62.60	5.5	5.5	50	6.40	—	—	4.3
14B 26	34.9	5.63	3.29	1.04	1.23	6.61	7.65	0.380	10.60	7.30	54.40	5.4	6.9	50	6.90	54.40	4.6	5.0
‡ 22	28.8	5.52	2.56	0.99	1.20	8.19	6.47	0.371	11.25	5.91	59.60	5.4	5.6	50	5.58	—	—	4.1
‡ 17.2	21.0	5.40	1.32	0.72	0.91	12.9	5.05	0.347	15.90	4.20	66.70	3.5	3.5	50	3.92	—	—	2.6
12B 22	25.3	4.91	2.26	0.84	1.01	7.20	6.47	0.327	11.20	—	47.35	4.4	6.3	50	6.11	47.35	3.7	4.6
19	21.4	4.81	1.83	0.81	0.98	8.69	5.62	0.318	11.70	5.47	50.60	4.3	5.2	50	5.11	50.60	3.7	3.8
‡ 16.5	17.5	4.65	1.39	0.76	0.95	11.2	4.86	0.300	12.60	4.62	52.16	4.1	4.1	50	4.29	—	—	3.2
† 14	14.8	4.61	1.13	0.74	0.93	13.4	4.14	0.298	13.10	3.68	—	—	3.4	50	3.43	—	—	3.1
‡10M 29.1	26.6	3.92	3.7	1.14	1.37	4.28	8.55	0.259	7.20	—	—	6.4	10.6	50	—	—	—	7.8
‡ 22.9	23.6	4.16	3.5	1.22	1.38	4.42	6.73	0.292	6.74	—	—	6.2	10.3	50	—	—	—	7.5
‡ 21.0	21.1	4.14	3.2	1.22	1.40	5.09	6.10	0.289	6.60	—	—	6.2	9.2	50	—	—	—	6.7
10B 19	18.8	4.14	2.08	0.86	1.02	6.47	5.61	0.278	9.04	—	—	4.4	7.0	50	—	41.00	3.7	5.2
17	16.2	4.05	1.72	0.83	1.00	7.67	4.98	0.270	9.41	—	42.20	4.3	5.9	50	4.92	42.20	3.7	4.3
‡ 15	13.8	3.95	1.39	0.80	0.97	9.29	4.40	0.260	9.92	—	43.48	4.3	4.9	50	4.26	—	—	3.6
† 11.5	10.5	3.92	1.02	0.77	0.94	12.3	3.39	0.259	10.30	3.16	—	—	3.7	50	2.96	—	—	3.1
‡8M 28	22.5	3.31	5.33	1.47	1.68	3.02	8.23	0.228	4.22	—	—	7.2	15.1	50	—	—	—	11.0
‡ 24	21.0	3.45	5.08	1.53	1.67	3.09	7.06	0.248	4.14	—	—	7.0	14.7	50	—	—	—	10.8
‡ 22.5	17.1	3.23	2.8	1.08	1.27	4.21	6.61	0.217	6.10	—	—	5.8	10.8	50	—	—	—	7.9
‡ 20	15.2	3.22	2.46	1.06	1.26	4.89	5.88	0.216	6.18	—	—	5.8	9.3	50	—	—	—	6.8
‡ 18.5	15.5	3.38	2.6	1.13	1.27	4.33	5.44	0.238	5.96	—	—	5.7	10.5	50	—	—	—	7.7
‡ 17	14.0	3.35	2.35	1.11	1.27	5.00	5.00	0.234	5.96	—	—	5.7	9.1	50	—	—	—	6.7
8B 15	11.8	3.29	1.65	0.86	1.01	6.44	4.43	0.223	7.15	—	—	4.3	7.1	50	—	—	3.7	5.2
‡ 13	9.88	3.21	1.31	0.83	0.99	7.87	3.83	0.215	7.55	—	—	4.3	5.8	50	—	—	—	4.2
† 10	7.79	3.23	1.01	0.82	0.97	9.83	2.95	0.221	7.70	—	—	—	4.6	50	2.82	—	—	3.4
6B 16	10.1	2.59	2.14	0.96	1.07	3.84	4.72	0.179	4.72	—	—	4.4	11.8	50	—	—	3.7	8.7
12	7.24	2.48	1.44	0.90	1.03	5.38	3.53	0.171	5.02	—	—	4.3	8.4	50	—	—	3.7	6.2
† 8.5	5.07	2.43	0.96	0.87	1.00	7.63	2.50	0.168	5.29	—	—	—	6.0	50	—	—	—	4.4

