2.2 CURVED PLATES.

Design information is presented in this section for the prediction of buckling in plates of single curvature which are both stiffened and unstiffened.

2.2.1 UNSTIFFENED CURVED PLATES.

2.2.1.1 Compression Buckling.

The behavior of curved plates uniformly compressed along their curved edges is similar in many respects to that of a circular cylinder under axial compression (e.g., both buckle at stresses considerably below the predictions of small deflection theory, and it is necessary to resort to semi-empirical methods to show agreement with the available test results).

It is recommended that the methods for predicting buckling of axially compressed monocoque cylinders (Section C3.1.1) be used to predict buckling of curved plates.

2.2.1.2 Shear Buckling.

Critical shear buckling stresses for curved plates are calculated by the following formula:

$$F_{s_{cr}} = \frac{k_s \eta \pi^2 E}{12(1-\nu_e^2)} \left(\frac{t}{b}\right)^2 \qquad (39)$$

where k is determined from Fig. C2-68, and $\eta = \sqrt{E_T/E}$.

2.2.2 STIFFENED CURVED PLATES IN COMPRESSION.

Information is presented in the following paragraphs for stiffened plates of single curvature in compression where the stiffening members are either axial or circumferential. In these considerations, both the local and general modes of instability must be considered.

2.2.2.1 Curved Plates With Axial Stiffeners.

A method for predicting buckling of simply supported curved plates with a single central axial stiffener has been developed in Reference 29. This method is similar to that presented in Paragraph 2.1.2.1 for stiffened flat plates in compression, in that the same basic equation is used in conjunction with specified buckling coefficients. However, in the present case, the buckling coefficients for the local and the general modes of instability are shown on the same chart. Figures C2-69a through C2-69d present these coefficients, which may be used with the following equation to predict buckling when $Z_b \leq 0.25$:

$$F_{c_{cr}} = \frac{k_c \pi^2 E}{12(1 - \nu_e^2)} \left(\frac{t}{b}\right)^2 \tag{40}$$

This equation may also be written as

$$F_{c_{cr}} = \frac{k_c \pi^2 E}{12\sqrt{1 - \nu_e^2}\; Z_b \left(\frac{R}{t}\right)} \tag{41}$$

where Z_b is the plate curvature parameter, $\frac{b^2}{Rt}\sqrt{1 - \nu_e^2}$; R is the plate radius of curvature; and b is the half-width of the loaded (curved) edge of plate.

Figures C2-69a through C2-69d yield buckling coefficients as a function of Z_b, A/bt, and EL_s/bD for values of the ratio a/b equal to 4/3, 2, 3, and 4, respectively, where terms are defined as follows:

- I_s bending moment of inertia of the stiffener cross section taken about the stiffener centroidal axis

  D flexural stiffness of the plate per inch of width, $Et^3/12(1 - \nu_e^2)$

  a length of plate

The sloping portions of the curves to the left in each of the charts of Figs. C2-69a through C2-69d represent designs wherein the general mode of instability is critical. Local instability is represented by the horizontal lines to the right in each chart. The intersection of these curves represents efficient design, since less moment-of-inertia in the stiffener induces general instability and a lowering of the buckling stress, while more moment-of-inertia in the stiffener has no effect on the buckling stress of the stiffened plate.

Although not specifically shown in Fig. C2-69a through C2-69d, the increase in the curved-plate buckling stress, due to the addition of a central axial stiffener, is negligible when $Z_b > 2.5$. Thus, plates with a large degree of curvature are not benefited by stiffening with a central axial member. In this case, buckling stress should be determined by the techniques in Section C3. 1. 1.

Also, the methods cited above should not be applied with two or more axial stiffeners, since the stiffener geometrical requirements needed to satisfy the general mode of instability are sensitive to the number of stiffeners when the number is small. With multiple stiffeners, the methods described for orthotropic cylinders in Section C3. 1. 2 should be used.

2. 2. 2. 2 Curved Plates With Circumferential Stiffeners.

Curved plates stiffened with a single central circumferential stiffener have been considered by Batdorf and Schildcrout [30]. They determined analytically that the addition of a single central circumferential stiffener increases the buckling stress of a curved plate but only within a rather restricted range of plate geometries. This range is a function of both the ratio a/b (where a is the half-length of the plate, b is the width of the curved, loaded edge) and the geometric parameter Z_b. For the buckling stress of the curved plate to increase with the addition of a single central circumferential stiffener, a/b must be 0. 6 or less. The parameter Z_b imposes further restrictions as a function of a/b which are shown in Fig. C2-70. For a given value of a/b, Z_b for the design must be equal to or smaller than that value read from the chart. If Z_b for the design is larger than the value read from the chart, no gain in the buckling stress results from the addition of the stiffener to the curved plate.

Small deflection theory was used in Reference 30 to predict the buckling stress of curved plates with circumferential stiffeners. Consequently, the results are presented in terms of a gain factor which indicates the gain in buckling stress for a stiffened curved plate over an unstiffened curved plate, where the gain is based on theoretical predictions of the buckling stress for both configurations. The information presented here, therefore, may be applied by multiplying the gain factor by the buckling stress for an unstiffened curved plate of the same overall dimensions by methods given in Paragraph 2. 2. 1. 1.

Maximum gain factors are presented as a function of a/b and Z_b in Fig. C2-71. The term "maximum" implies that the stiffener has sufficient bending rigidity to enforce a buckle node at the stiffener line.

The required stiffener bending rigidity needed to enforce a buckle node at the stiffener line is defined in Fig. C2-72 when the figure is entered with a maximum gain factor obtained from Fig. C2-71.

Figure C2-72 may also be used to determine gain factors when an existing stiffener has either more or less bending rigidity than that required to enforce a node along the stiffener line. In this case, the same geometrical limitations stipulated in Fig. C2-70 apply and must be observed. (Note that the gain factors obtained here may not be maximum; therefore, the ordinate of Fig. C2-72 is labeled to take this possibility into account.)

After first referring to Fig. C2-70 to ascertain whether or not a gain is indeed possible, find the gain factor (from Fig. C2-72) based on the properties of the existing stiffener. Now plot this gain factor on Fig. C2-71. If the point is below and to the left of the a/b curve to which it relates, then the gain factor is less than the maximum permissible and the bending rigidity of the stiffener is less than the minimum required. In this case, general instability of the curved plate represents the critical mode, and buckling may be predicted using the gain factor obtained from Fig. C2-70. When the point is above and to the right of the a/b curve in Fig. C2-71 to which it relates, the contrary is true, and local instability of the curved plate represents the critical mode. In this case, buckling may be predicted using the maximum gain factor obtained from the a/b, Z_b intersection in Fig. C2-71.

The methods of this section should not be applied to curved plates with two or more circumferential stiffeners. The general instability stresses predicted by the design charts are sensitive to the number of stiffeners when their total number is small. In this case, recourse should be had to Section C3. 1. 2.

