Rapid Selection of Beam-Columns for Wind or Earthquake Effects

E. I. FIESENHEISER AND J. G. RONAN

MANY FLOOR BEAMS, particularly those along column lines, are subjected to axial forces due to wind or earthquake effects together with bending due to floor loads. The use of the AISC formulas for this case is somewhat involved and time-consuming. The bending stress, F_{bx}, depends upon resistance of the compression flange to lateral buckling over unsupported lengths, whereas the allowable axial stress is governed by the slenderness ratios $K_x l_x/r_x$ or $K_y l_y/r_y = Kl/r$, whichever is greater. The Kl/r values also depend upon locations of restraint points. Further, all allowable unit stresses are increased by one-third. One of the difficulties is that both slenderness ratios need to be taken into account simultaneously.

The charts in this paper presented will expedite economical selections, since the curves cover the essential investigations of AISC Specification Sect. 1.6—Combined Stresses, when bending occurs only about the x-axis. Any member stressed to its full moment-carrying capacity will also have an additional axial load capacity which should be utilized. This is the additional strength f_a which is given by the charts.

When the permissible stress increase is applied, AISC Specification Formula (1.6-1a) may be transformed into the inequality

$$\frac{f_a}{F_a} + \frac{C_m F'_{ex} f_{bx}}{(F'_{ex} - \tfrac{3}{4} f_a) F_{bx}} \leq \frac{4}{3} \qquad (1.6\text{-A})$$

in which F_a, F_{bx}, and F'_{ex} are without the one-third increase.

In the design process, f_{bx} should approach F_{bx} as nearly as possible. Therefore these stresses are set equal. Then,

$$F_a \geq \frac{F'_{ex} - \tfrac{3}{4} f_a}{[(\tfrac{4}{3} - C_m) F'_{ex}/f_a] - 1} \qquad (1.6\text{-B})$$

which is the general equation of the plotted curves.

E. I. Fiesenheiser is Professor Emeritus of Civil Engineering, Illinois Institute of Technology, and Consulting Structural Engineer, Blue Island, Illinois.

J. G. Ronan is Structural Engineer, Fluor-Pioneer, Inc., Chicago, Illinois.

After a tentative size selection for moment, the slenderness ratios are calculated. Then, entering the appropriate chart with these ratios, their intersection point is spotted. The point may lie on a curve or between two curves. In the latter case interpolation by eye is sufficient. The point satisfies both slenderness ratios simultaneously and any point above or to the right of any curve is a valid solution for f_a. These are limit curves for which f_{bx} is exactly equal to F_{bx}. Stress F_{bx} must of course be determined from AISC Formula (1.5-6a), (1.5-6b), or (1.5-7). The four charts are for F_y of 36 or 50 ksi and C_m of 0.85 or 1.00.

It was noted that by solving for f_a in inequality Eq. (1.6-A), its value becomes zero when f_a/F_a is equal to $(\tfrac{4}{3} - C_m)$. In order to avoid this critical value of f_a, corresponding critical values for the term $(\tfrac{4}{3} - C_m)$ become 0.333 and 0.483, respectively, for $C_m = 1.00$ and 0.85. An arbitrary boundary curve is established at the left of each chart for $f_a/F_a = 1.32 - C_m$, which yields the values 0.32 for $C_m = 1$ and 0.47 for $C_m = 0.85$. The boundary curves are straight for $Kl/r \geq C_c$ and curved below this limit. For $K_x l_x/r_x$ to the left of a boundary curve, the value of Kl/r is constant and f_a is governed only by $K_x l_x/r_x$.