Table 3 (continued)

Member		X-X Axis		Y-Y Axis							A36				A242		A440	A441	
		S_x (in.³)	r_x (in.)	S_y (in.³)	r_y (in.)	r_4 (in.)	d/A_f (1/in.)	A (in.²)	C'_{PM} (ft)	S_x/S_y	A' (in.²)	d/t	L_c (ft)	L_u (ft)	F_y (ksi)	A'' (in.²)	d/t	L_c (ft)	L_u (ft)
AMERICAN STANDARD BEAMS																			
24I	120	251	9.26	21.1	1.56	1.89	2.71	35.13	0.595	11.90	—	—	8.7	16.8	50	—	—	7.4	12.3
	105.9	234	9.53	20.0	1.60	1.89	2.76	30.98	0.630	11.71	—	—	8.5	16.5	50	—	38.40	7.2	12.1
	100	198	9.05	13.4	1.29	1.62	3.81	29.25	0.569	14.71	—	—	7.9	11.9	50	—	—	6.6	8.7
	90	186	9.21	12.8	1.32	1.63	3.87	26.30	0.589	14.50	—	—	7.7	11.7	50	—	38.50	6.5	8.6
	79.9	174	9.46	12.2	1.36	1.64	3.94	23.33	0.621	14.25	—	48.00	7.6	11.5	50	21.95	48.00	6.4	8.5
20I	95	160	7.59	14.0	1.35	1.66	3.03	27.74	0.480	11.42	—	—	7.8	15.0	50	—	—	6.6	11.0
	85	150	7.78	13.3	1.38	1.66	3.09	24.80	0.504	11.29	—	—	7.6	14.7	50	—	—	6.5	10.8
	75	126	7.60	9.4	1.17	1.46	3.97	21.90	0.482	13.44	—	—	6.9	11.4	50	—	—	5.9	8.4
	65.4	117	7.83	8.9	1.21	1.47	4.05	19.08	0.511	13.10	—	—	6.8	11.2	50	—	40.00	5.7	8.2
18I	70	102	6.70	7.8	1.09	1.39	4.17	20.46	0.416	13.10	—	—	6.8	10.9	50	—	—	5.7	8.0
	54.7	88.4	7.07	7.1	1.15	1.40	4.35	15.94	0.463	12.40	—	—	6.5	10.4	50	—	39.20	5.5	7.7
15I	50	64.2	5.74	5.7	1.05	1.29	4.28	14.59	0.366	11.30	—	—	6.1	10.6	50	—	—	5.2	7.8
	42.9	58.9	5.95	5.3	1.08	1.29	4.39	12.49	0.393	11.10	—	—	6.0	10.4	50	—	36.60	5.0	7.6