2. 2. 3 STIFFENED CURVED PLATES IN SHEAR.

Methods are presented in the following paragraphs for predicting the buckling stress of plates of single curvature in shear having a single stiffener in either the axial or circumferential direction. The methods account for both the local and general modes of instability, and charts are given that present the buckling coefficient k_s versus EI/bD, where at low values of EI/bD the general mode of instability is critical. As EI/bD increases, the local mode of instability becomes critical and is signified by a constant value of k_s. Thus, to enforce a node at the stiffener, the design must have an EI/bD which falls on the horizontal portion of the design curve. Note that the EI/bD value representing the extreme left point of the horizontal line yields the most efficient design; local and general instability are both critical here.

2.2.3.1 Curved Plates With Axial Stiffeners.

The buckling stress for curved plates with a single, central stiffener may be determined from the equation:

$$F_{c_{cr}} = \eta \frac{k_s \pi^2 E}{12(1 - \nu_e{}^2)} \left(\frac{t}{b}\right)^2 \qquad (42)$$

where k_s is taken from Fig. C2-73, b is the overall dimension of the curved plate, and t is the thickness of the curved plate. Figure C2-73(a) applies when axial length is greater than circumferential width, and Fig. C2-73(b) applies when axial length is less than circumferential width. Note that in both cases, b is denoted the short overall dimension of the plate. Curves are presented as a function of the aspect ratio of the plate, a/b, as well as of the plate curvature parameter, Z_b. Note also that the data of Fig. C2-73 are based on small deflection theory and agree satisfactorily with experimental results except in the case of cylinders for which a 16 percent reduction is recommended.

The preceding method should not be extended to apply to curved plates with multiple axial stiffeners. The bending rigidity required of each stiffener to support general instability is sensitive to the total number of stiffeners when this number is small.

2. 2. 3. 2 Curved Plates With Circumferential Stiffeners.

The buckling stress for curved plates stiffened circumferentially with a single central stiffener may be determined from equation (42) with the buckling coefficients, k_s, taken from Fig. C2-74. As in Fig. C2-73 for a cylinder, a 16 percent reduction of the horizontal portions of the curves (the portion signifying local instability) is recommended.

The data above should not be applied to curved plates with multiple circumferential stiffeners for the reasons noted previously in Paragraph 2. 2. 3. 1.

2. 2. 4 CURVED PLATES UNDER COMBINED LOADING.

Interaction relations for longitudinal compression combined with normal pressure, shear combined with normal pressure, and longitudinal compression combined with shear are presented in the following paragraphs for unstiffened, curved plates. Interaction relations for stiffened, curved plates are presently unavailable; however, techniques discussed in Section C3. 1. 2 may be used. The normal pressure in the first two cases is applied to the concave face of the curved plate. The interaction relations apply only to elastic stress conditions, since verification of their application to plastic stress conditions is lacking at present.

2.2.4.1 Longitudinal Compression Plus Normal Pressure.

The interaction equation for longitudinal compression plus normal pressure applied to the concave face of an unstiffened curved plate is

$$R_c^2 - R_p = 1 \tag{43}$$

where $R_c = F_c/F_{c_{cr}}$ and $R_p = p/p_{cr}$, where the following definitions apply:

F_c applied longitudinal compression stress

$F_{c_{cr}}$ buckling stress of the curved plate where subjected to simple axial compression, determined by the methods of Section 2.2.1.1

p absolute value of the applied normal pressure

p_{cr} absolute value of the external pressure which would buckle the cylinder of which the plate is a section, determined by the methods of Section C3.1.1.5

Note that absolute values of the quantities p and p_{cr} are substituted into the interaction equation since their difference in sign is already accounted for in the equation. It can be seen that normal pressure applied to the concave face of the unstiffened, curved plate increases the axial compression load which may be carried by the plate prior to buckling.

2.2.4.2 Shear Plus Normal Pressure.

When an unstiffened curved plate is subjected to shear combined with normal pressure acting on the concave face of the plate, the following interaction equation applies:

$$R_s^2 - R_p = 1 \tag{44}$$

where $R = F_s/F_{s_{cr}}$ (F_s is applied shear stress and $F_{s_{cr}}$ is buckling stress of the curved plate when subjected to simple in-plane shear, determined by the methods of Section 2.2.1.2), and R_p is as previously defined.

2.2.4.3 Longitudinal Compression Plus Shear.

The interaction equation for an unstiffened curved plate subjected to longitudinal compression and shear is

$$R_c + R_s^2 = 1 \tag{45}$$

where R_c and R_s are as defined in previous paragraphs. This relationship represents approximately an average curve through the available experimental results while the lower bound of the test results may be represented by a linear relation between R_c and R_s.

Table C2-1. Values of Material Properties

Material	Temp Exp (hr)	Temp (°F)	e (%)	F_{TU} (ksi)	F_{cy} (ksi)	E_c 10^6 ksi	$F_{0.7}$ (ksi)	$F_{0.85}$ (ksi)	n
Stainless Steel									
AISI 301 1/2 Hard Sheet Longitudinal Compression	1/2	R. T.	15	150	58	26.0	48	37	4.4
AISI 301 Full Hard Longitudinal Compression	1/2	R. T.	8	185	85	26.0	77.5	63	5.2
17-7 PH(TH1050) Sheet, Plate and Strip t = 0.01 - 0.125	1/2	R. T.		180	162	29.0	166	145	7.4
Low Carbon and Alloy Steels									
AISI 4130, 4140, 4340 Heat Treated	1/2	R. T.	18.5	150	145	29.0	145	140	25
Heat Resistant Alloys									
A-286 (AMS 5725A)	1/2	R. T.	15	140	95	29.0	93	87	14
Sheet, Plate and Strip	1/2	1000		115	81.7	19.8	81	75	12.5
Inconel-X	1/2	R. T.	20	155	105	31.0	104	100	23.5
	1/2	1200		104	83	23.2	82	78.6	21
Aluminum Alloys									
2014-T6 Extrusions	2	R. T.	7	60	53	10.7	53	50.3	18.5
T ≤ 0.499 in.	2	450		28	21	9.2	20.5	19.5	25

Table C2-1. (Concluded)

