DESIGN DATA SHEET
DEPARTMENT OF THE NAVY
Naval Sea Systems Command

23 June 1989

DDS 100-4 - STRENGTH OF STRUCTURAL MEMBERS -
Supersedes DDS 100-4 of 15 November 1982

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PART I: INTRODUCTION

100-4-a. References

(a) A Design Manual on the Buckling Strength of Metal Structures by Dr. Friedrich Bleich and Cdr. Lyle B. Ramsey, USN, Society of Naval Architects and Marine Engineers, Technical Research Bulletin No. 2-2, 1951.

(b) General Specifications for Ships of the United States Navy.

(c) Structural Shipbuilding Details using Tee Stiffeners, MIL-HDBK-283(SH).

(d) Properties of Steel Shapes and Plate-Beam Combination Used in Shipbuilding, MIL-HDBK-264(SH).

100-4-b. Purpose and Scope

This design data sheet provides uniform standards for the design of structural members subjected to compression, bending, and shear. The standards are based on the previous editions which rely extensively on reference (a).

Strength parameters are presented for columns in compression in Part II, for panels of plating in Part III, and for plate-stiffener combinations in bending in Part IV; since they are presented in non-dimensional form, they can be used for any metal structural material and any consistent system of measurement. Part V contains strength curves for the most commonly used materials in inch-pound units.

When a structural member is subjected to both compressive and bending loads, interaction formulae must be used; for details as well as for required minimum factors of safety, see the governing specifications.

100-4-c. Symbols and Abbreviations

The symbols and abbreviations used herein generally conform to standard Navy usage and are listed in Table 1, below.

TABLE 1: LIST OF SYMBOLS

A	area of column cross section
a	length of panel of plating (long edge)
b	breadth of panel of plating (short edge)
b_f	width of flange of stiffener
b_e	effective plating acting with stiffener
C	column factor; $C = K_c\ L/r\ \sqrt{(F_y/E)}$
D	outside diameter of circular section
d_w	depth of web of stiffener
d	depth of Tee stiffener
E	modulus of elasticity (Young's Modulus, see 100-4-d)
F_c	column strength; compressive stress on column to cause buckling
F_{cr}	critical elastic buckling strength of plating (theoretical value)

TABLE 1: LIST OF SYMBOLS (Continued)

F_p	plate buckling strength; in-plane uniform compressive stress
F_{pb}	plate buckling strength; in-plane bending stress
F_u	ultimate compressive strength of plating
F_y	tensile yield strength of material; for aluminum alloys, stress for 0.2% set
F_s	plate buckling strength; in-plane shear stress
F_{sy}	shear yield strength of material; $F_y/\sqrt{3}$
F_{PL}	proportional limit; (assumed to be 76% of F_y)
F_{SPL}	shear proportional limit; (assumed to be 76% of F_{sy})
f_c	axial compressive stress on column
f_p	net in-plane compressive stresses on panel of plating
f_{pc}	uniform compressive stresses on panel of plating
f_{pb}	bending stresses on panel of plating
f_{ps}	shear stresses on panel of plating
I	moment of inertia of cross section
K	plate buckling coefficient (see 100-4-h)
K_c	column end condition coefficient (see 100-4-e)
K_p	plate buckling coefficient (see Figure ~~5)~~ 4b
K_{pb}	plate in-plane bending buckling coefficient (see Figure ~~6)~~ 5b
K_s	plate shear buckling coefficient (see Figure ~~7)~~ 6b
K_t	stiffener tripping coefficient
L	unsupported length of column or stiffener
L_t	tripping length; permissible unsupported span of tee stiffener attached to plating

TABLE 1: LIST OF SYMBOLS (Continued)

r	radius of gyration of cross section of column ($\sqrt{(I/A)}$)
t	thickness of plating
t_f	thickness of flange of stiffener
t_w	thickness of web of stiffener
β	plate's slenderness ratio, $b/t \sqrt{(F_y/E)}$
μ	Poisson's ratio

100-4-d. Material Design Properties

The strength criteria contained in this Design Data Sheet which are presented in non-dimensional form, apply to any commonly used naval and commercial marine grade steels and aluminum.

For a number of commonly used naval materials, charts are provided in 100-4-j for easy reference. These charts are based on the material design properties shown in Table 2.

TABLE 2: SELECTED MATERIAL DESIGN PROPERTIES

MATERIAL	F_y (ksi)	F_{PL} (ksi)	F_{sy} (ksi)	F_{SPL} (ksi)	$\sqrt{(F_y/E)}$	$2t/\sqrt{(F_y/E)}$
STEEL: $E = 29600$ ksi; $\mu = 0.30$						
$\pi^2E/12(1 - \mu^2) = 26753$ ksi						
Ordinary Strength (OS)	34	25.8	19.6	14.9	0.0339	60t
Higher Strength (HS)	51	38.8	29.4	22.4	0.0415	50t
High Strength Low Alloy						
- (HSLA80)	80	60.8	46.2	35.1	0.0520	38.5t
- (HSLA100)	100	76.0	57.7	43.9	0.0581	34.5t
High Yield - (HY80)	80	60.8	46.2	35.1	0.0520	38.5t
- (HY100)	100	76.0	57.7	43.9	0.0581	34.5t
*ALUMINUM: $E = 10000$ ksi; $\mu = 0.33$						
$\pi^2E/12(1 - \mu^2) = 9230$ ksi						
5086 - H111 (extrusions)	16				0.0400	
- H116 (plate)	22	16.7	12.7	9.7	0.0469	42.5t
5456 - H111 (extrusions)	21				0.0458	
- H116 (plate)	26	19.8	15.0	11.4	0.0510	39t
5454 - H111 (extrusions)	16				0.0400	
- H34 (plate)	16	12.2	9.2	7.0	0.0400	50t

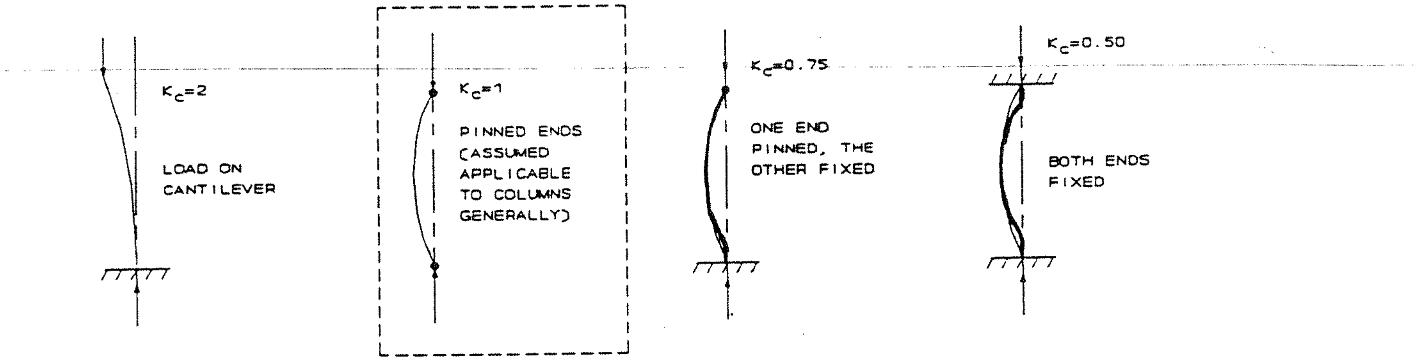
* Values are for welded aluminum. For prime material refer to material specifications given by reference (b). The design curves presented in this DDS use the welded yield strength for aluminum.

PART II: STRENGTH OF COLUMNS

100-4-e. Column Strength

The column strength, F_c, represents the average stress at failure of a column subjected to pure axial loading. F_c depends on the slenderness ratio (L/r), material properties F_y and E, and a coefficient (K_c) which takes into account varying end conditions.

The end coefficient K_c may vary between 0.50 and 2.0, as shown below. A value of K_c less than 1.0 should not be used unless full rotational restraint is provided and the effects of all bending stresses, including any secondary bending are taken into account.



Column of Uniform Cross Section

For stocky columns, having a column buckling factor $C \leq 1.4$, $[C = K_c\, L/r \sqrt{(F_y/E)}]$, the column compressive strength,

$$F_c = F_y.$$

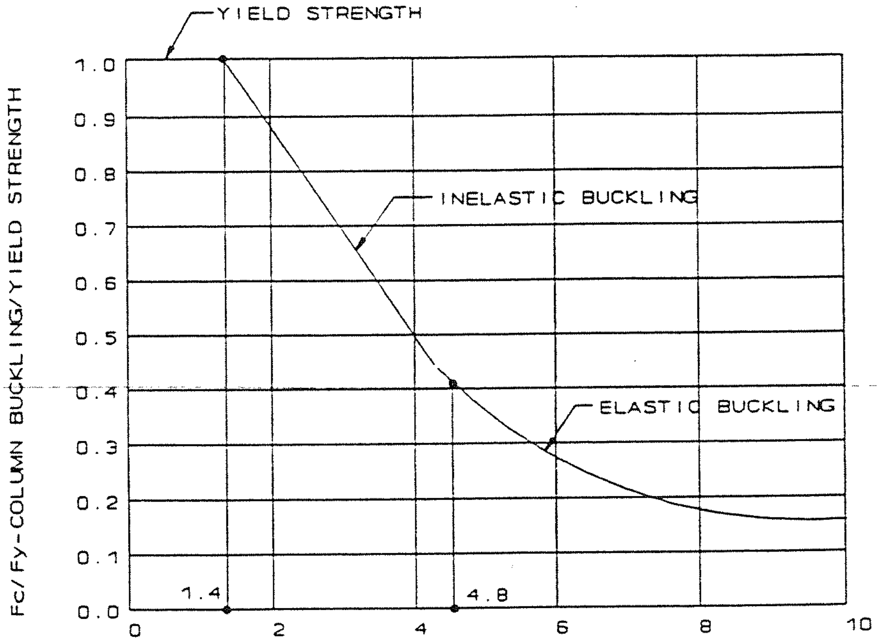
For intermediate slenderness columns $(1.4 < C \leq 4.8)$, F_c is given by the straight line expression below.

$$F_c = F_y\,(1.235 - 0.168\,C)$$

For slender columns, $C > 4.8$, F_c is independent of material yield strength, and is given by Euler's equation, below.

$$F_c = \frac{\pi^2 E}{(K_c\, L/r)^2} = \cancel{\frac{9.87E}{(K_c\, L/r)^2}} \approx F_y\left(9.87/C^2\right)$$

The above relationship between F_c and C is shown schematically in the sketch below. Additionally, for design purposes, Figure 1 provides curves of F_c for selected material.