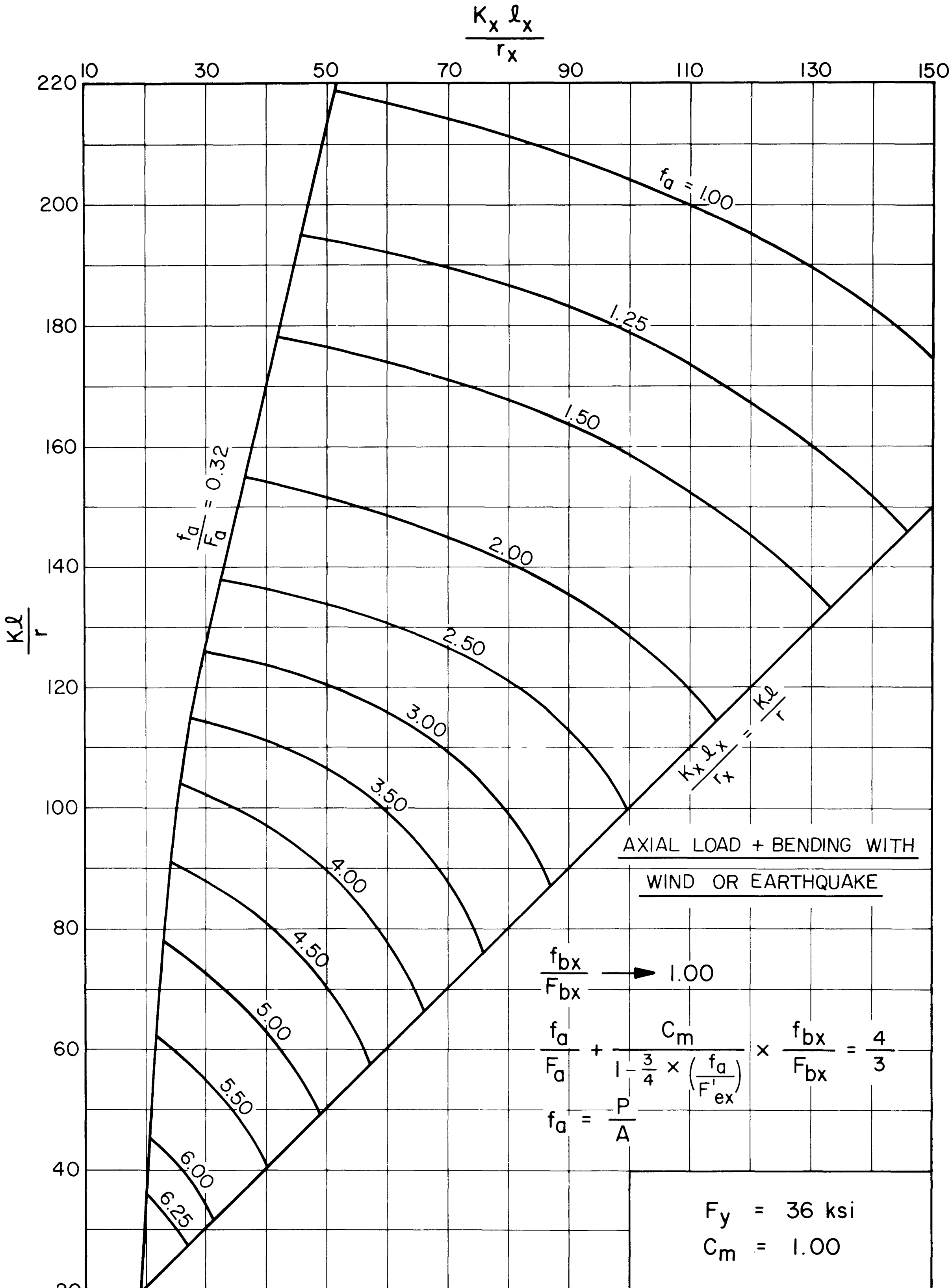
Allowable axial stress is controlled by either slenderness ratio. Therefore the curves extend only to the line at the right, where these are equal. For points to the right of this line, $K_x l_x/r_x$ is constant and f_a depends only on Kl/r.

REFINEMENTS

The available commercial sizes often do not coincide closely with the bending requirements, that is, the ratio f_{bx}/F_{bx} may be appreciably less than 1. Since the charts assume this ratio to be exactly 1, there is additional axial load capacity which is not incorporated in the charts. Advantage should be taken of this additional capacity. The true f_a can be solved for readily as explained below.