Material	Temp Exp (hr)	Temp (°F)	e (%)	F_{TU} (ksi)	F_{cy} (ksi)	$\frac{E_c}{10^3 \text{ ksi}}$	$F_{0.7}$ (ksi)	$F_{0.85}$ (ksi)	n
2024-T81 Clad Sheet Heated Treated, t < 0.064	2	R. T.	5	62	55	10.7	56	51.6	11.2
6061-T6 Sheet, Heat Treated Annealed,	1/2	R. T.	10	42	35	10.1	35	34	31
t < 0.25	1/2	450			20.5	8.5	19.3	17.7	10.9
7075-T6 Bare Sheet and Plate,	2	R. T.	7	76	67	10.5	70	63	9.2
t ≤ 0.50	2	425			25.5	8.1	25.4	23.5	12.1
7075-T6 Extrusions,	2	R. T.	7	75	70	10.5	72	68	16.6
t ≤ 0.25	2	600			8	5.3	6.5	4.3	3.2
7075-T6 Clad Sheet and Plate, t ≤ 0.5	2	R. T.	8	70	64	10.5	64.5	61.6	19.5
Magnesium Alloys									
HK31A-0 Sheet,	1/2	R. T.	12	30	12	6.5	10	8.4	6
t = 0.016 - 0.25	1/2	500		15	9.3	4.94	7.5	5.6	4.2
Titanium Alloys									
Ti-6Al-4V Annealed Bar and	1/2	R. T.	10	130	126	16	127	124.5	43
Sheet, t ≤ 0.187 in.	1/2	600		99	84.5	13	85.5	82	22
	1/2	1000		70	60.6	7.7	61	59.5	36

Table C2-2. Cutoff Stresses for Buckling of Flat Unstiffened Plates

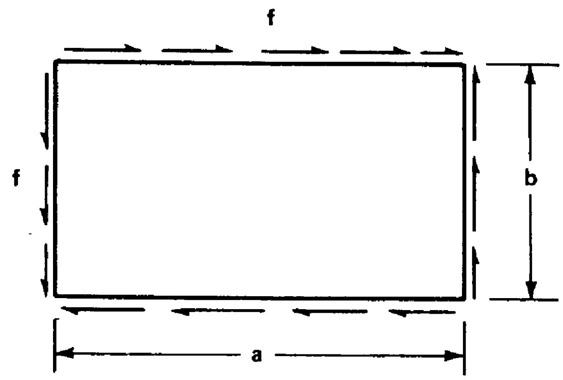
Material	Cutoff Stress: Compression Buckling	Cutoff Stress: Bending Buckling	Cutoff Stress: Shear Buckling F_{cy}
2024-T 2014-T 6061-T	$F_{cy}\left(1 + \frac{F_{cy}}{200\,000}\right)$	$F_{cy}\left(1 + \frac{F_{cy}}{200\,000}\right)$	0.61 0.61 0.61
7075-T	$1.075\ F_{cy}$	$1.075\ F_{cy}$	0.61
18-8(1/2 H)[a]	$0.835\ F_{cy}$	$0.835\ F_{cy}$	0.51
(3/4 H)	$0.875\ F_{cy}$	$0.875\ F_{cy}$	0.53
(FH)	$0.866\ F_{cy}$	$0.866\ F_{cy}$	0.53
All Other Materials	F_{cy}	F_{cy}	0.61

a. Cold-rolled, with grain, based on MIL-HDBK-5 properties.

Table C2-3. Summary of Simplified Cladding Reduction Factors

Loading	$\sigma_{cl} < \bar{\sigma}_{cr} < \sigma_{pl}$	$\bar{\sigma}_{cr} > \sigma_{pl}$
Short Plate Columns	$\frac{1 + \left(\frac{3\beta f}{4}\right)}{1 + 3f}$	$\frac{1}{1 + 3f}$
Long Plate Columns	$\frac{1}{1 + 3f}$	$\frac{1}{1 + 3f}$
Compression and Shear Panels	$\frac{1 + 3\beta f}{1 + 3f}$	$\frac{1}{1 + 3f}$

Table C2-4. Shear Buckling Coefficients for Rectangular Plates with Mixed Boundary Conditions

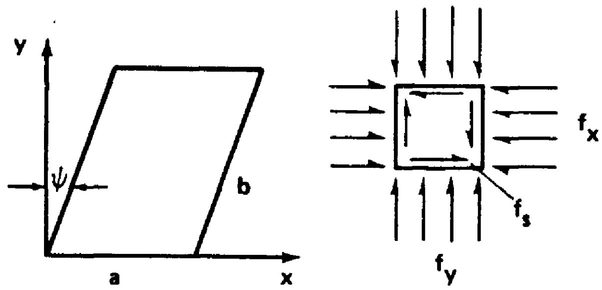


$$\frac{f_{cr}}{\eta} = k_s \frac{\pi^2 E}{12(1-\nu_e^2)} \left(\frac{t}{b}\right)^2$$

NOTE: b IS SMALLER DIMENSION ALWAYS

Edge Conditions	Two Short Edges Clamped, Two Long Edges Simply Supported	One Short Edge Clamped, Three Edges Simply Supported	One Long Edge Clamped, Three Edges Simply Supported
Aspect Ratio b/a	k_s	k_s	k_s
0	5.35	5.35	7.07
0.2	5.58	5.58	
0.333	6.13		7.96
0.5	6.72	6.72	8.43
0.667	7.83	7.59	9.31
0.80	9.34	8.57	9.85
0.90	10.83	9.66	10.38
1.00	12.60	10.98	10.98

Table C2-5. Critical Plate Buckling Parameters for Parallelogram Plates, all Edges Clamped



a/b	ψ	k_x	k_y	k_s	
0.5	0	19.35	32.13	- 42.28	+ 42.28
	15	21.63	34.09	- 34.58	+ 55.36
	30	30.38	39.72	- 31.58	+ 76.90
	45	55.26	53.22	- 40.54	+ 128.3
	60	130.5	86.20	- 85.0	531.5
0.6	0	14.92			
	15	16.49			
	30	22.55			
	45	39.73			
	60	90.50			
0.75	0	11.70			
	15	12.76			
	30	16.71			
	45	27.06			
	60	60.59			
1.0	0	10.08	10.08	- 14.83	14.83
	15	10.87	10.43	- 14.39	17.24
	30	13.58	11.76	- 16.66	23.64
	45	20.44	15.26	- 24.08	32.56
	60	42.14	25.78	- 46.58	69.86
1.25	0	9.25			
	15	9.92			
	30	12.32			
	45	18.50			
	60	38.01			
1.50	0	8.33	5.78	- 11.56	11.56
	15	8.91	6.151	- 12.01	12.73
	30	11.16	7.271	- 14.05	15.19
	45	17.10	10.10	- 20.21	22.37
	60	36.84	18.54	- 40.24	45.83
2.0	0	8.033	4.838	- 10.57	10.57
	15	8.70	5.132	- 10.84	11.10
	30	10.53	6.208	- 13.34	13.73
	45	15.74	8.938	- 19.24	20.35
	60	39.35	17.08	- 39.38	44.40