COLUMN BUCKLING FACTOR: C=~~(L/r)x~~(Fy/E)

$C = K_c L/r \sqrt{(F_y/E)}$

Columns of Nonuniform Cross Section

The strength of a column of nonuniform cross section may be based on the least radius of gyration and the full length of the column.

100-4-f. Proportions of Columns and Stiffeners

Effective Plating

Radius of gyration of a plate-stiffener combination in compression may be calculated assuming an effective breadth of plating, based on post-buckling strength of plating, of $2t/\sqrt{(F_y/E)}$. For commonly used values see Table 2.

FOR DIFFERENT MATERIAL FOR PLATES & STIFFENERS SEE PG 8

The effective breadth of plating shall not exceed one-half the sum of spacing on each side of the member. For members along openings, the effective breadth of plating shall not exceed the sum of the actual plating breadth on the opening side and one-half the spacing on the other side.

For section modulus of plate-stiffener combinations in bending see 100-4-i.

Diameter-Thickness Ratio of Cylindrical Stanchions

In general, cylindrical stanchions and similar compression members should have a D/t ratio of no more than 40 for steel and 30 for aluminum alloys. This ratio is significantly lower than the theoretical compressive strength for local buckling; it is, however, warranted to provide sufficient ruggedness to withstand concentrated loads from connections and other sources.

Outstanding Flanges of Columns

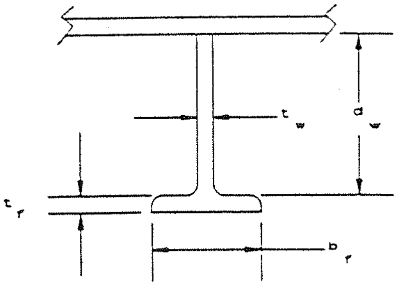
The breadth-thickness ratio of flanges of columns of Tee stiffeners should not exceed $1/\sqrt{(F_y/E)}$. Table 3 lists maximum permissible b_f/t_f ratios for selected materials. For flat bar stiffener application use one half these values.

Webs of Columns

The breadth-thickness ratios of the webs of columns of Tee stiffeners should not exceed $2.2/\sqrt{(F_y/E)}$. Table 3 lists maximum permissible d_w/t_w ratios for selected materials.

TABLE 3: MAXIMUM BREADTH TO THICKNESS RATIOS FOR STIFFENER FLANGE AND WEB

Material	Flange Maximum b_f/t_f	Web Maximum d_w/t_w
OS	29	64
HS	24	53
HSLA80 & HY80	19	42
HSLA100 & HY100	17	37
AL-5085 - H111	25	55
- H116	21	46
AL-5456 - H111	21	46
- H116	19	43
AL-5454 - H111	25	55



Lateral Support of Tee Stiffeners to Prevent Tripping

The outstanding flanges of a plate-stiffener must be adequately supported to prevent lateral buckling (tripping). To determine requirements for locating lateral support of tee-stiffeners, compare the actual unsupported span length, L, with the tripping length, L_t as follows.

$$L_t = \frac{1.283\ b_f}{(F_y/E)^{1/2}\ [1 + 1/3(d/b_f)(t_w/t_f) - 0.128(t_f/d)^2 E/F_y]^{1/2}}$$

For t_w/t_f of about 0.6 and b_f/t_f equal to the limiting value of $1/\sqrt{(F_y/E)}$, L_t may be determined from Figure 2 or the following formula.

$$L_t = K_t(b_f) = \frac{1.283\ b_f}{(F_y/E)^{1/2}\ [1 + .2(d/b_f) - 0.128(b_f/d)^2]^{1/2}}$$

Generally, the simplified formula above gives reasonable approximations of the full expression.

If L is less than L_t, lateral support is required at both ends.

If L exceeds L_t, but is less than $1.75L_t$, one intermediate lateral support located near midspan is required, in addition to supports at the end.

If L exceeds $1.75L_t$, multiple intermediate lateral supports spaced at no more than $0.75L_t$ are required, in addition to supports at the ends.

For structural details of intermediate lateral supports, see reference (c). The members providing lateral support must be designed to avoid overstress under loading normal to the plating. These members (in alternate panels) may be considered as simply supported beams.

Different Materials for Plate and Stiffeners

If the plating and stiffeners have different yield strengths, the yield strength of the plate is used in determining effective plating; the yield strength of the stiffener is used in determining requirements for lateral support of stiffeners, the minimum yield strength shall be used in determining the column strength.

PART III: STRENGTH OF PLATING IN COMPRESSION AND SHEAR

100-4-g. Ultimate Compressive Strength of Plating

The ultimate strength of plating (F_u) represents the average stress at failure over the width of a panel fully supported at its boundaries, when the panel is subjected to in-plane compressive loading on its short edges. F_u may be calculated as follows.

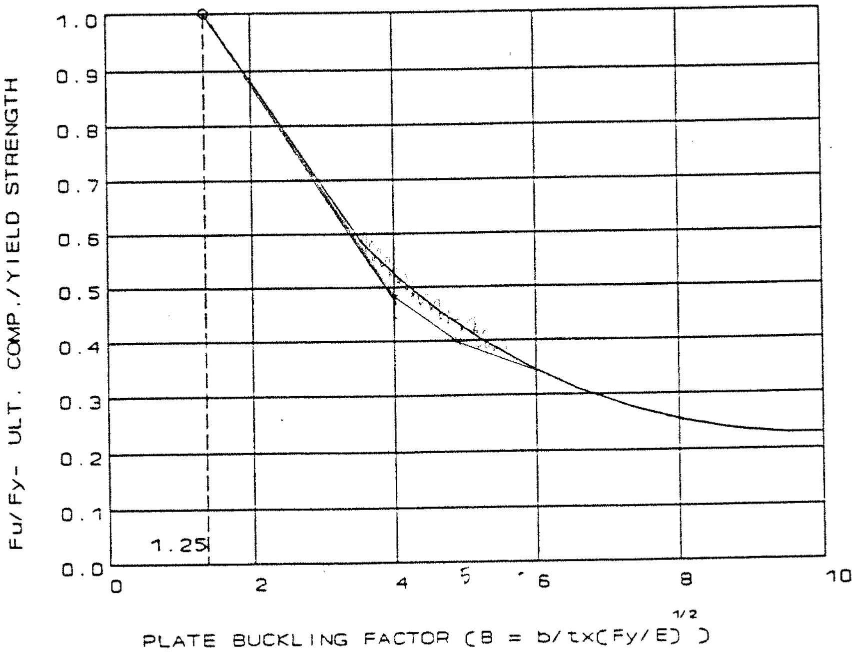
For thickly proportioned panels, having a plate buckling factor $\beta \leq 1.25$, $[\beta = b/t\sqrt{(F_y/E)}]$, the ultimate plating strength,

$$F_u = F_y$$

For more thinly proportioned panels $\beta > 1.25$, F_u is less than F_y, as follows.

$$F_u = F_y \left[\frac{2.25}{\beta} - \frac{1.25}{\beta^2} \right]$$

The above relationship between F_u and β is shown schematically in the sketch below. Also, Figure 3 provides curves of F_u for selected materials.



Since the stiffeners which provide the panel support are also subjected to compressive loading, they, in turn must be checked in accordance with 100-4-e. In addition, a composite safety factor for panel and stiffener is usually established by the governing specifications. The composite factor reduces the ultimate plating strength, F_u, by the ratio of column strength to plating yield strength, F_c/F_y, of the plate-stiffener combination.

CHANGE
FROM
1982 VERSION

100-4-h. Buckling Strength of Plating

The buckling strengths of plating, F_p, F_{pb}, and F_s, represent the values of peak stress on an edge to cause buckling of plating panels loaded with in-plane uniform compression, bending, and shear, respectively.

To calculate F_p, F_{pb}, or F_s, the following two step procedure may be used. Additionally, Figures 4a, 5a, and 6a in 100-4-j provide curves of F_p, F_{pb}, and F_s for selected materials.

The first step is to compute the theoretical value of the elastic plate buckling strength, F_{cr}, using the following formula.

$$F_{cr} = K \frac{\pi^2 E}{12(1 - \mu^2)} \frac{1}{(b/t)^2}$$

F_{cr} varies depending on the coefficient K, which depends on relative panel dimensions as well as on the type of loading and boundary conditions. Table 4 gives expressions for K, assuming simply supported edges. Note that K is not equivalent to K_p, K_{pb}, or K_s in 100-4-j, and that b is always the shorter edge of the panel.

The second step is to compare F_{cr} with the assumed proportional limit of Table 2 to determine whether initial buckling is elastic or inelastic and determine plate buckling strength, as follows. For edge shear the yield strength in shear, F_{sy}, is applicable instead of F_y.

If F_{cr} is less than the proportional limit of the plating, initial buckling is elastic, and F_p, F_{pb}, or F_s, equals F_{cr}.

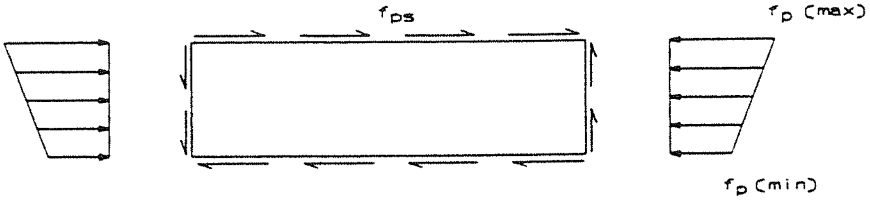
If F_{cr} is greater than the proportional limit, the buckling strength is reduced, based on F_{cr} and the yield strength, as follows.

$$F_p,\ F_{pb} = \frac{F_y}{1 + .1824\ (F_y/F_{cr})^2}$$

$$F_s = \frac{F_{sy}}{1 + .1824\ (F_{sy}/F_{cr})^2}$$

This accounts for actual construction materials in the low b/t range where inelastic buckling will occur before the theoretical value for F_{cr} is reached.