12I	50	50.3	4.55	5.8	1.05	1.28	3.32	14.57	0.288	8.69	—	—	5.9	13.7	50	—	—	5.0	10.0
	40.8	44.8	4.77	5.3	1.08	1.27	3.47	11.84	0.317	8.45	—	—	5.7	13.1	50	—	—	4.8	9.6
	35	37.8	4.72	3.9	0.99	1.19	4.34	10.20	0.310	9.70	—	—	5.5	10.5	50	—	—	4.7	7.7
	31.8	36.0	4.83	3.8	1.01	1.19	4.41	9.26	0.324	9.49	—	—	5.4	10.3	50	—	—	4.6	7.6
10I	35	29.2	3.78	3.4	0.91	1.12	4.12	10.22	0.238	8.59	—	—	5.4	11.0	50	—	—	4.5	8.1
	25.4	24.4	4.07	3.0	0.97	1.12	4.37	7.38	0.277	8.12	—	—	5.0	10.4	50	—	—	4.3	7.6
8I	23	16.0	3.09	2.1	0.81	0.97	4.51	6.71	0.199	7.62	—	—	4.5	10.1	50	—	—	3.8	7.4
	18.4	14.2	3.26	1.9	0.84	0.97	4.71	5.34	0.222	7.48	—	—	4.3	9.7	50	—	—	3.7	7.1
7I	20	12.0	2.68	1.6	0.74	0.88	4.62	5.83	0.171	7.50	—	—	4.2	9.8	50	—	—	3.5	7.2
	15.3	10.4	2.86	1.5	0.78	0.89	4.88	4.43	0.195	6.94	—	—	4.0	9.3	50	—	—	3.4	6.8
6I	17.25	8.7	2.28	1.3	0.68	0.82	4.69	5.02	0.145	6.70	—	—	3.9	9.7	50	—	—	3.3	7.2
	12.5	7.3	2.46	1.1	0.72	0.80	5.02	3.61	0.168	6.64	—	—	3.6	9.1	50	—	—	3.1	6.7
5I	14.75	6.0	1.87	1.0	0.63	0.76	4.67	4.29	0.117	6.00	—	—	3.6	9.7	50	—	—	3.0	6.1
	10	4.8	2.05	0.82	0.65	0.73	5.11	2.87	0.140	5.85	—	—	3.3	8.9	50	—	—	2.8	6.5
4I	9.5	3.3	1.56	0.65	0.58	0.67	4.89	2.76	0.102	5.09	—	—	3.0	9.3	50	—	—	2.6	6.8
	7.7	3.0	1.64	0.58	0.59	0.66	5.13	2.21	0.112	5.18	—	—	2.9	8.9	50	—	—	2.4	6.5
3I	7.5	1.9	1.15	0.47	0.52	0.61	4.60	2.17	0.074	4.04	—	—	2.7	9.9	50	—	—	2.3	7.2
	5.7	1.7	1.23	0.40	0.53	0.58	4.95	1.64	0.084	4.25	—	—	2.5	9.2	50	—	—	2.1	6.7