Table C2-6. Values of k for a Plate Stiffened by One Longitudinal Stiffener

α	$\gamma = 5$			$\gamma = 10$			$\gamma = 15$			$\gamma = 20$			$\gamma = 25$		
	$\delta = 0.05$	$\delta = 0.10$	$\delta = 0.20$	$\delta = 0.05$	$\delta = 0.10$	$\delta = 0.20$	$\delta = 0.05$	$\delta = 0.10$	$\delta = 0.20$	$\delta = 0.05$	$\delta = 0.10$	$\delta = 0.20$	$\delta = 0.05$	$\delta = 0.10$	$\delta = 0.20$
0.6	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
0.8	15.4	14.6	13.0	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8
1.0	12.0	11.1	9.72	16.0	16.0	15.8	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
1.2	9.83	9.06	7.88	15.3	14.2	12.4	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
1.4	8.62	7.91	6.82	12.9	12.0	10.3	16.1	15.7	13.6	16.1	16.1	16.1	16.1	16.1	16.1
1.6	8.01	7.38	6.32	11.4	10.5	9.05	14.7	13.6	11.8	16.1	16.1	14.4	16.1	16.1	16.1
1.8	7.84	7.19	6.16	10.6	9.70	8.35	13.2	12.2	10.5	15.9	14.7	12.6	16.2	16.2	14.7
2.0	7.96	7.29	6.24	10.2	9.35	8.03	12.4	11.4	9.80	14.6	13.4	11.6	16.0	15.4	13.3
2.2	8.28	7.58	6.50	10.2	9.30	7.99	12.0	11.0	9.45	13.9	12.7	10.9	15.8	14.5	12.4
2.4	8.79	8.06	6.91	10.4	9.49	8.15	11.9	10.9	9.37	13.5	12.4	10.6	15.1	13.8	11.9
2.6	9.27	8.50	7.28	10.8	9.86	8.48	12.1	11.1	9.53	13.5	12.4	10.6	14.8	13.6	11.6
2.8	8.62	7.91	6.31	11.4	10.4	8.94	12.5	11.5	9.85	13.7	12.6	10.8	14.8	13.6	11.6
3.0	8.31	7.62	6.53	12.0	11.1	9.52	13.1	12.0	10.3	14.1	13.0	11.1	15.2	13.9	11.9
3.2	8.01	7.38	6.32	11.4	10.5	9.05	13.9	12.7	10.9	14.8	13.5	11.6	15.6	14.3	12.3
3.6	7.84	7.19	6.16	10.6	9.70	8.35	13.2	12.2	10.5	15.9	14.7	12.6	16.2	15.7	13.5
4.0	7.96	7.29	6.24	10.2	9.35	8.03	12.4	11.4	9.8	14.6	13.4	11.6	16.0	15.4	13.3

Table C2-7. Values of k for Two Longitudinal Stiffeners Dividing the Plate into Three Equal Parts

α	$\gamma = \frac{10}{3}$		$\gamma = 5$		$\gamma = \frac{20}{3}$		$\gamma = 10$	
	$\delta = 0.05$	$\delta = 0.10$	$\delta = 0.05$	$\delta = 0.10$	$\delta = 0.05$	$\delta = 0.10$	$\delta = 0.05$	$\delta = 0.10$
0.6	26.8	24.1	36.4	33.2	36.4	36.4	36.4	36.4
0.8	16.9	15.0	23.3	20.7	29.4	26.3	37.2	37.1
1.0	12.1	10.7	16.3	14.5	20.5	18.2	28.7	25.6
1.2	9.61	8.51	12.6	11.2	15.5	13.8	21.4	19.0
1.4	8.32	7.36	10.5	9.32	12.7	11.3	17.2	15.2
1.6	7.70	6.81	9.40	8.31	11.1	9.82	14.5	12.8
1.8	7.51	6.64	8.85	7.83	10.2	9.02	12.9	11.4
2.0	7.61	6.73	8.70	7.69	9.78	8.65	11.9	10.6

Table C2-8. Limiting Values of γ For One, Two, and Three Transverse Stiffeners

α	0.5	0.6	0.7	0.8	0.9	1.0	1.2	$\sqrt{2}$
One Rib	12.8	7.25	4.42	2.82	1.84	1.19	0.435	0
Two Ribs	65.5	37.8	23.7	15.8	11.0	7.94	4.43	2.53
Three Ribs	177	102	64.4	43.1	30.2	21.9	12.6	7.44

Table C2-9. Limiting Values of the Ratio γ For Plate With One Stiffener Under Shearing Stress

a/b	1	1.25	1.5	2
$\gamma = EI/Da$	15	6.3	2.9	0.83

Table C2-10. Limiting Values of the Ratio γ For Plate With Two Stiffeners Under Shearing Stress