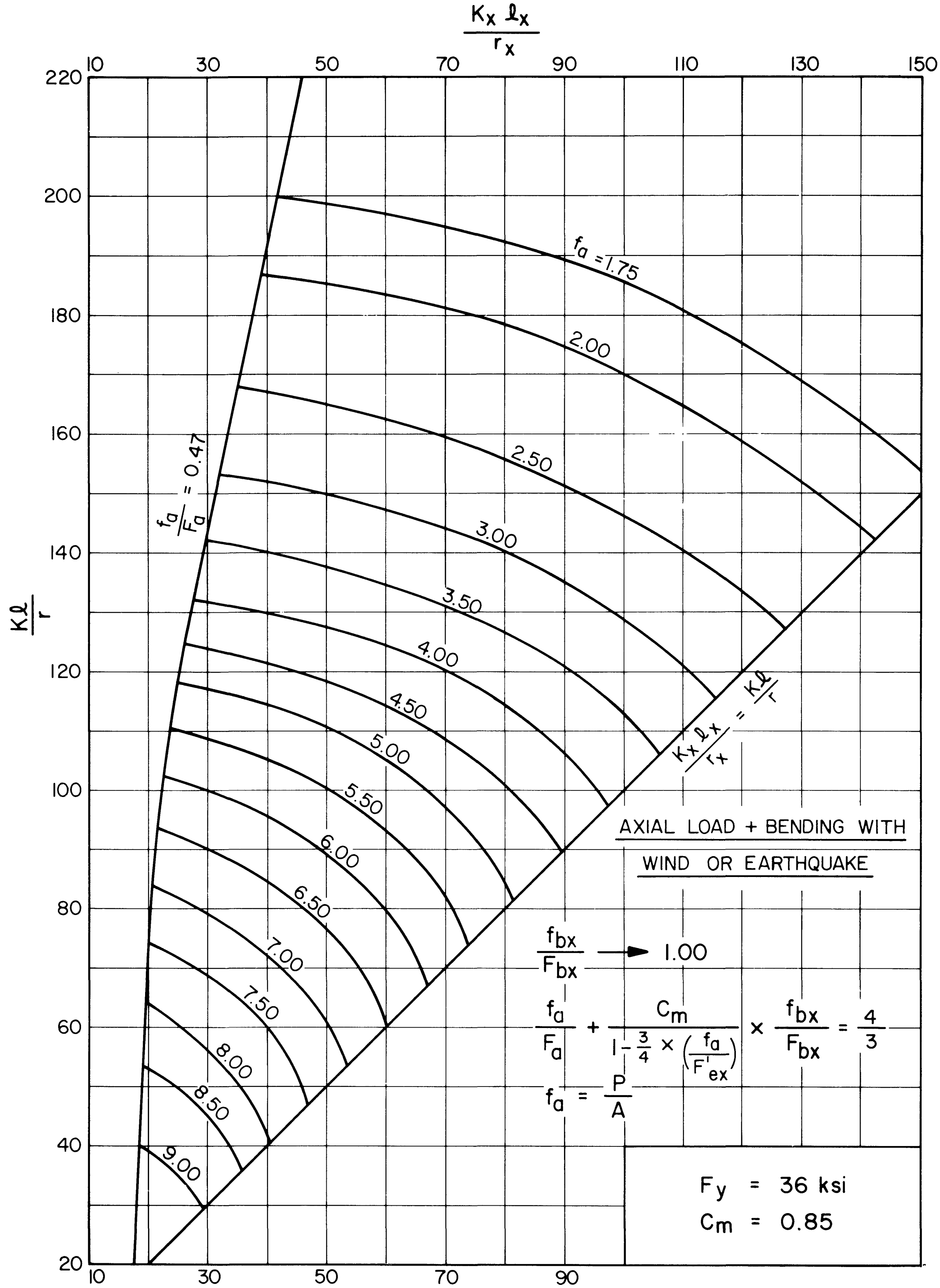
By writing Eq. (1.6-A) as an equality, f_a may be solved for as a function of the ratio f_{bx}/F_{bx} and F'_{ex}, the latter being a function only of $K_x l_x/r_x$.

$$f_a = \left[\frac{4}{3} - \frac{C_m F'_{ex}(f_{bx}/F_{bx})}{F'_{ex} - \tfrac{3}{4} f_a}\right] F_a \qquad (1.6\text{-C})$$