For a general loading condition, such as illustrated below,

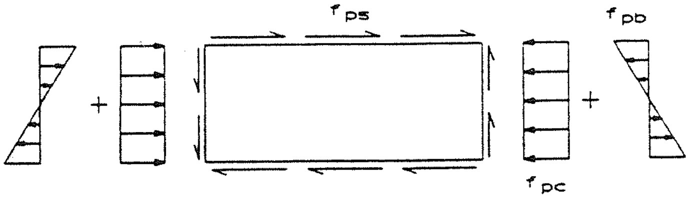


It is important to note that f_p is the net in-plane compressive stress resulting from the summation of in-plane axial/bending stress and the uniform plate-stiffener secondary bending stress in the above figure.

The buckling strength may be evaluated as an equivalent combination of simple loads as follows. First determine the combination of simple loads, f_{pc}, and f_{pb}, as below.

$$f_{pc} = \frac{1}{2}\left[f_{p(max)} + f_{p(min)}\right]$$

$$f_{pb} = \frac{1}{2}\left[f_{p(max)} - f_{p(min)}\right]$$

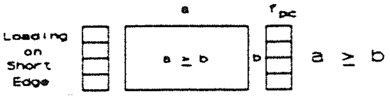
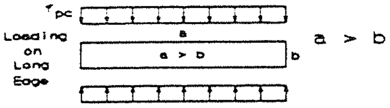
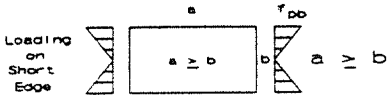
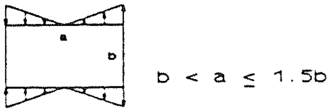
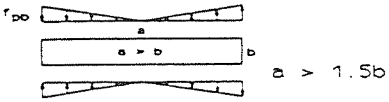
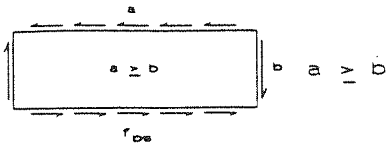


Next, compute the individual plate buckling strengths, F_p, F_{pb}, and F_s for the simple load cases, using the procedure described above. A plate panel is adequate against buckling if the following interaction formula is satisfied;

$$\frac{f_{pc}}{F_p} + \left(\frac{f_{pb}}{F_{pb}}\right)^2 + \left(\frac{f_{ps}}{F_s}\right)^2 \leq 1.0$$

TABLE 4: PLATE BUCKLING STRENGTH AND COEFFICIENTS

$$F_{cr} = K \frac{\pi^2 E}{12(1 - \mu^2)} \frac{1}{(b/t)^2}$$

Loading	Buckling Coefficient, K	Buckling Strength
Uniform Compression (K_p) On Short Edge 	4	$F_p = F_{cr}$ except if $F_{cr} > F_{PL}$, $F_p = \dfrac{F_y}{1 + 0.1824(F_y/F_{cr})^2}$
On Long Edge 	$[1 + (b/a)^2]^2$	
In-Plane Bending (K_{pb}) On Short Edge 	24	$F_{pb} = F_{cr}$ except if $F_{cr} > F_{PL}$, $F_{pb} = \dfrac{F_y}{1 + .1824(F_y/F_{cr})^2}$
On Long Edge  	$24\ (b/a)^2$ $[24 + 73(b/a - 2/3)^2] \times (b/a)^2$	
Edge Shear (K_s) 	$5.34 + 4(b/a)^2$	$F_s = F_{cr}$ except if $F_{cr} > F_{SPL}$, $F_s = \dfrac{F_{sy}}{1+.1824(F_{sy}/F_{cr})^2}$

PART IV: PLATING AND STIFFENERS IN BENDING

100-4-i. Effective Plating for Plate-Stiffener Combinations In Bending

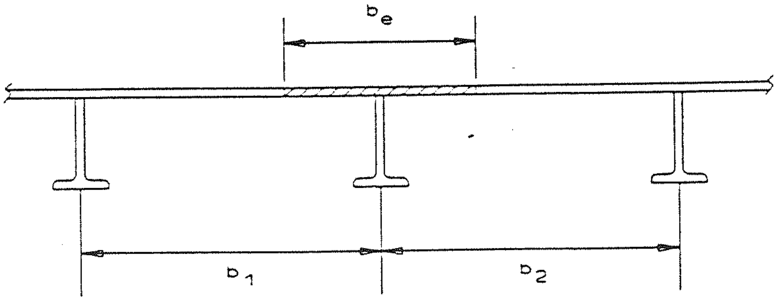
Section modulus of plate stiffener combinations in out-of-plane bending may be calculated assuming an effective breadth of plating based on either shear lag or post-buckling compression.

Maximum effective breadth of plating based on shear lag shall be one-fourth the stiffener's unsupported span for members under distributed loads, and one-eighth the span for members under concentrated loads.

Maximum effective breadth of plating, based on post-buckling strength, of $2t/\sqrt{(F_y/E)}$ (i.e. 60t, 50t, etc.) may be used, as given in Section 100-4-f.

For either basis, the effective breadth of plating shall not exceed the sum of one-half the spacing to the next similarly loaded member on each side of the member. For members along openings, the effective breadth of plating shall not exceed the sum of the actual plating breadth on the opening side and one-half the spacing. Table 5 summarizes these criteria.

TABLE 5: SUMMARY OF EFFECTIVE PLATING CRITERIA FOR PLATING AND STIFFENERS IN BENDING

Approach	Effective Plating Breadth, be
SHEAR LAG (Distributed Loads)	Lesser of L/4, $1/2(b_1 + b_2)$
(Concentrated Loads)	Lesser of L/8, $1/2(b_1 + b_2)$
POST BUCKLING COMPRESSION	Lesser of $2t/\sqrt{(F_y/E)}$, $1/2(b_1 + b_2)$
	

Generally, when the effective area of plating is much greater than that of the stiffener flange, variations in the effective area of plating have little effect on the lesser section modulus to the flange. Reference (d) provides a convenient tabulation of section properties for commonly available Tee's and angles using the generally more conservative post-buckling approach.

PART V: STRENGTH CURVES FOR SELECTED MATERIALS

100-4-j. Strength Curves

Strength curves are presented in inch-pound units for commonly used materials (OS, HS, HSLA80, HY80, HSLA100, HY100, AL-5086, and AL-5456).

Table 6 serves as a guide to the appropriate figure for a given strength parameter.

For the buckling strength of a panel, under compression and in-plane bending on the short edge, Figures 4a and 5a should be used directly. If the loading is on the long edge of the panel or is in shear, the appropriate coefficients K_p, K_{pb} and K_s must first be determined from Figures 4b, 5b or 6b and then the buckling strength from Figures 4a, 5a or 6a are determined.

TABLE 6: GUIDE TO STRENGTH CURVES

Strength Parameter		Figure No.
Column Strength	F_c	1
Tripping Coefficient	K_t	2
Ultimate Compressive Strength of Plating	F_u	3
Plate Buckling Strength, Uniform Compression	F_p	4a
Plate Buckling Coefficient, Uniform Compression on Long Edge	K_p	4b
Plate Buckling Strength, In-Plane Bending	F_{pb}	5a
Plate Buckling Coefficient, In-Plane Bending on Long Edge	K_{pb}	5b
Plate Buckling Strength, Edge Shear	F_s	6a
Plate Buckling Coefficient, Edge Shear	K_s	6b