a/b	1.2	1.5	2	2.5	3
$\gamma = EI/Da$	22.6	10.7	3.53	1.37	0.64

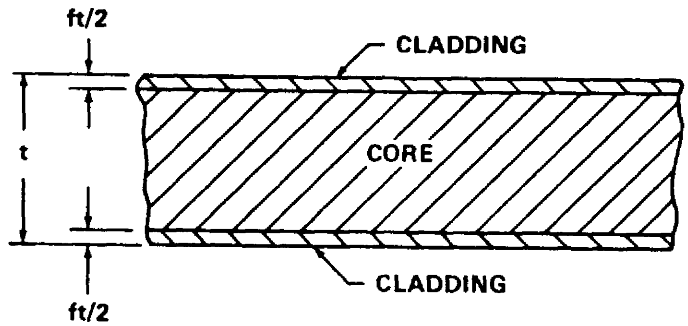


FIGURE C2-1. ALUMINUM CLADDING

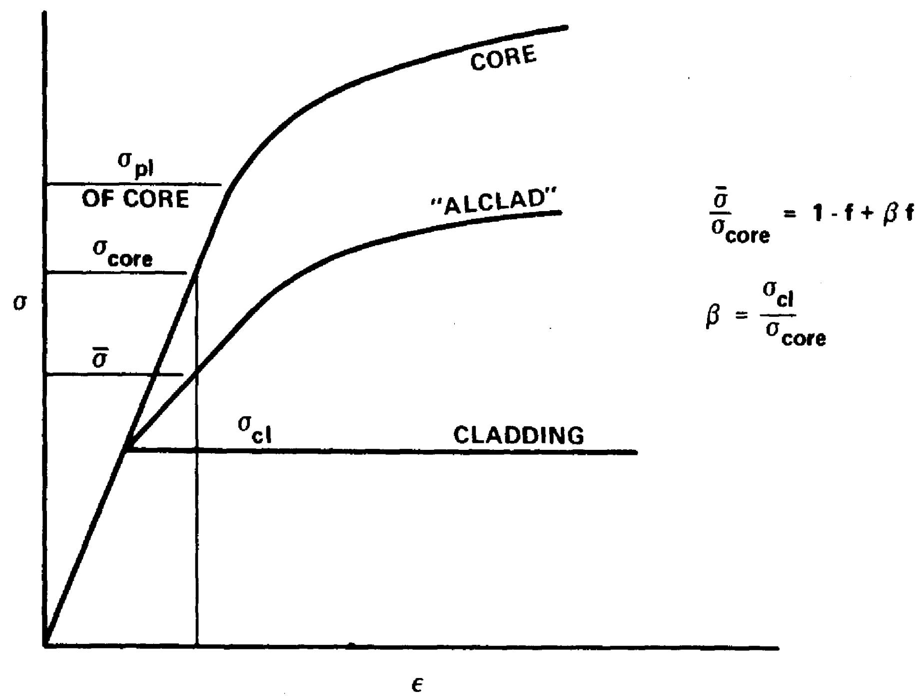


FIGURE C2-2. STRESS-STRAIN CURVES FOR CLADDING, CORE, AND "ALCAD" COMBINATIONS

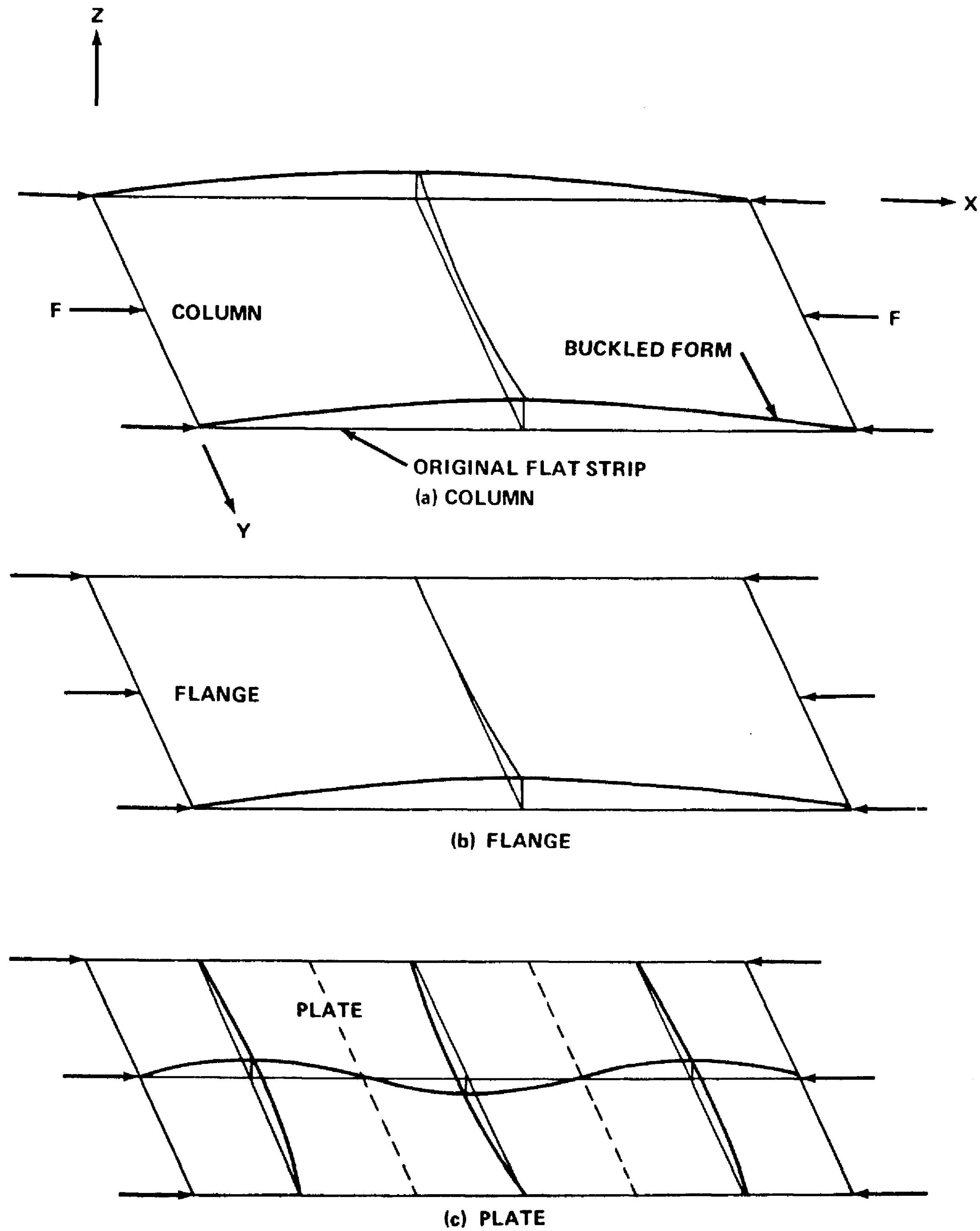
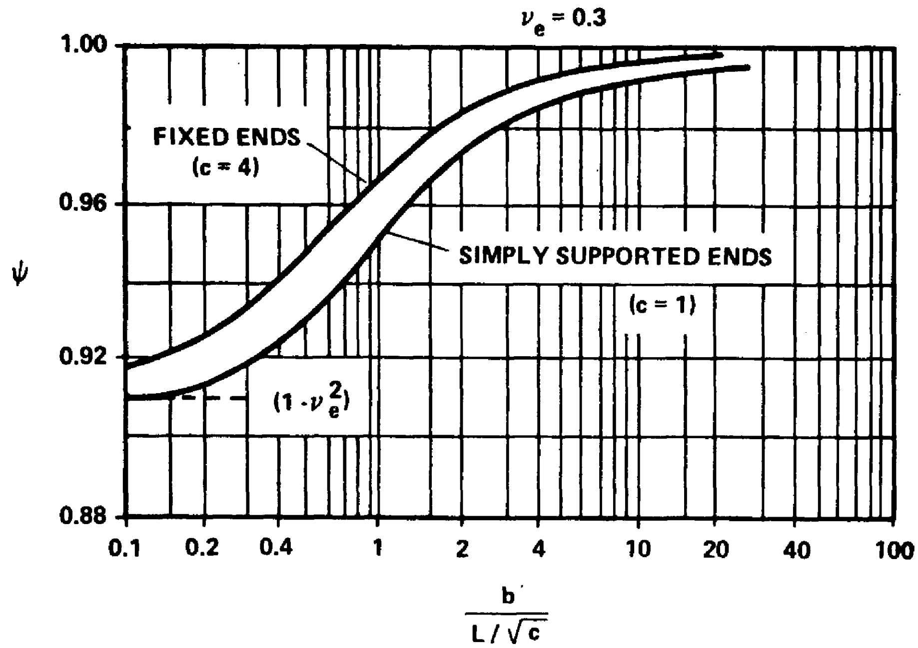


FIGURE C2-3. TRANSITION FROM COLUMN TO PLATE AS SUPPORTS ARE ADDED ALONG UNLOADED EDGES (Note changes in buckle configurations.)



$$\frac{f_{cr}}{\eta} = c \, \frac{\psi}{1 - \nu_e^2} \, \frac{\pi^2 E}{12} \left[\frac{t}{L} \right]^2$$