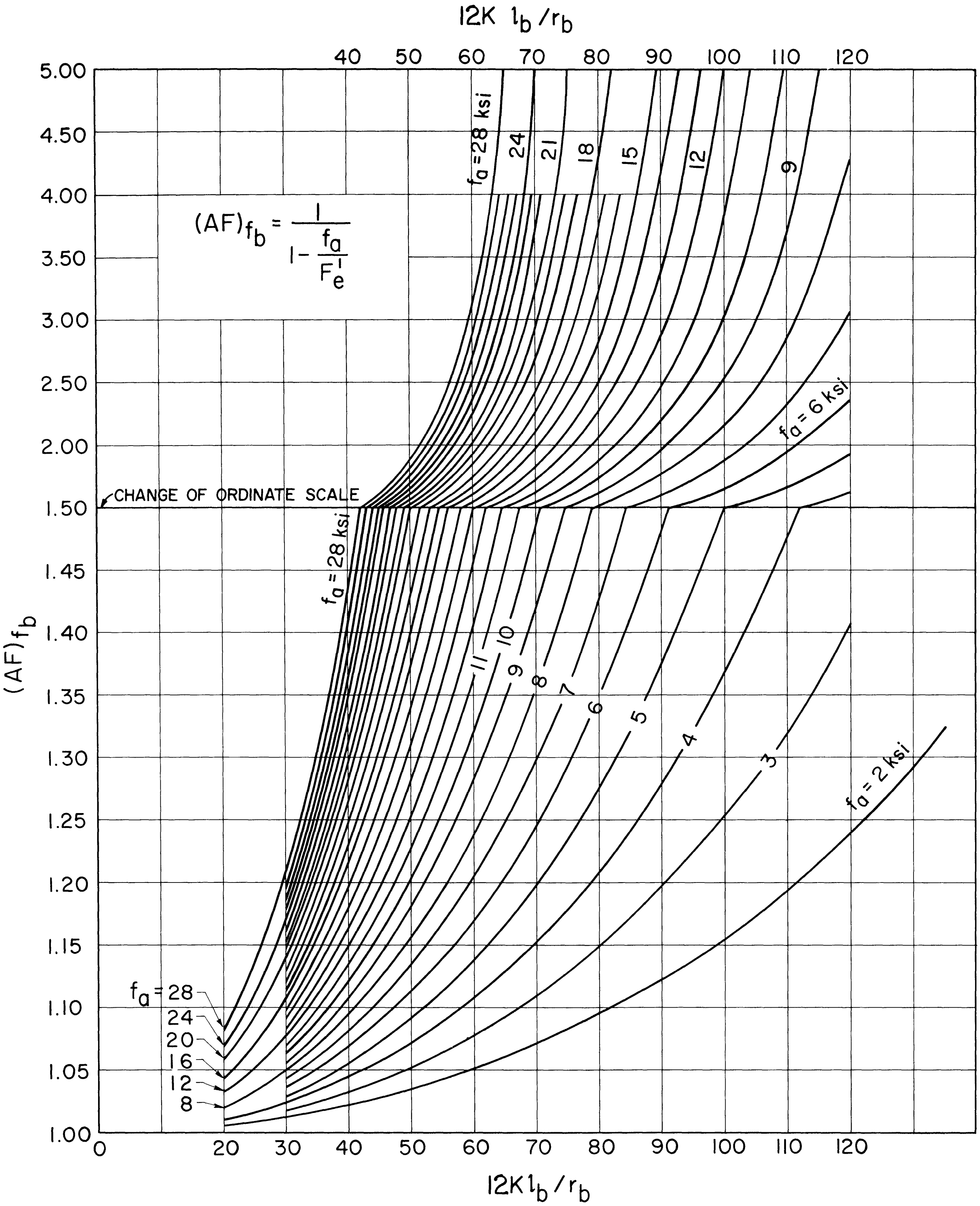

4.0
3.0
2.0
1.0
1.8
1.6
1.4
1.2
1.0
APPROX. F_{bx}/F_a
0
10
20
30
40
ℓ_{yu} (ft.)
8 WF
10 WF
12 WF
18 WF
18 WF
8 WF
10 WF
12 WF
10 WF
12 WF
8 WF
12 WF
16 WF
21 WF
14 WF
27 WF
24 WF
12 WF
16 WF
21 WF
14 WF
24 WF
27 WF
30 WF
36 WF
33 WF
12 WF
16 WF
36 WF
30 WF
33 WF
30 WF
36 WF