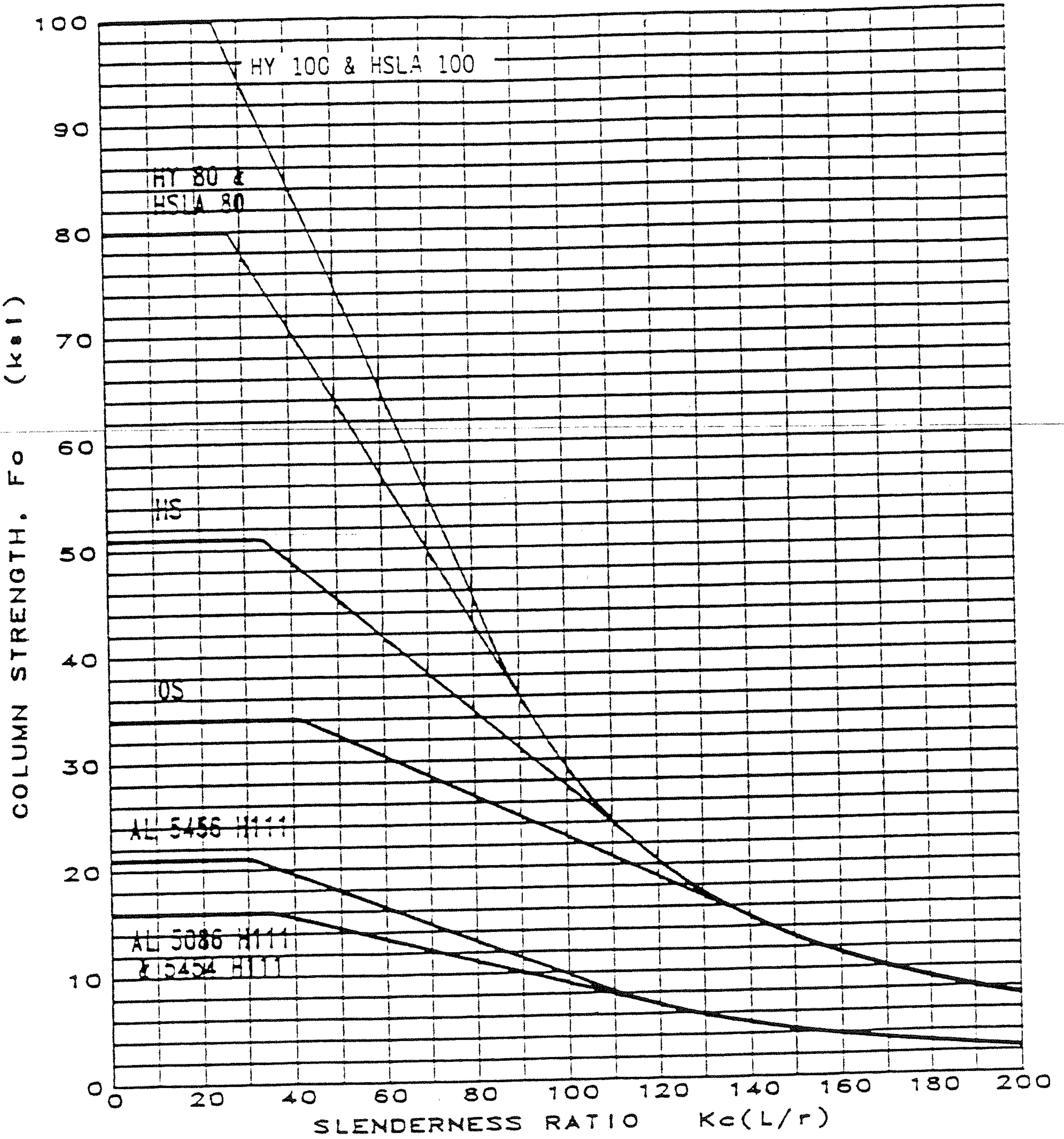


FIGURE 1: Column Strength, F_c

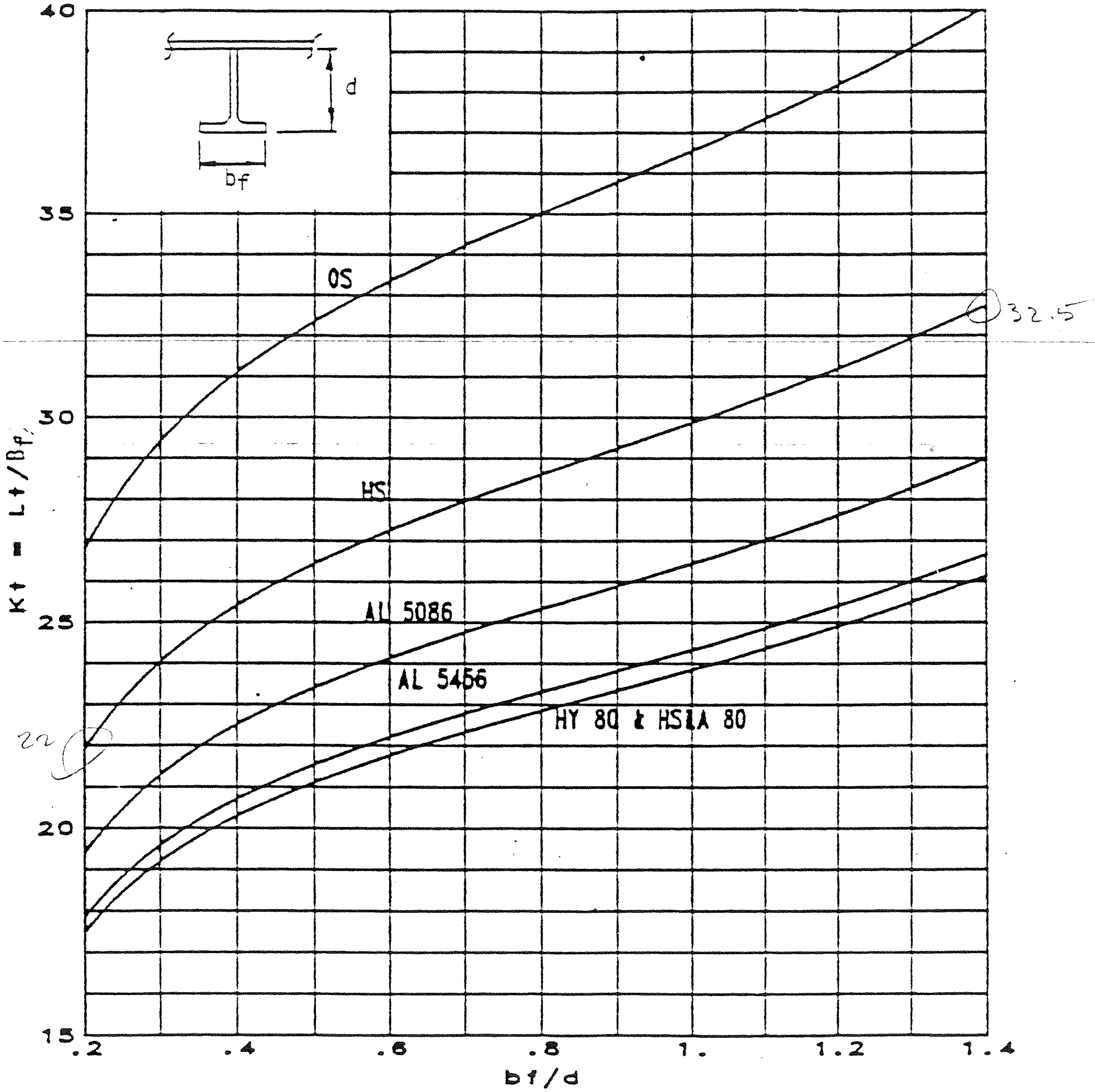
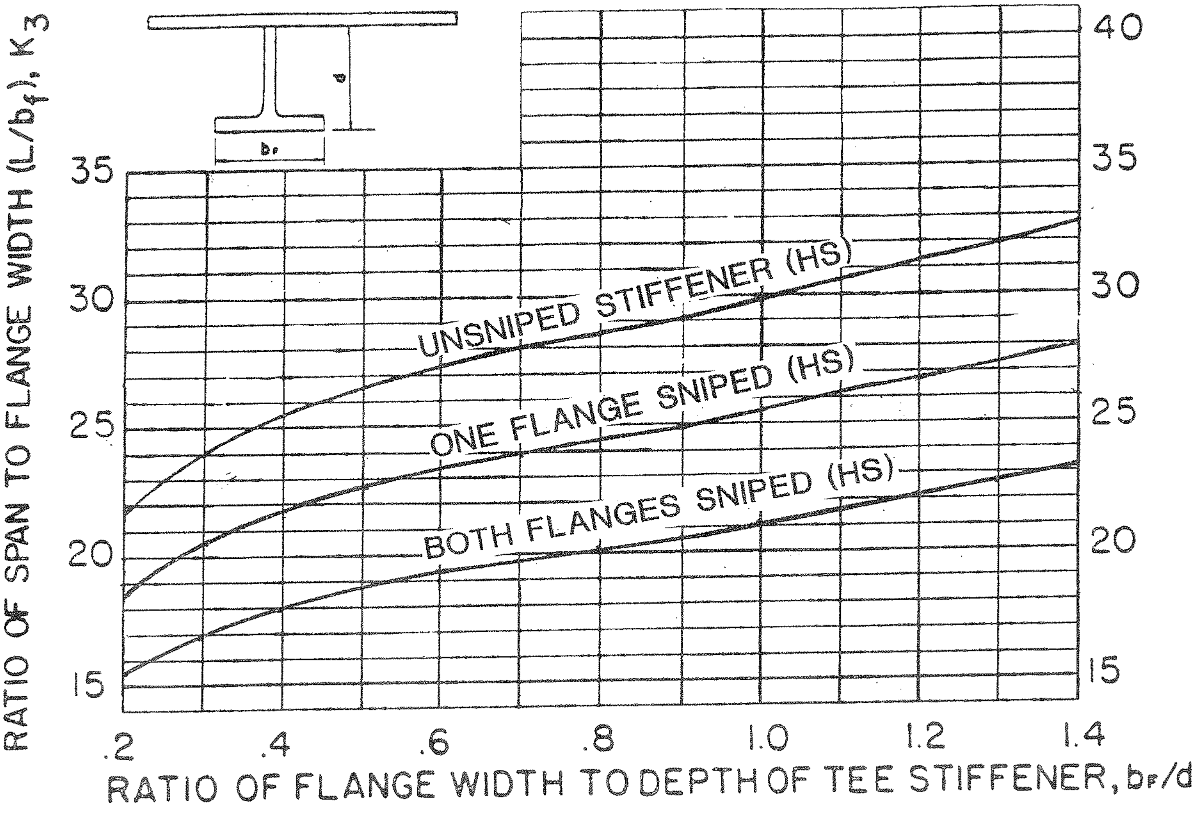


FIGURE 2: Tripping Coefficient, K_t; Ratio of Tripping Length to Flange Width For Plate-Tee Combination in Compression