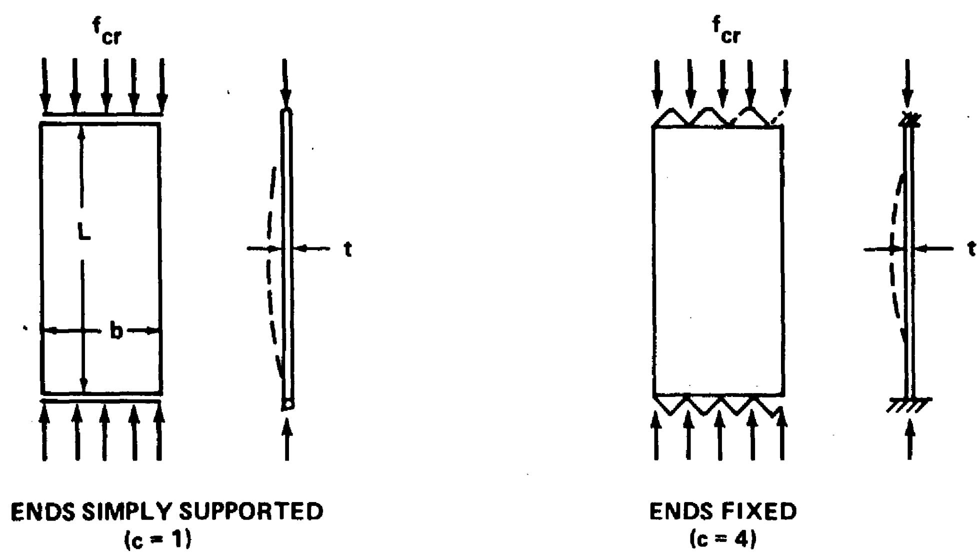


FIGURE C2-4. CRITICAL COMPRESSIVE STRESS FOR PLATE COLUMNS

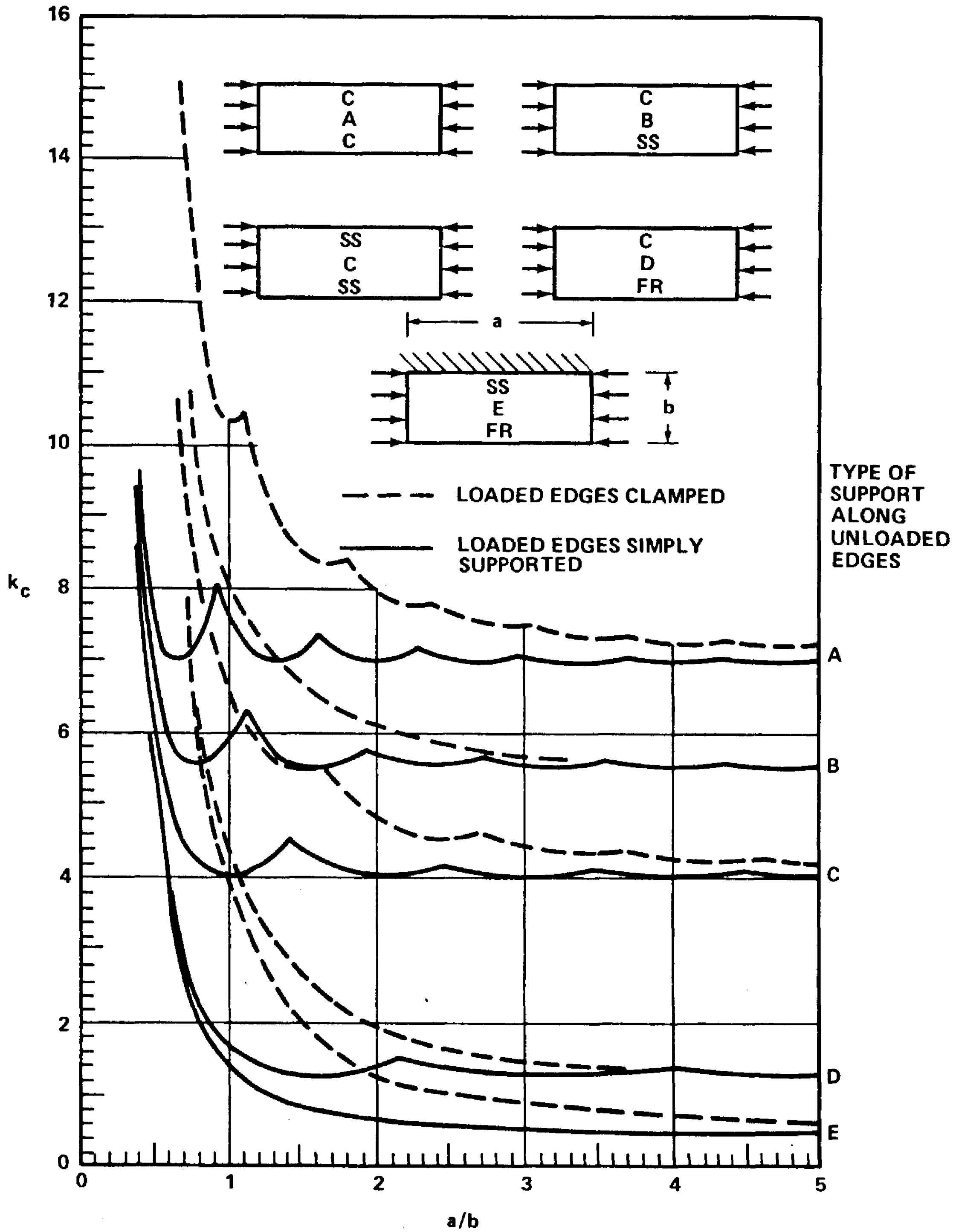


FIGURE C2-5. COMPRESSIVE-BUCKLING COEFFICIENTS FOR FLAT RECTANGULAR PLATES