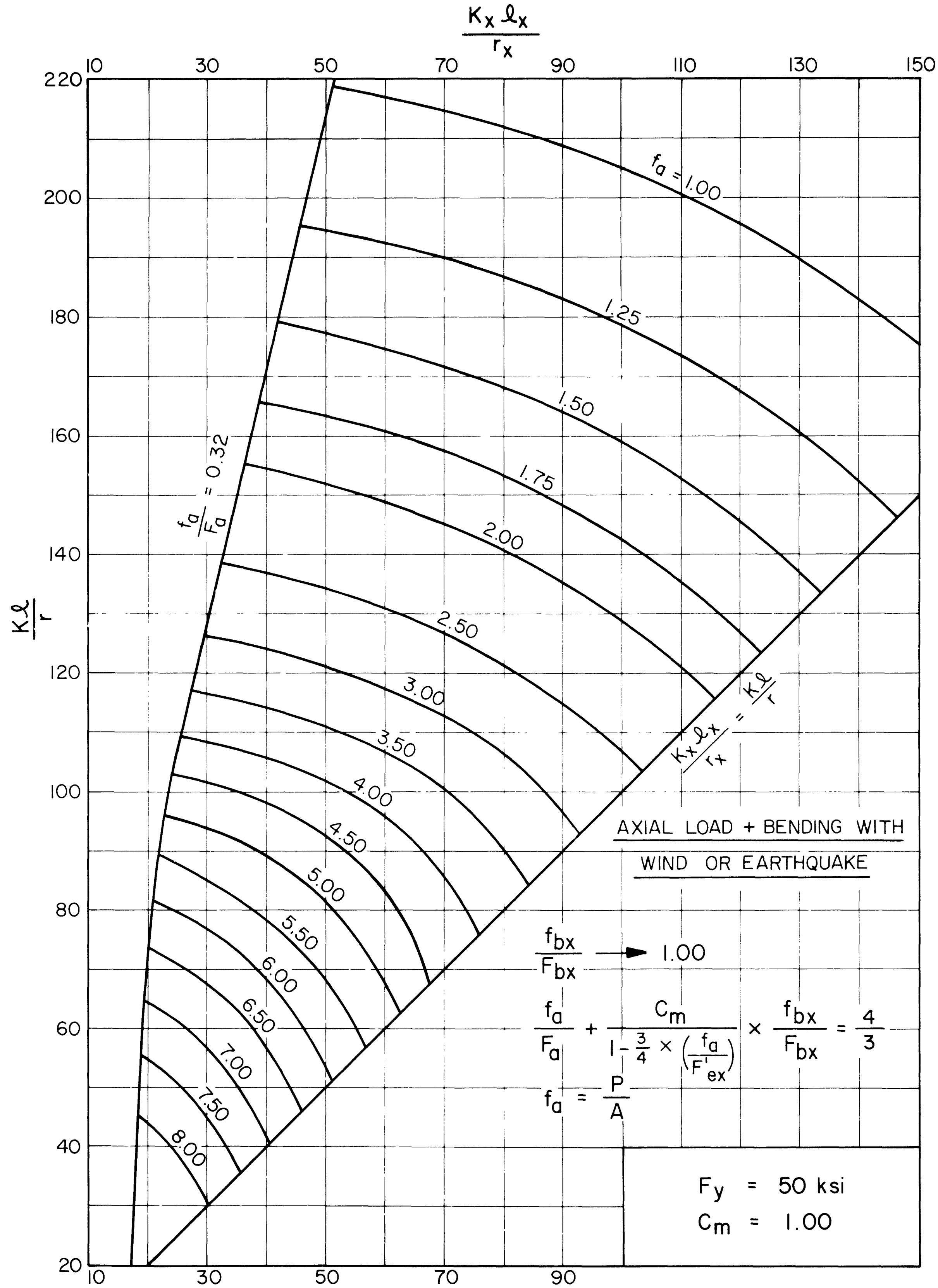
$\frac{K_x \ell_x}{r_x}$
10 30 50 70 90 110 130 150
$\frac{K\ell}{r}$
220 200 180 160 140 120 100 80 60 40 20
$f_a = 1.00$
1.25
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.25
$\frac{f_a}{F_a} = 0.32$
$\frac{K_x \ell_x}{r_x} = \frac{K\ell}{r}$
AXIAL LOAD + BENDING WITH
WIND OR EARTHQUAKE
$\frac{f_{bx}}{F_{bx}} \rightarrow 1.00$
$\frac{f_a}{F_a} + \frac{C_m}{1 - \frac{3}{4} \times \left(\frac{f_a}{F'_{ex}}\right)} \times \frac{f_{bx}}{F_{bx}} = \frac{4}{3}$
$f_a = \frac{P}{A}$
F_y = 36 ksi
C_m = 1.00
10 30 50 70 90