A. MAXIMUM PERMISSIBLE RATIO OF SPAN TO FLANGE WIDTH FOR TEE STIFFENER WITHOUT INTERMEDIATE LATERAL SUPPORT



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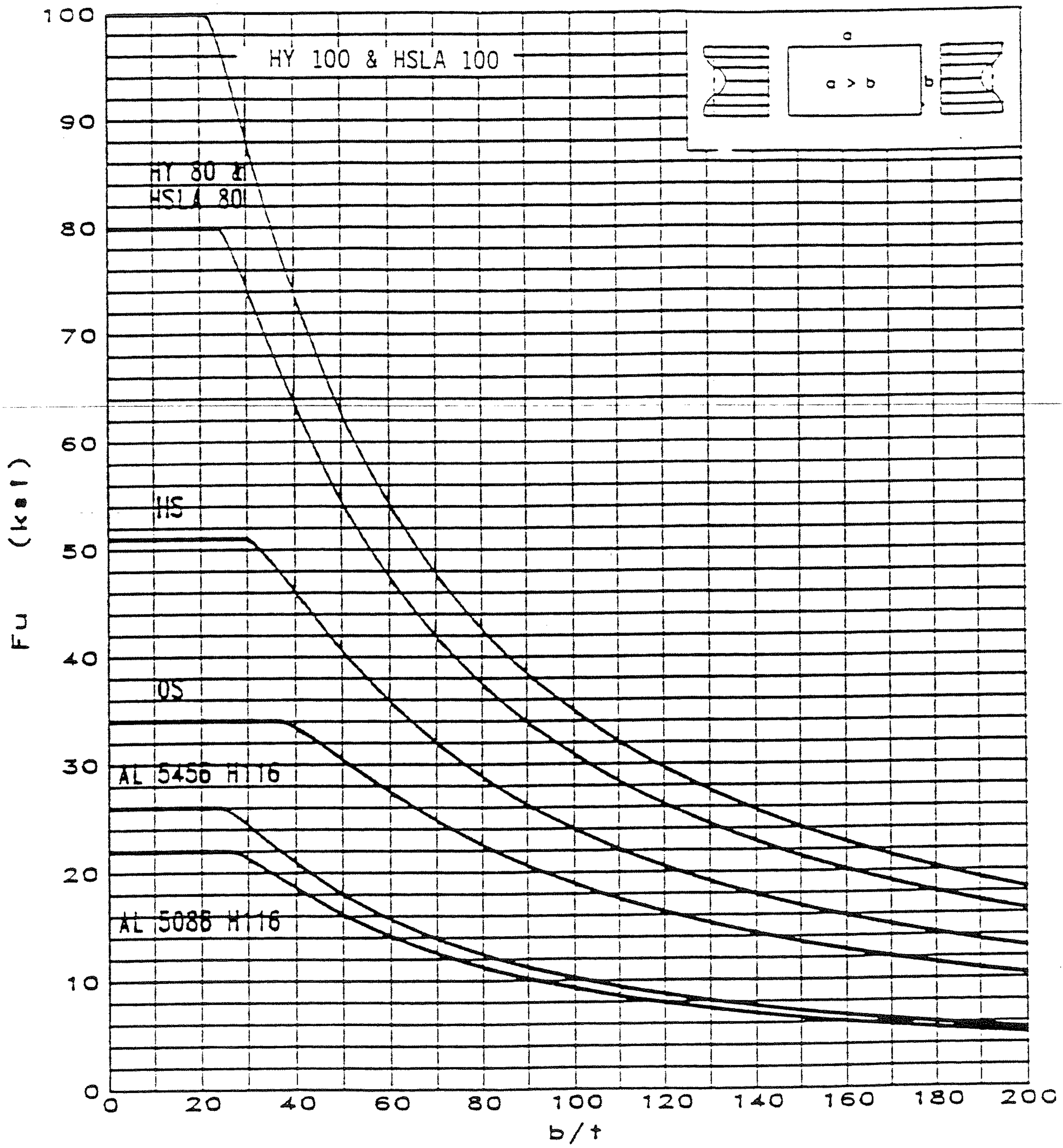
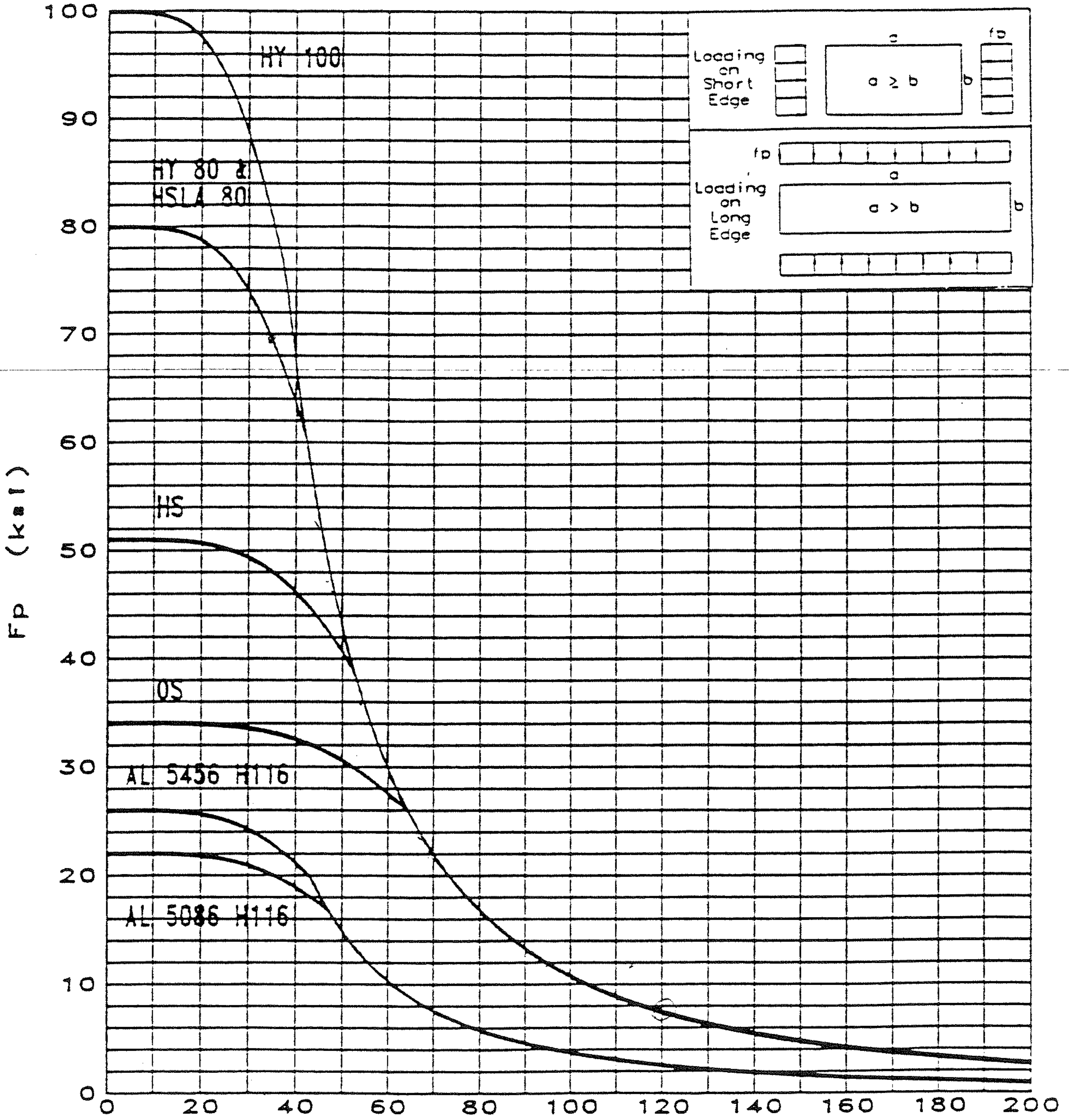