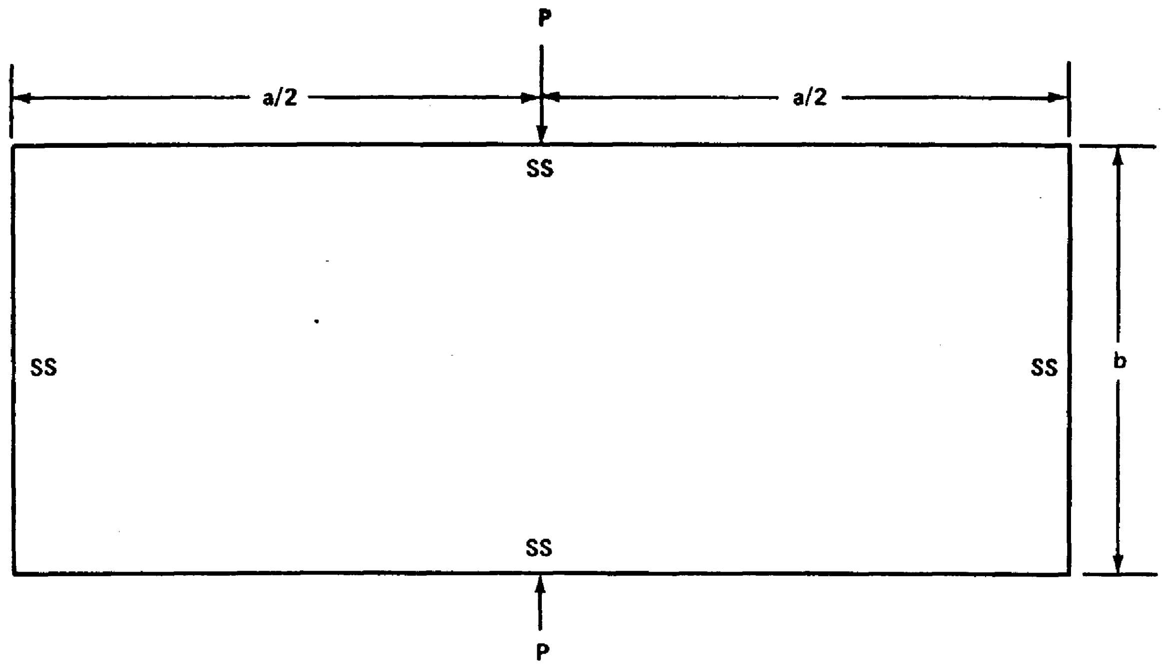


FIGURE C2-6. PLATE WITH CONCENTRATED LOAD

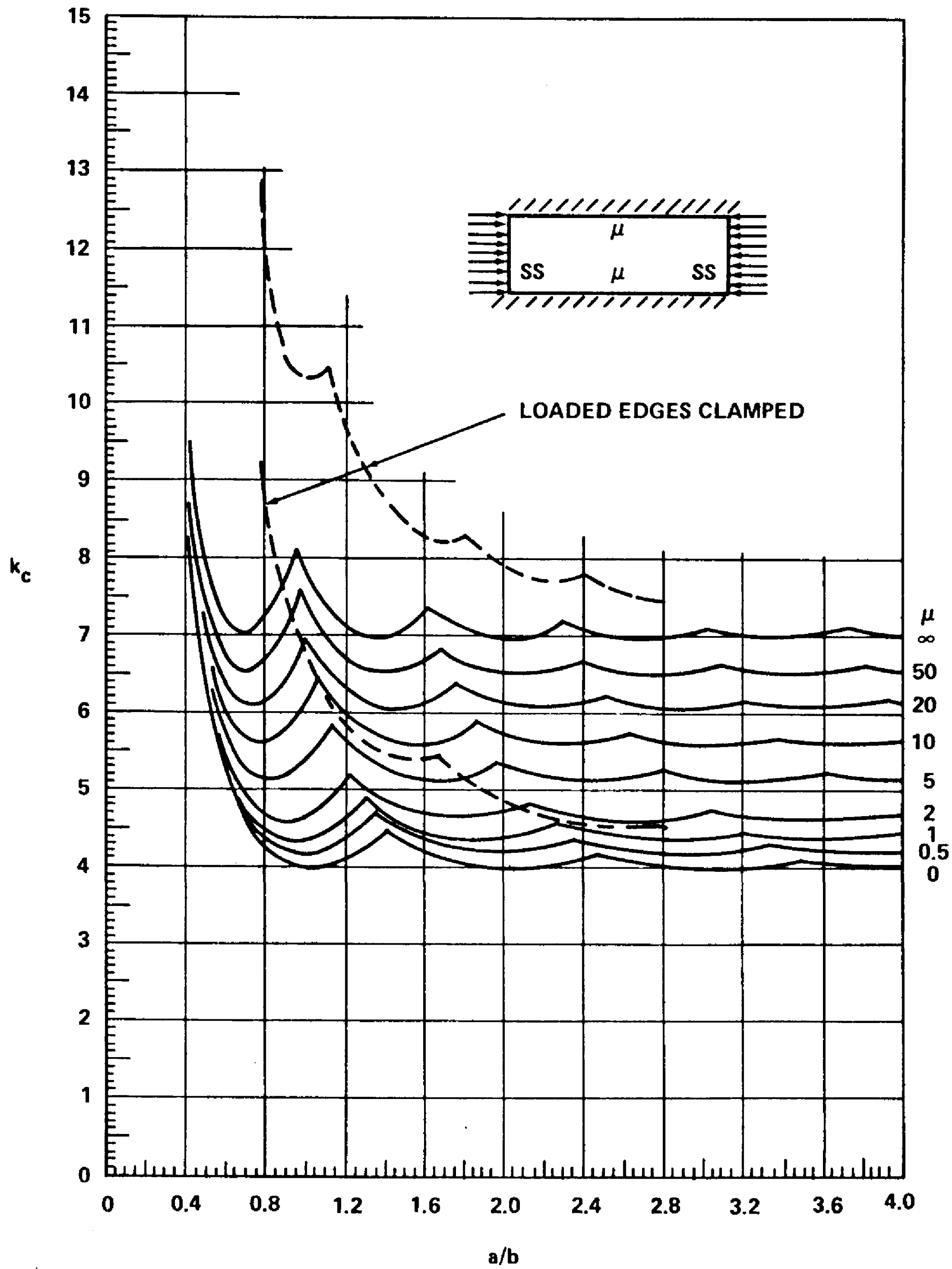


FIGURE C2-7. COMPRESSIVE-BUCKLING-STRESS COEFFICIENT OF PLATES AS A FUNCTION OF a/b FOR VARIOUS AMOUNTS OF EDGE ROTATIONAL RESTRAINT