Chart 1



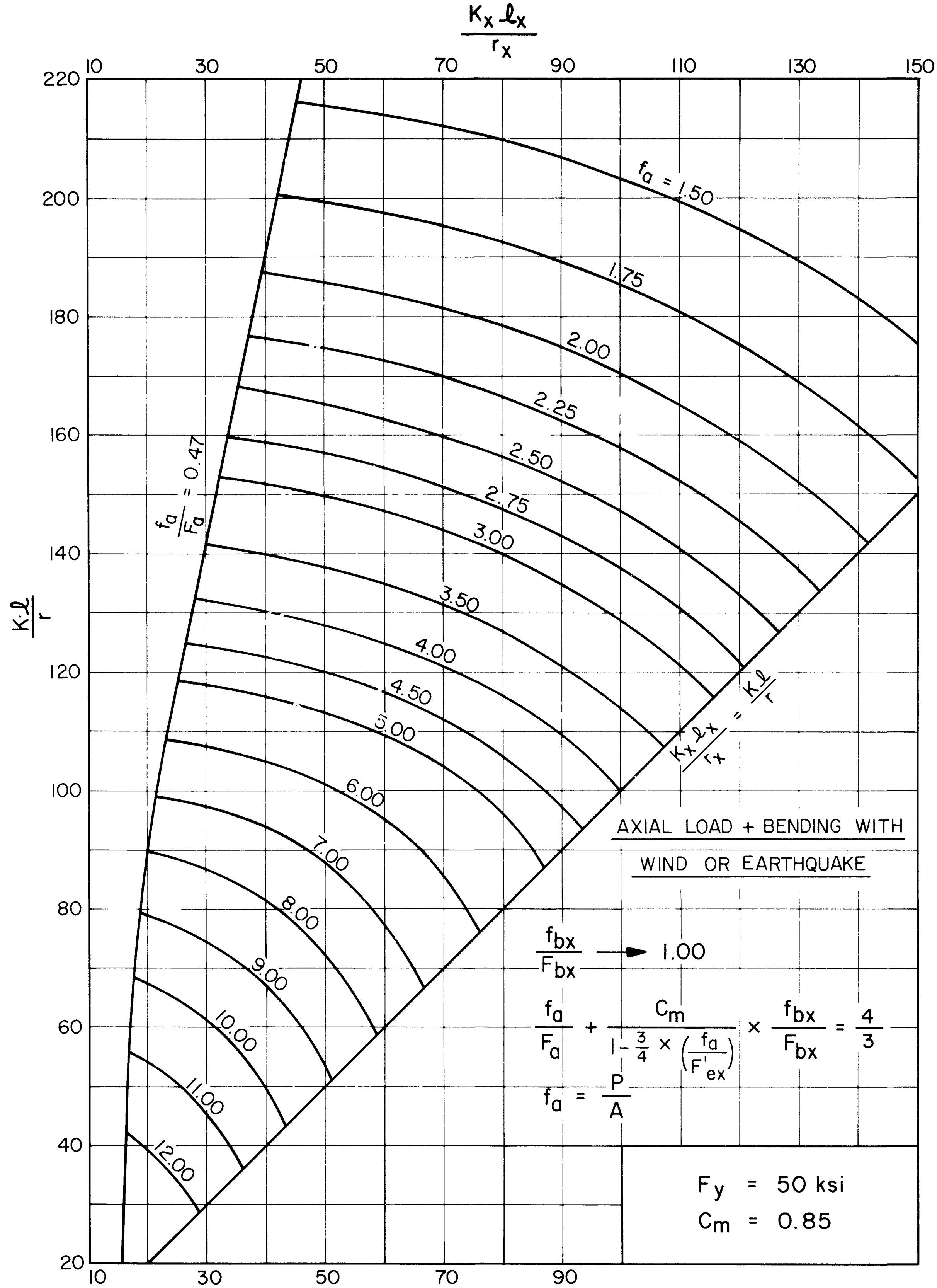
$\frac{K_x \ell_x}{r_x}$
10
30
50
70
90
110
130
150
220
200
180
160
140
120
100
80
60
40
20
$\frac{K\ell}{r}$
$\frac{f_a}{F_a} = 0.47$
$f_a = 1.75$
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00
$\frac{K_x \ell_x}{r_x} = \frac{K\ell}{r}$
AXIAL LOAD + BENDING WITH
WIND OR EARTHQUAKE
$\frac{f_{bx}}{F_{bx}} \longrightarrow 1.00$
$\frac{f_a}{F_a} + \frac{C_m}{1 - \frac{3}{4} \times \left(\frac{f_a}{F'_{ex}}\right)} \times \frac{f_{bx}}{F_{bx}} = \frac{4}{3}$
$f_a = \frac{P}{A}$
F_y = 36 ksi
C_m = 0.85