FIGURE 3: Ultimate Strength of Plating, F_u



b/t FOR LOADING ON SHORT EDGE
or K_p(b/t) FOR LOADING ON LONG EDGE, FOR K_p
SEE FIGURE 4b

FIGURE 4a: Plate Uniform Buckling Strength, F_p
Uniform Compression

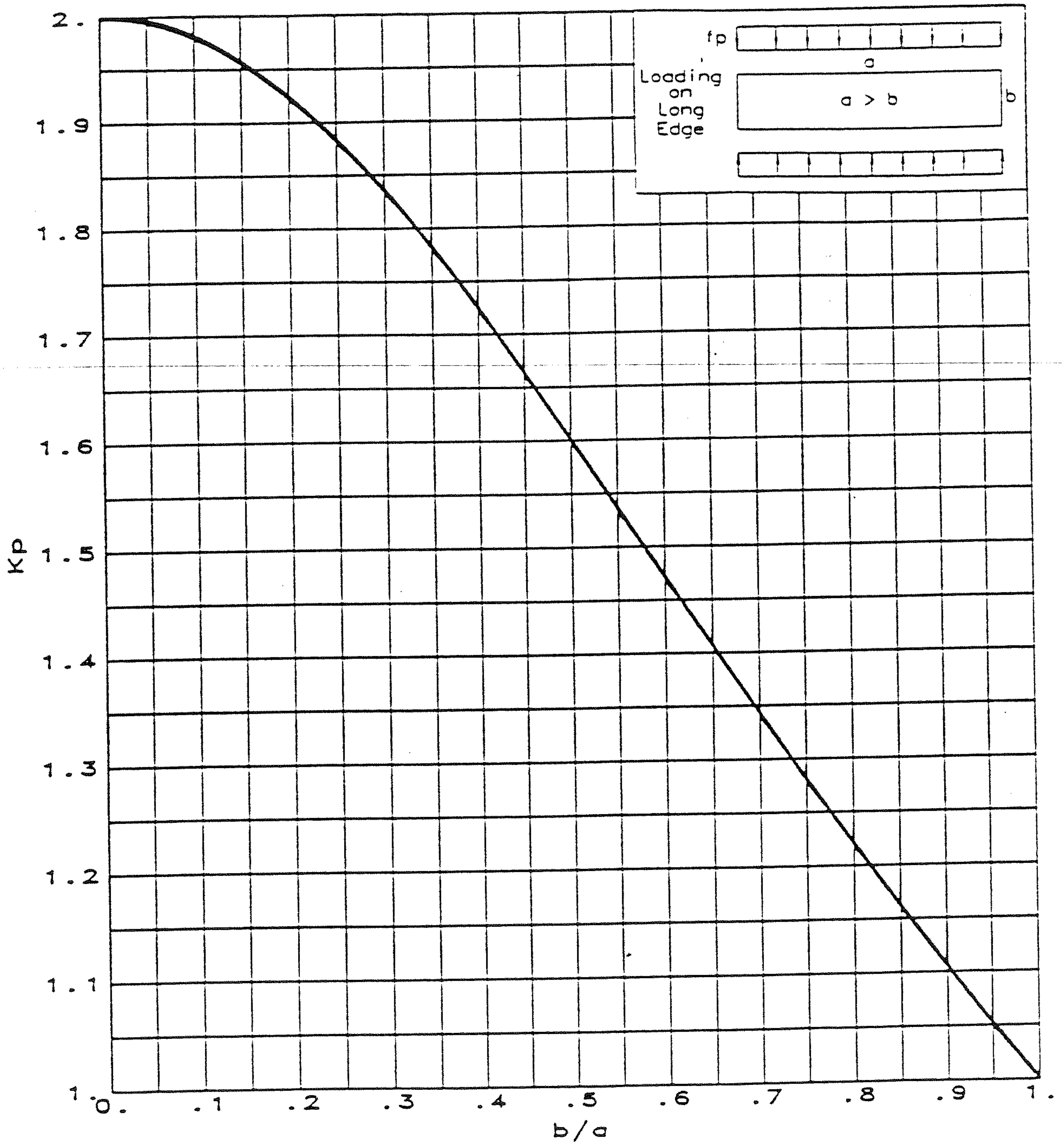
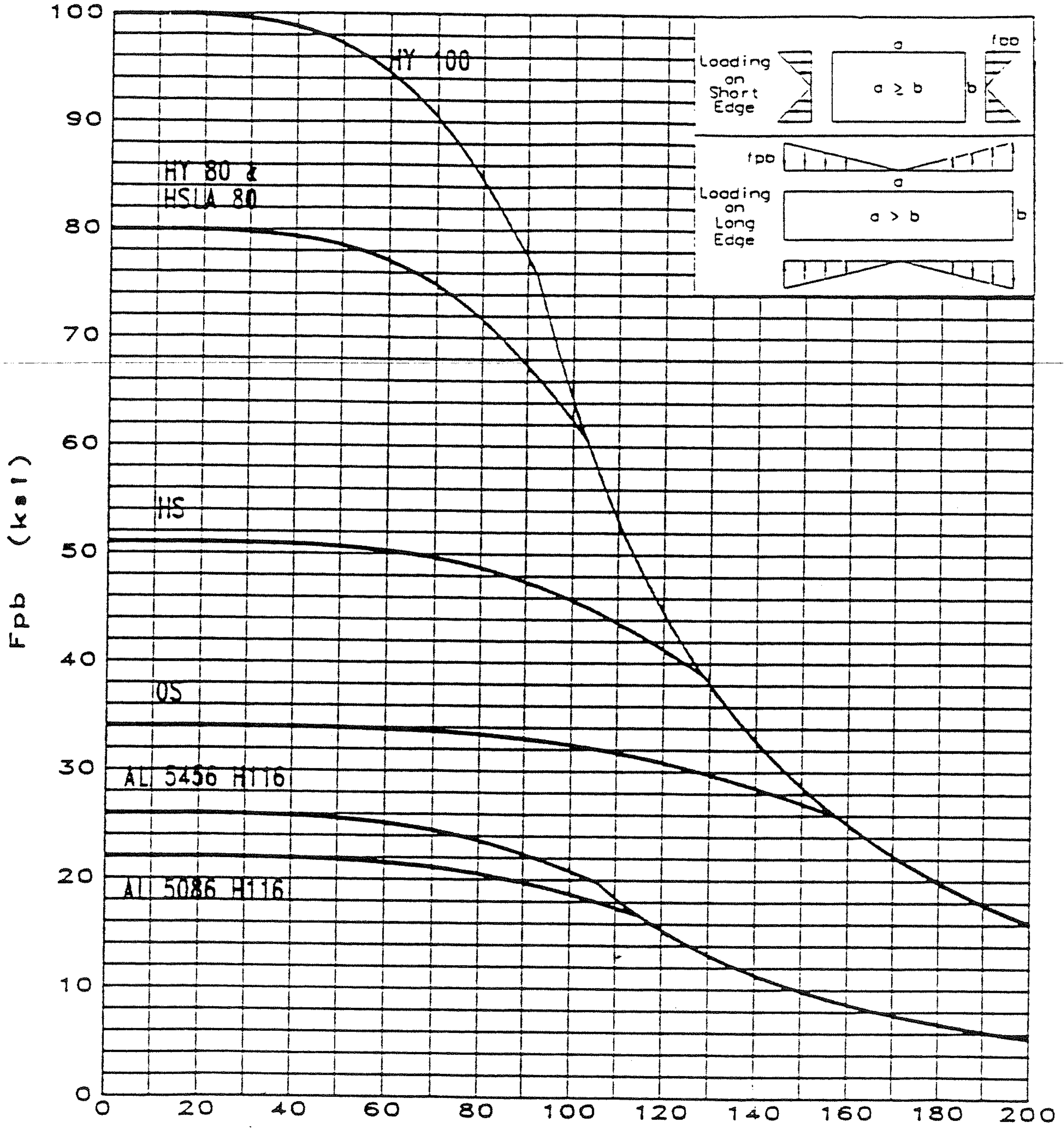


FIGURE 4b: Plate Buckling Coefficient, K_p
Uniform Compression on Long Edge



b/t FOR LOADING ON SHORT EDGE
or K_{pb}(b/t) FOR LOADING ON LONG EDGE, FOR K_{pb}
SEE FIGURE 5b

Figure 5a: Plate Buckling Strength, F_{pb}
In-Plane Bending

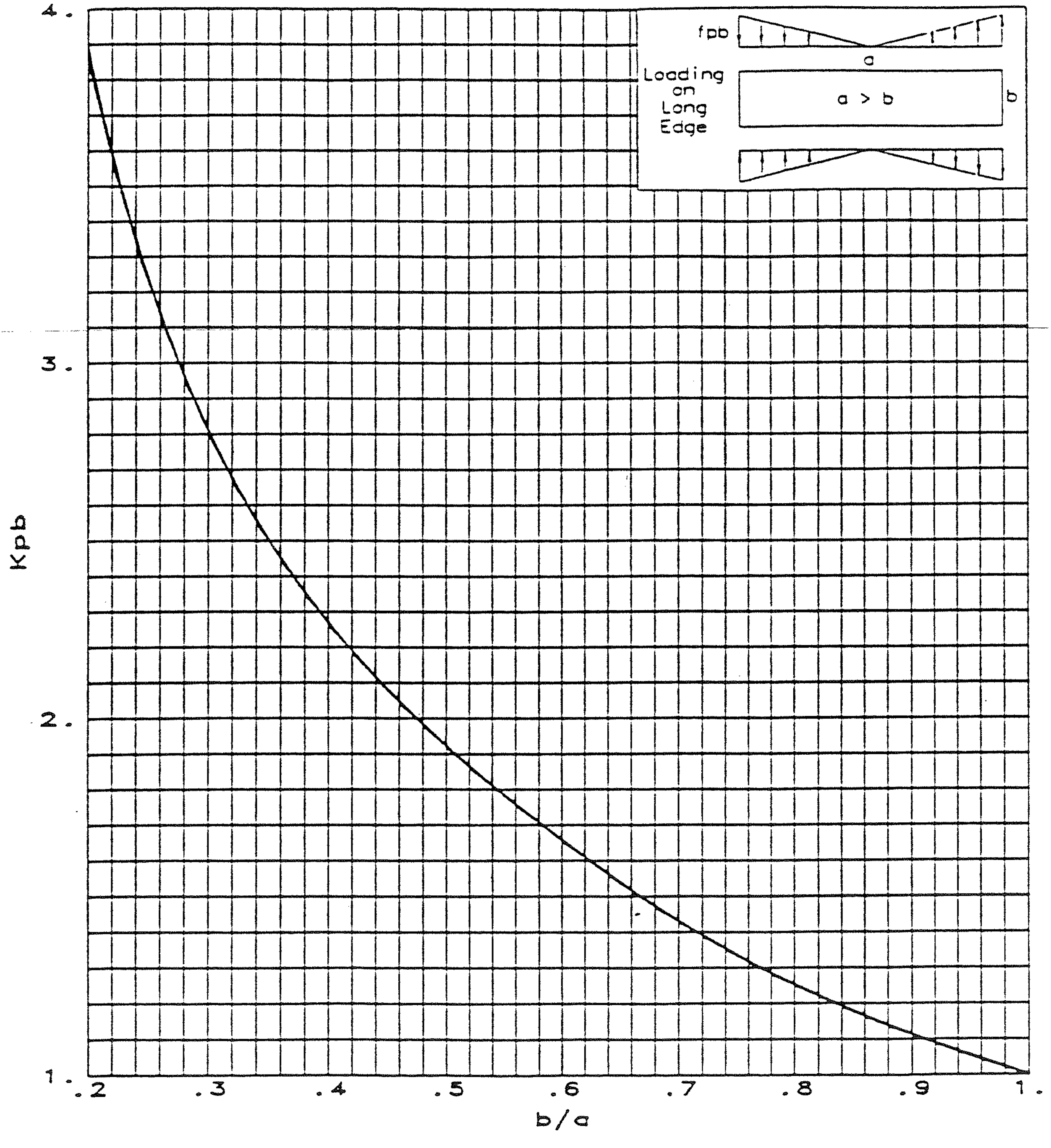
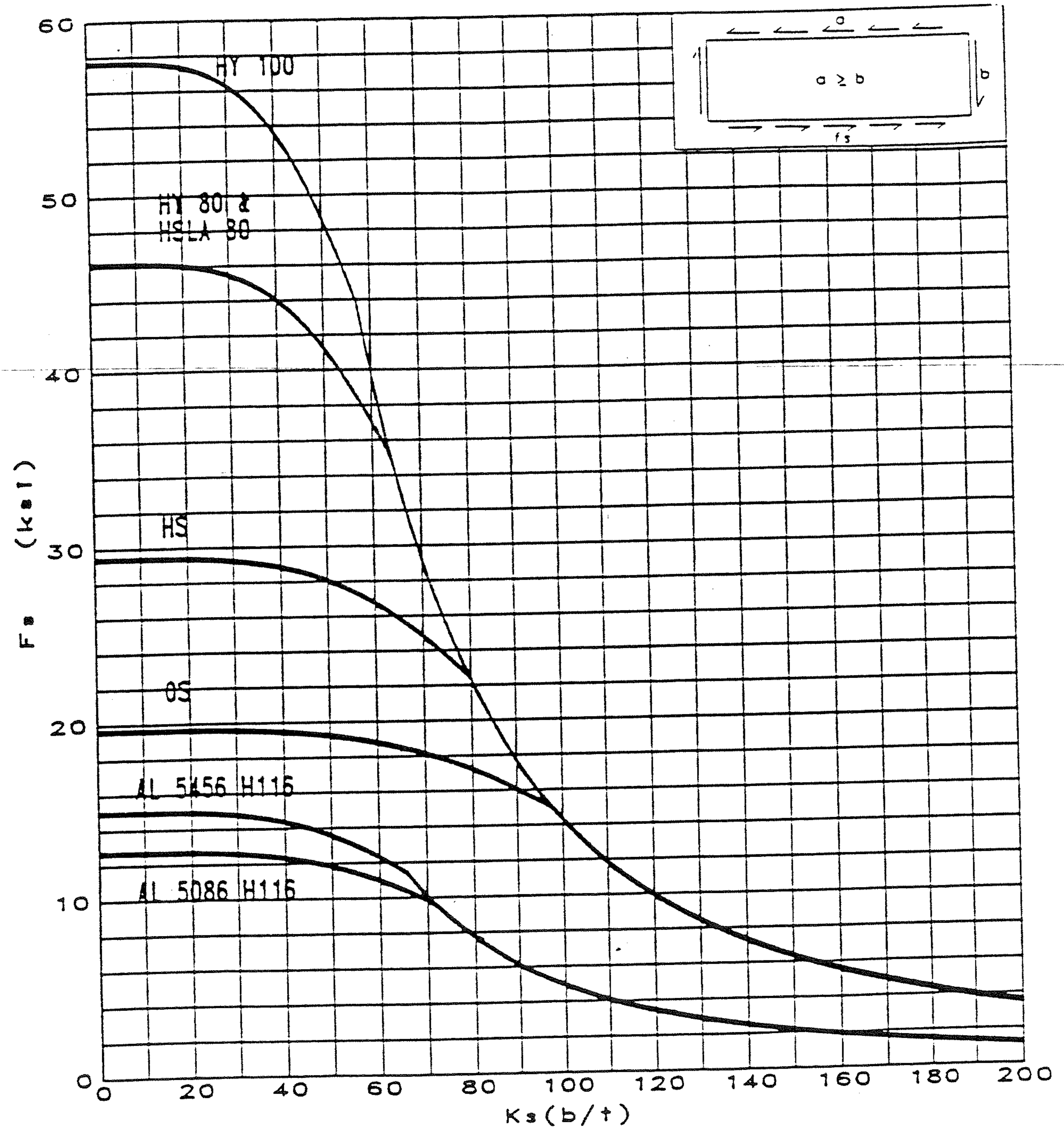