Graph A



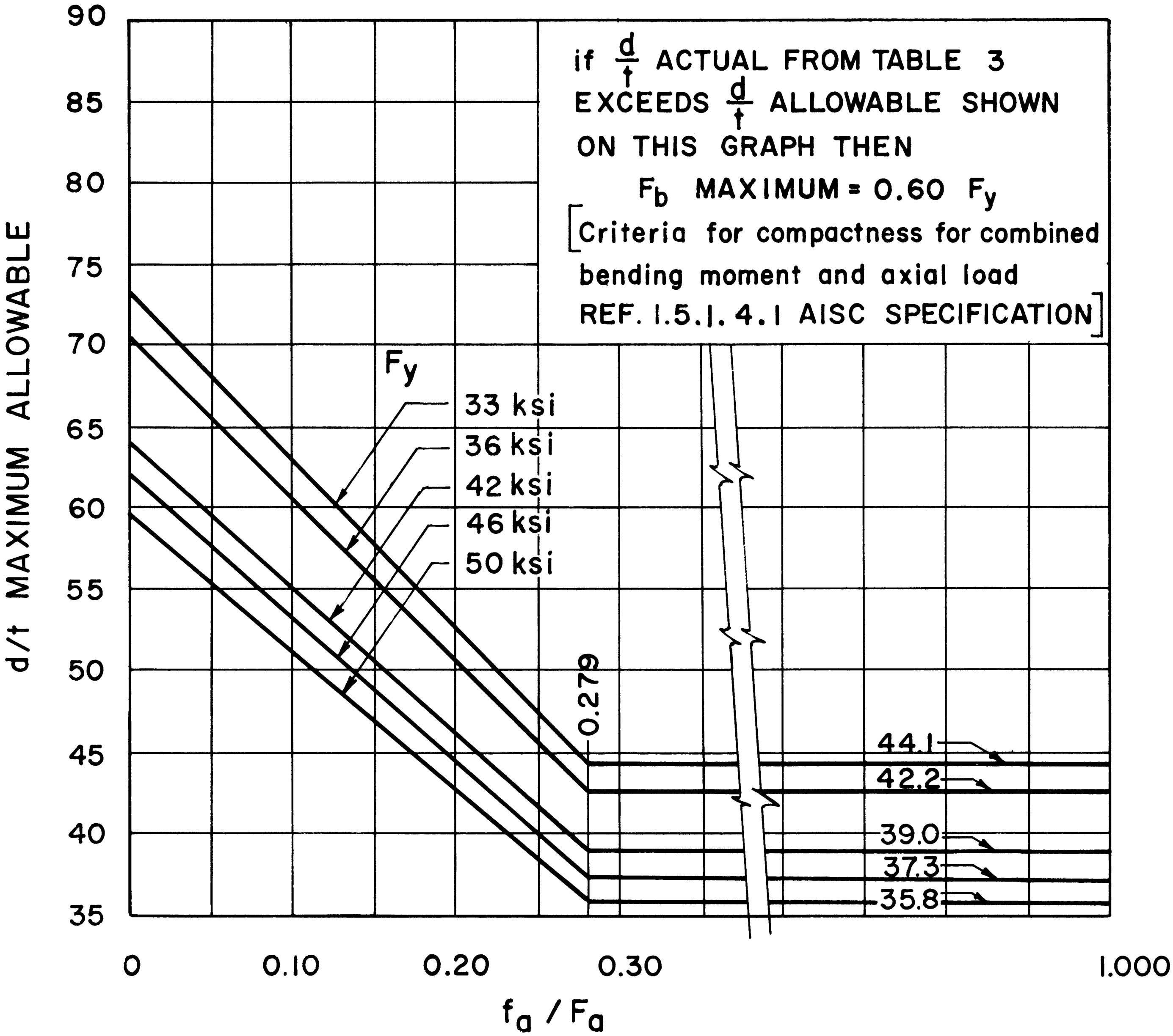
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
12K l/r
SEC.
MEMBERS
MAIN
MEMBERS
42 ksi
46 ksi
50 ksi
33 ksi
36 ksi
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Fa (ksi)