Chart 2



$\frac{K_x \ell_x}{r_x}$
10 30 50 70 90 110 130 150
220 200 180 160 140 120 100 80 60 40 20
$\frac{K\ell}{r}$
10 30 50 70 90
$f_a = 1.00$
1.25
1.50
1.75
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00
7.50
8.00
$\frac{f_a}{F_a} = 0.32$
$\frac{K_x \ell_x}{r_x} = \frac{K\ell}{r}$
AXIAL LOAD + BENDING WITH
WIND OR EARTHQUAKE
$\frac{f_{bx}}{F_{bx}} \rightarrow 1.00$
$\frac{f_a}{F_a} + \frac{C_m}{1 - \frac{3}{4} \times \left(\frac{f_a}{F'_{ex}}\right)} \times \frac{f_{bx}}{F_{bx}} = \frac{4}{3}$
$f_a = \frac{P}{A}$
F_y = 50 ksi
C_m = 1.00

Chart 3



$\frac{K_x \ell_x}{r_x}$
$\frac{K\ell}{r}$
$\frac{f_a}{F_a} = 0.47$
$f_a = 1.50$
1.75
2.00
2.25
2.50
2.75
3.00
3.50
4.00
4.50
5.00
6.00
7.00
8.00
9.00
10.00
11.00
12.00
$\frac{K_x \ell_x}{r_x} = \frac{K\ell}{r}$
AXIAL LOAD + BENDING WITH
WIND OR EARTHQUAKE
$\frac{f_{bx}}{F_{bx}} \rightarrow 1.00$
$\frac{f_a}{F_a} + \frac{C_m}{1 - \frac{3}{4} \times \left(\frac{f_a}{F'_{ex}}\right)} \times \frac{f_{bx}}{F_{bx}} = \frac{4}{3}$
$f_a = \frac{P}{A}$
F_y = 50 ksi
C_m = 0.85

Chart 4

A suggested simple procedure is to solve Eq. (1.6-C) by a cycling procedure, using the chart value of f_a as a first lower bound. This value may be entered in the denominator as the only unknown, since all of the other values in this equation are known numerically. A more accurate value of the true f_a is then solved for. By repeating this process, always using the last f_a value determined, only one or two cycles are needed to obtain very accurate results. As an alternative, a direct solution may be used by solving for f_a directly in Eq. (1.6-C). This is a quadratic whose precise solution is

$$f_a = \tfrac{2}{3}[(F'_{ex} + F_a) - \sqrt{(F'_{ex} - F_a)^2 + 3F'_{ex}F_aC_mf_{bx}/F_{bx}}] \quad (1.6\text{-D})$$

EXAMPLES

Four examples are solved in Table 1. Examples 1, 2, and 3 are floorbeams subject to axial loads due to wind or earthquake force effects, whereas Example 4 is a column. In Example 1 the chart value for f_a is sufficiently exact, since the ratio f_{bx}/F_{bx} is 0.993, nearly 1.000. For the other examples the chart values of f_a were corrected to higher values using the cycling procedure described previously.

Table 1. Examples

	Example No.			
Design Data	1	2	3	4
M_x (k-ft)	85	118	118	378
P (k)	73	61	56	385
L (ft)	20	30	30	18
L_b (ft)	6.67	19	19	18
F_y (ksi)	50	36	36	50
K_x	1	1	1	1
$K = K_y$	1	1	1	1
C_m	0.85	1	1	1
Size	W12 × 27	W18 × 60	W21 × 55	W14 × 119
S (in.^{3})	34.2	108	110	189
A (in.^{2})	7.95	17.7	16.2	35.0
L_c (ft)	5.8	8.0	8.7	13.1
L_u (ft)	7.2	13.3	9.5	31.4
F_{bx} (ksi)	30	15.2	14.0	30.0
f_{bx} (ksi)	29.8	13.1	12.9	24.0
f_{bx}/F_{bx}	0.993	0.862	0.921	0.800
K_xL_x/r_x	47.3	48.2	42.9	34.5
KL/r	52.6	135.7	131.8	57.6
f_a (Chart)	9.2	2.5	2.7	6.7
f_a (1.6-C)	. . .	3.5	3.5	11.0
$P = f_aA$	73.1	62	57	385