Figure 5b: Plate Buckling Coefficient, K_{pb}
In-Plane Bending on Long Edge



FOR K_s SEE FIGURE 6b

Figure 6a: Plate Buckling Strength, F_s
Edge Shear

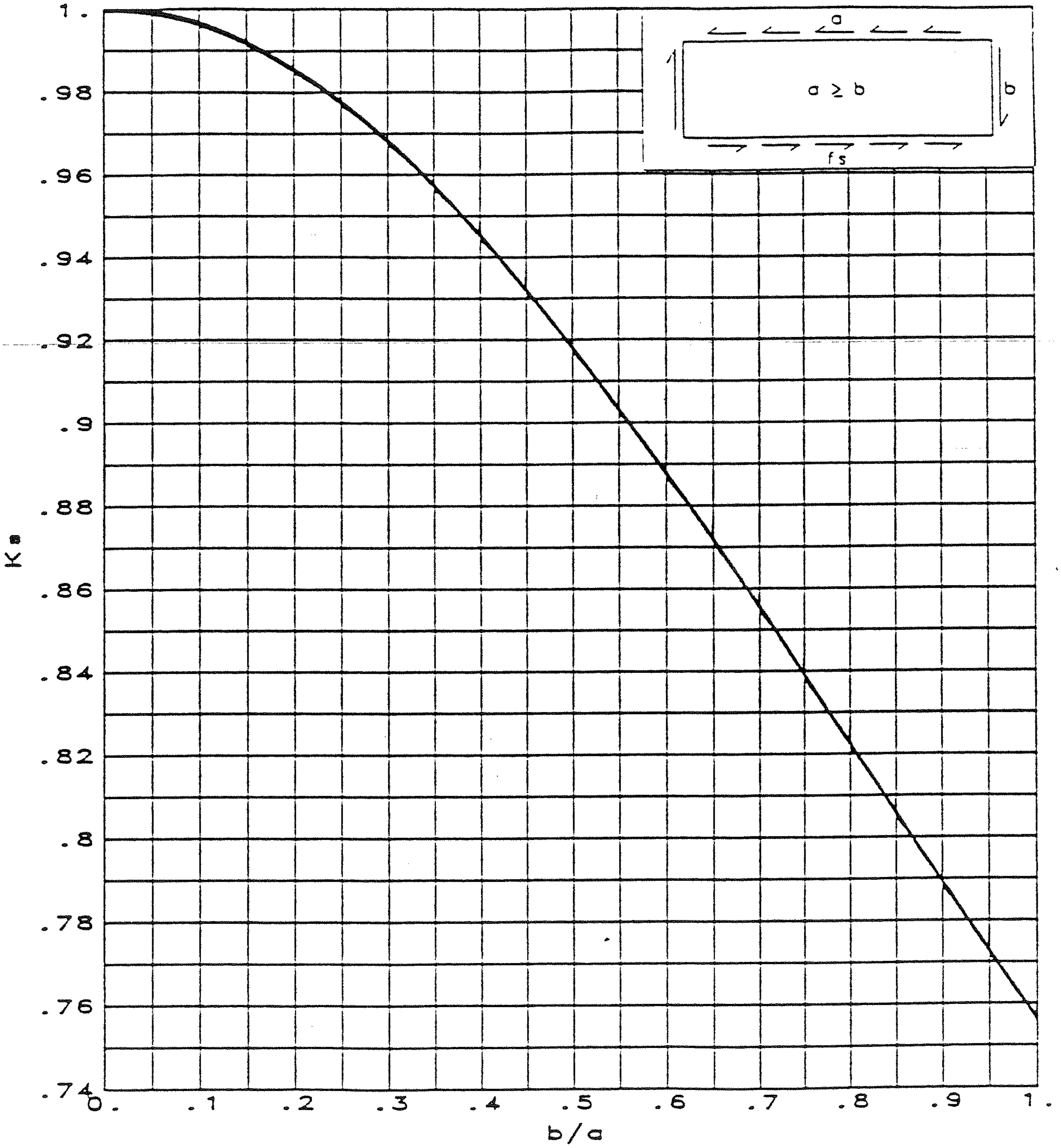
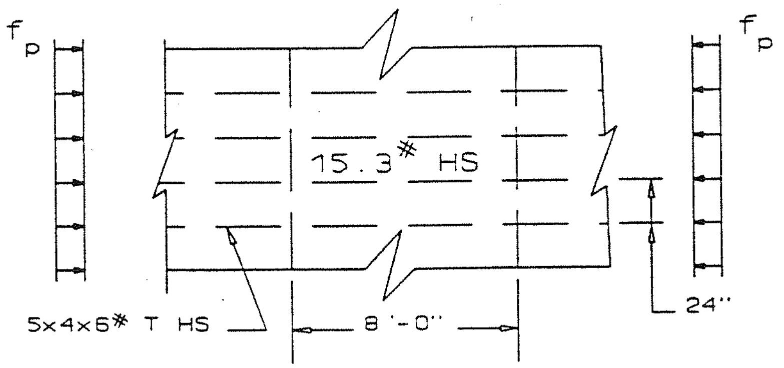


Figure 6b: Plate Buckling Coefficient, K_s
Edge Shear

APPENDIX A
EXAMPLES

Example 1. Column Strength, Lateral Support Requirements, Ultimate Strength of Plating (100-4-e, 100-4-f, 100-4-g, 100-4-h)

Given the longitudinally framed strength deck structure shown, compute (a) column strength, F_c, (b) lateral support requirements to prevent tripping, and (c) ultimate compressive strength of plating.



For HS material from Table 2, F_y = 51 ksi, F_{PL} = 38.8 ksi, $\pi^2E/12(1 - \mu^2)$ = 26753 ksi, and $\sqrt{(F_y/E)}$ = 0.0415.

(a) Column Strength (100-4-e, 100-4-f)

From 100-4-f, effective breadth, b_e, is the lesser of 50 x 0.375" = 18.75" or the average of stiffener spacing on either side b = 24", therefore b_e = 18.75". From reference (d), the radius of gyration, r, is 1.65" for this member.

The slenderness ratio K_c L/r is 1.0 x 96"/1.65" = 58.2, and the column factor, C = (K_c L/r) $\sqrt{(F_y/E)}$ is 58.2 x 0.0415 = 2.42. Since 2.42 is between 1.4 and 4.8, the column has intermediate slenderness and F_c is given by $F_c = F_y$ [1.235 - 0.168C].

Thus, F_c = 51 ksi x [1.235 - 0.168 x (2.42)] = <u>42.3 ksi</u>

(b) Lateral Support Requirements to Prevent Tripping (100-4-f)

From reference (d), the stiffener has the following dimensions: $d = 4.94"$, $b_f = 3.96"$, $t_f = 0.210"$, and $t_w = 0.190"$.

The tripping length, L_t can be obtained using the formula:

$$L_t = \frac{1.283 b_f}{\sqrt{(F_y/E)}\ [1 + 0.333(d/b_f)\ (t_w/t_f) - 0.128(t_f/d)^2\ E/F_y]^{1/2}}$$

Computing applicable ratios: $t_f/d = 0.210"/4.94" = 0.0425$, $t_w/t_f = 0.190"/0.210" = 0.905$, $d/b_f = 4.94"/3.96" = 1.248$.

Computing tripping length:

$$L_t = \frac{1.283\ (3.96")}{0.0415\ [1 + 0.333\ (1.248)\ (0.905) - .128\ (.0425)^2\ (580.4)]^{1/2}}$$

$$= \underline{110"}$$

Since the permissible length, $L_t = 110"$ is greater than the actual span length $L = 96"$, intermediate lateral support is not required.

(c) Ultimate Compressive Strength of Plating (100-4-g)

Calculating breadth to thickness ratio: $b/t = 24"/0.375" = 64.0$, plate's slenderness ratio, $\beta = b/t \sqrt{(F_y/E)} = 64.0 \times 0.0415 = 2.66$.