Graph B

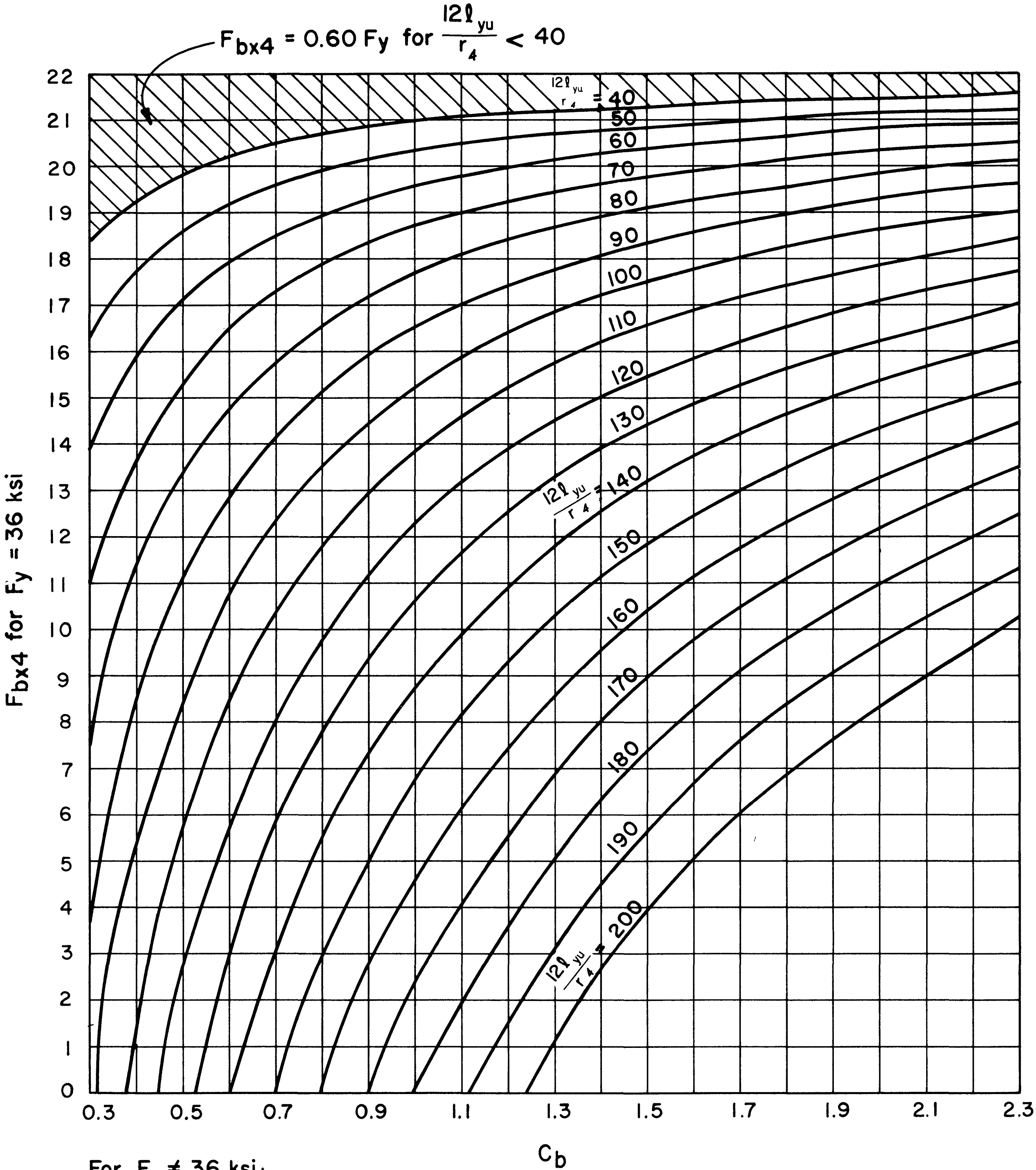


12K l_b/r_b
$(AF)_{f_b} = \frac{1}{1-\frac{f_a}{F'_e}}$
CHANGE OF ORDINATE SCALE
f_a = 28 ksi
24
21
18
15
12
9
f_a = 6 ksi
11
10
9
8
7
6
5
4
3
f_a = 2 ksi
f_a = 28
24
20
16
12
8
$(AF)_{f_b}$
12K l_b/r_b

Graph C


if d/t ACTUAL FROM TABLE 3
EXCEEDS d/t ALLOWABLE SHOWN
ON THIS GRAPH THEN
Fb MAXIMUM = 0.60 Fy
[Criteria for compactness for combined
bending moment and axial load
REF. 1.5.1.4.1 AISC SPECIFICATION]
Fy
33 ksi
36 ksi
42 ksi
46 ksi
50 ksi
0.279
44.1
42.2
39.0
37.3
35.8
d/t MAXIMUM ALLOWABLE
90
85
80
75
70
65
60
55
50
45
40
35
0
0.10
0.20
0.30
1.000
fa / Fa

Graph D



For $F_y \neq 36$ ksi:

Find $C_b' = C_{b\text{-act}} \times \dfrac{36}{F_{y\text{-act}}}$

Using C_b' as abcissa obtain ordinate which equals F_{bx4}

Calculate $F_{bx4\text{-act}} = F_{bx4} \times \dfrac{F_{y\text{-act}}}{36}$

Graph E