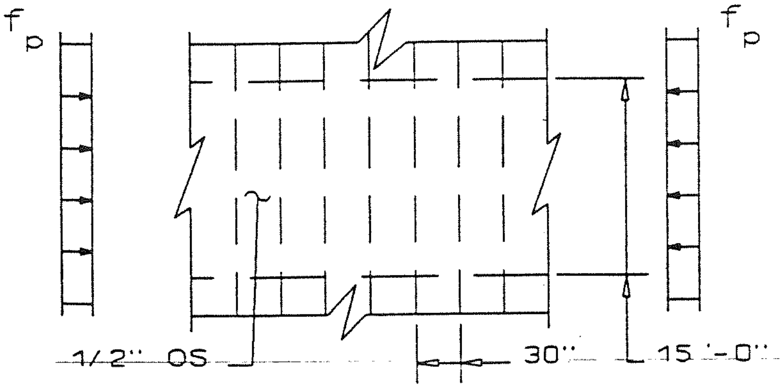
Since 2.66 is greater than 1.25, F_u is calculated using the following formula:

$$F_u = F_y \left[\frac{2.25}{\beta} - \frac{1.25}{\beta^2} \right].$$

$$F_u = 51\ ksi \left[\frac{2.25}{2.66} - \frac{1.25}{2.66^2} \right] = \underline{34.1\ ksi}$$

Example 2. Plate Buckling (Simple Loading on Long Edge) (100-4-h)

Given the transversely framed strength deck structure shown, compute plate buckling strength, F_p.



For OS material, from Table 2, $F_y = 34$ ksi and $F_{PL} = 25.8$ ksi.

Determining the plate buckling coefficient, $b/a = 30"/180" = 0.167$. From Table 4 for uniform compression on the long edge:

$$K = [1 + (b/a)^2]^2$$

$$K = [1 + (0.167)^2]^2 = 1.06$$

Computing F_{cr}:

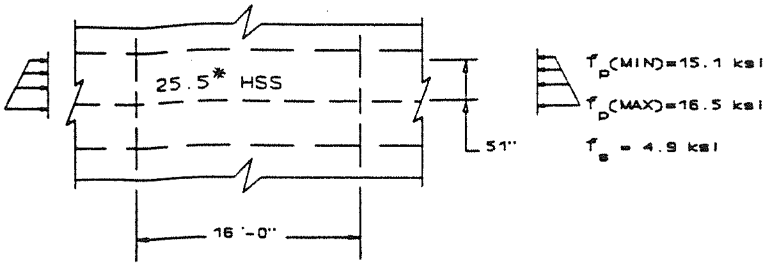
$$F_{cr} = K \frac{\pi^2 E}{12(1 - \mu^2)} \frac{1}{(b/t)^2}$$

$$F_{cr} = 1.06\ (26753 \text{ ksi})\ (0.5"/30")^2 = 7.9 \text{ ksi}$$

Since $F_{cr} = 7.9$ ksi is less than $F_{PL} = 25.8$ ksi, $F_p = F_{cr} =$ 7.9 ksi.

Example 3 Plate Buckling (Combined Loading on Short Edge) (100-4-h)

Evaluate the plate buckling strength of the panel of longitudinally framed side shell structure shown.



From Table 2, F_y = 51 ksi, F_{sy} = 29.4 ksi, F_{PL} = 38.8 ksi, .76 F_{sy} = 22.4 ksi, and $\pi^2 E/12\ (1 - \mu^2)$ = 26753 ksi.

Resolving the net stresses into uniform compression and in-plane bending components:

f_{pc} = ½ (16.5 ksi + 15.1 ksi) = 15.8 ksi

f_{pb} = ½ (16.5 ksi - 15.1 ksi) = 0.7 ksi

Check, $f_p + f_{pb}$ = 16.5 ksi = f_p (max)

Computing breadth to thickness ratio, b/t = 51"/0.625 = 81.6. Computing plate buckling strengths F_p, F_{pb}, and F_s for component loadings using the following formula:

$$F_{cr} = K \frac{\pi^2 E}{12(1 - \mu^2)} \frac{1}{(b/t)^2}$$

For uniform compression on short edge, K = 4 from Table 4.

$$F_{cr} = 4\ (26753\ \text{ksi})\ (1/81.6)^2 = 4\ (4.02\ \text{ksi}) = 16.1\ \text{ksi}$$

Since F_{cr} = 16.1 ksi is less than F_{PL} = 38.8 ksi,
$F_p = F_{cr}$ = <u>16.1 ksi</u>.

For in-plane bending on short edge, K = 24 from Table 4.

$$F_{cr} = 24\ (4.02\ \text{ksi}) = 96.4\ \text{ksi}$$

Since 96.4 ksi is greater than F_{PL} = 38.8 ksi,

$$F_{pb} = \frac{51\ \text{ksi}}{1 + .1824\ (51/96.4)^2} = \underline{48.5\ \text{ksi}}$$

For edge shear, b/a = 51"/192" = 0.266. From Table 4, K = [5.34 + 4(0.266)^2] = 5.62.

$$F_{cr} = 5.62\ (4.02\ \text{ksi}) = 22.6\ \text{ksi}$$

Since 22.6 is greater than F_{PL} = 22.4 ksi,

$$F_s = \frac{29.4}{1 + .1824\ (29.4/22.6)^2} = \underline{22.5\ \text{ksi}}$$

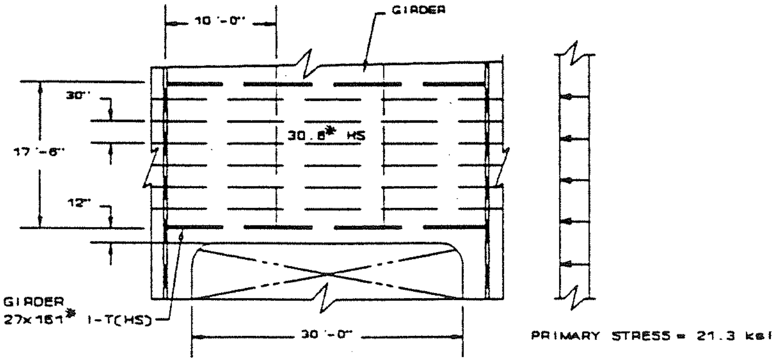
Checking interaction:

$$f_{pc}/F_p + (f_{pb}/F_{pb})^2 + (f_{ps}/F_s)^2 \leq 1.0$$

$$15.8/16.1 + (0.7/48.5)^2 + (4.9/22.5)^2 = \underline{1.0} \quad 1.0\ \text{O.K.}$$

Example 4. Plate-Stiffener Combination in Bending and Compression (100-4-i)

Given the longitudinal deck girder along the hatch opening shown with primary stress equal to 21.3 ksi and bending moments due to distributed lateral deck loading as shown. Determine effective plating breadth, b_e, and calculated compressive stress in plating, f_p, according to (a) shear lag approach and (b) post buckling approach.



END MOMENT = 4860 K-in
CENTER SPAN MOMENT = 2025 K-in

(a) Shear Lag Approach

Load is distributed, therefore maximum effective breadth is 360"/4 = 90", or 45" per side. Since only 12" exists on the opening side, b_e = 12" + 45" = 57".

Girder lies along an opening, therefore effective breadth is limited to b/2 = 17.5'/2 = 105".

Since 57" is less than 105", effective breadth is <u>57"</u>.

Effective section modula are as follows:

to flange 1105 in^3
to plate 526 in^3

Calculated secondary compressive stress is bending moment divided by section modulus as follows:

in plate: 2025 $k\text{-}in/1105\ in^3 = 1.8$ ksi
in flange: 4860 $k\text{-}in/526\ in^3 = 1.8$ ksi

Calculated compressive stress in plate is as follows:

$f_p = 21.3 + 1.8 = 23.1$ ksi

Checking plate buckling using Figure 5a:

for $b/t = 30"/0.75" = 40.0$,
$F_p = 46$ ksi $> f_p = 23.1$ ksi

Therefore effective breadth based on shear lag may be assumed in this case.

For f_p add secondary plate stress of deck stiffener lying within the effective breadth of the longitudinal girder.

Note that the girder must be checked for combined bending and compression according to the governing ship specifications.

(b) Post Buckling Approach

Maximum effective breadth is $50t = 50(0.75") = 37.5"$, or 18.75" per side. Similar to part (a), $b_e = 12" + 18.75" = 30.75"$.

Effective breadth is limited to $1/3(30) + 12 = 27"$.

Since 30.75" is greater than 27", effective breadth is 27".

Effective section moduli are as follows:

to flange 660 in^3
to plate 493 in^3

Calculated secondary compressive stress is determined as in part (a).

in plate: 2025 k-in/660 in^3 = 3.1 ksi
in flange: 4860 k-in/493 in^3 = 9.9 ksi

Calculated compressive stress in plate is as follows:

$f_p = 21.3 + 3.1 = 24.4$ ksi

Effective breadth by post-buckling approach is generally a more conservative method for computing the secondary bending stresses.

APPENDIX B

SELECTED MEASUREMENT UNITS AND CONVERSION FACTORS

This design data sheet establishes strength requirements both in Inch-Pound and SI units. Measurement units recommended for use as well as the pertinent conversion factors are compiled in Table A.

TABLE A: SELECTED SI CONVERSION FACTORS

Category	To Convert From Inch-Pound Units	To SI Units	Multiply By	
LENGTH:	foot (ft)	meter (m)	0.3048	
	inch (in)	meter (m)	2.540	10^{-2}
	inch (in)	mm	25.4	
AREA:	foot^2 (ft^2)	meter^2 (m^2)	9.290	10^{-2}
	inch^2 (in^2)	mm^2	6.452	10^{-2}
FORCE:	kip	newton (N)	4.448	10^3
	pound-force (lbf)	newton (N)	4.448	
MASS:	pound (lb)	kilogram (kg)	.454	
	ton (long, 2240 lb)	metric ton	1.016	
STRESS:	kip/inch^2 (ksi)	pascal (Pa)	6.895	10^6
FORCE/AREA)	pound-force/inch^2 (psi)	pascal (Pa)	6.895	10^3

SI makes extensive use of prefixes to form decimal multiples; it officially establishes 16 prefixes. Those 5 prefixes most frequently used are as follows:

mega	M	1 000 000 = 10^6
kilo	k	1 000 = 10^3
centi	c	0.01 = 10^{-2}
milli	m	0.001 = 10^{-3}
micro	μ	0.000 001 = 10^{-6}