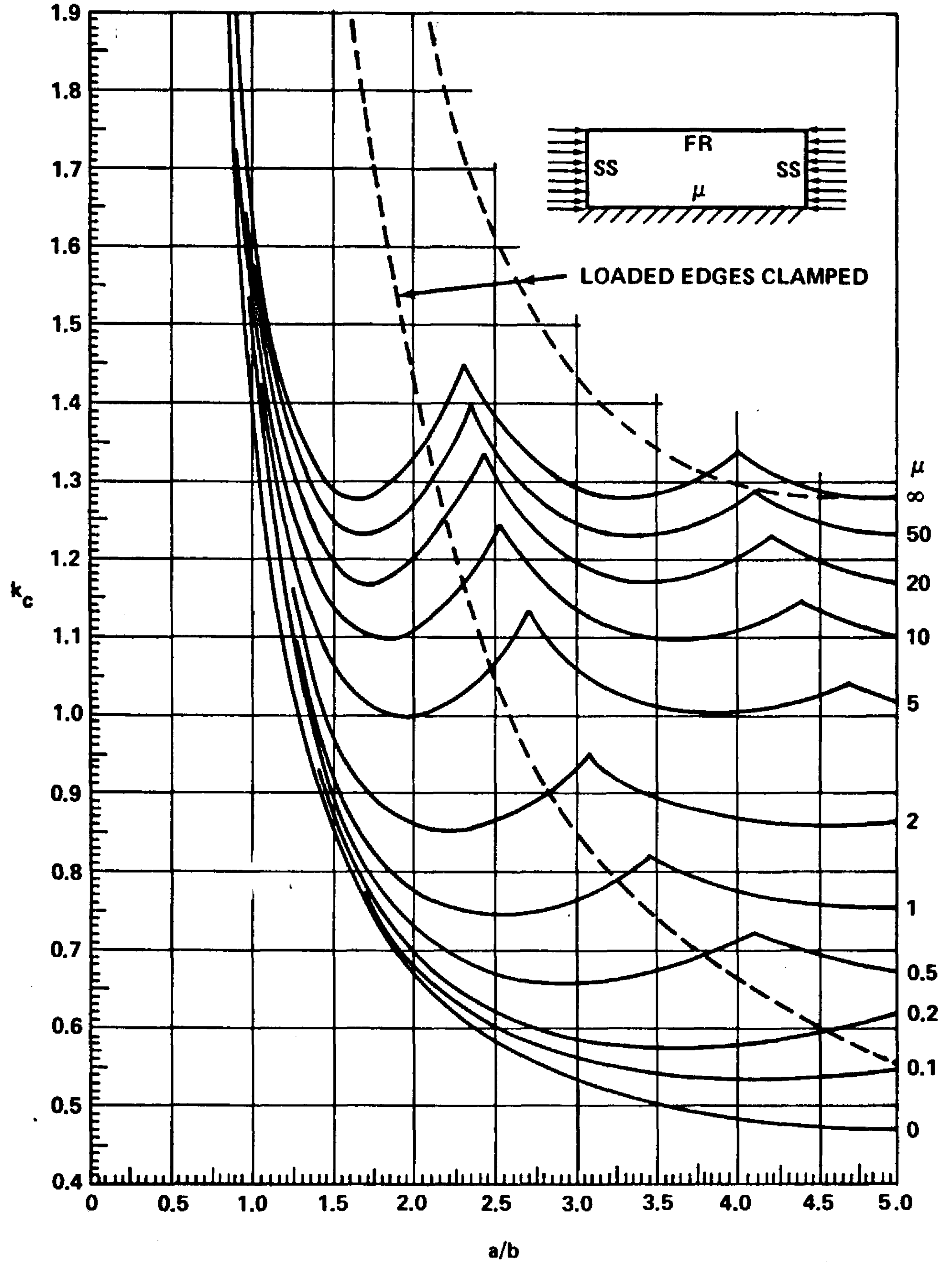


FIGURE C2-8. COMPRESSIVE-BUCKLING-STRESS COEFFICIENT OF FLANGES AS A FUNCTION OF a/b FOR VARIOUS AMOUNTS OF EDGE ROTATIONAL RESTRAINT

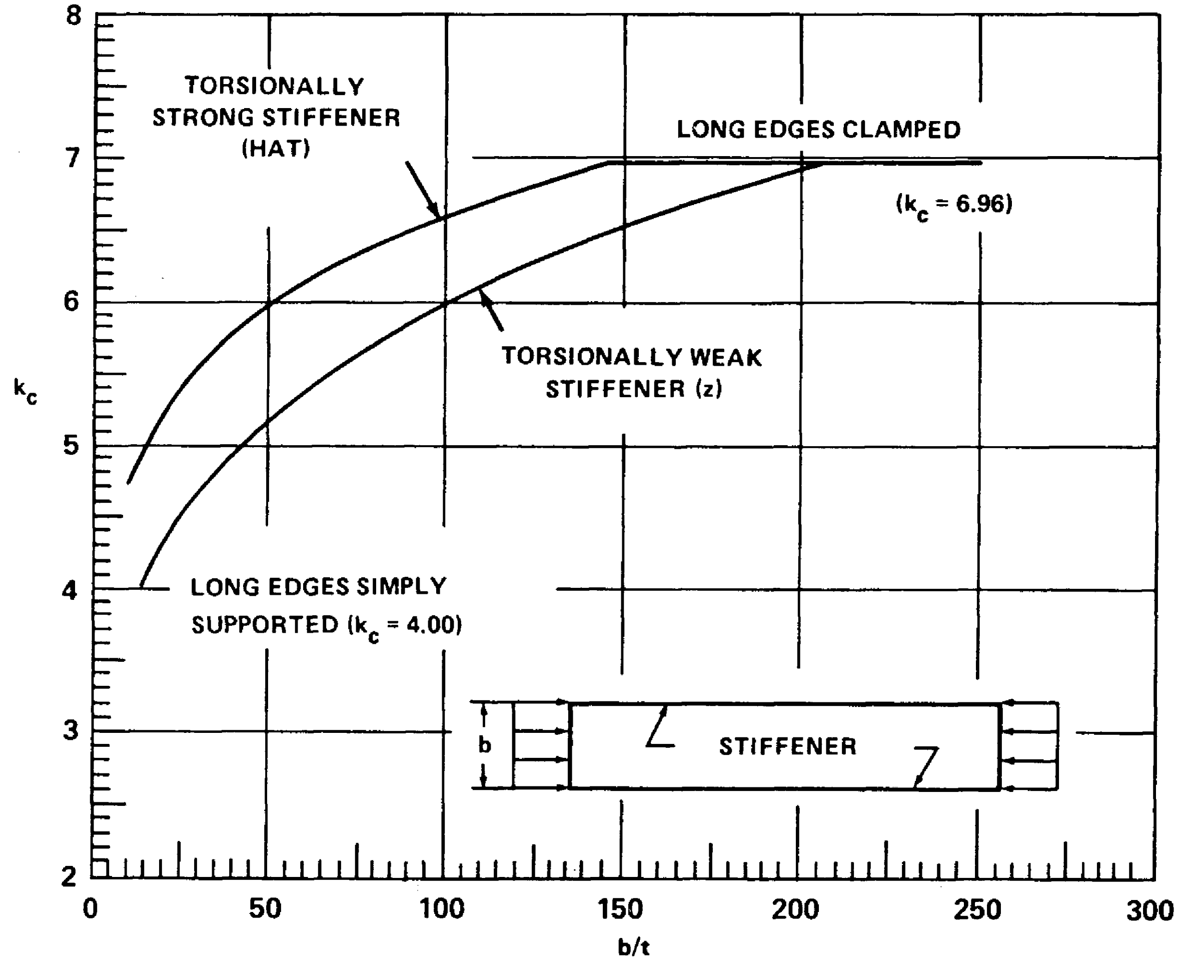


FIGURE C2-9. COMPRESSIVE-BUCKLING COEFFICIENT FOR LONG RECTANGULAR STIFFENED PANELS AS A FUNCTION OF b/t AND STIFFENER TORSIONAL RIGIDITY

$$\eta = (E_s/2E)\left\{1 + 0.5\left[1 + (3E_t/E_s)\right]^{1/2}\right\}(1 - \nu_e^2)\Big/(1 - \nu^2)$$

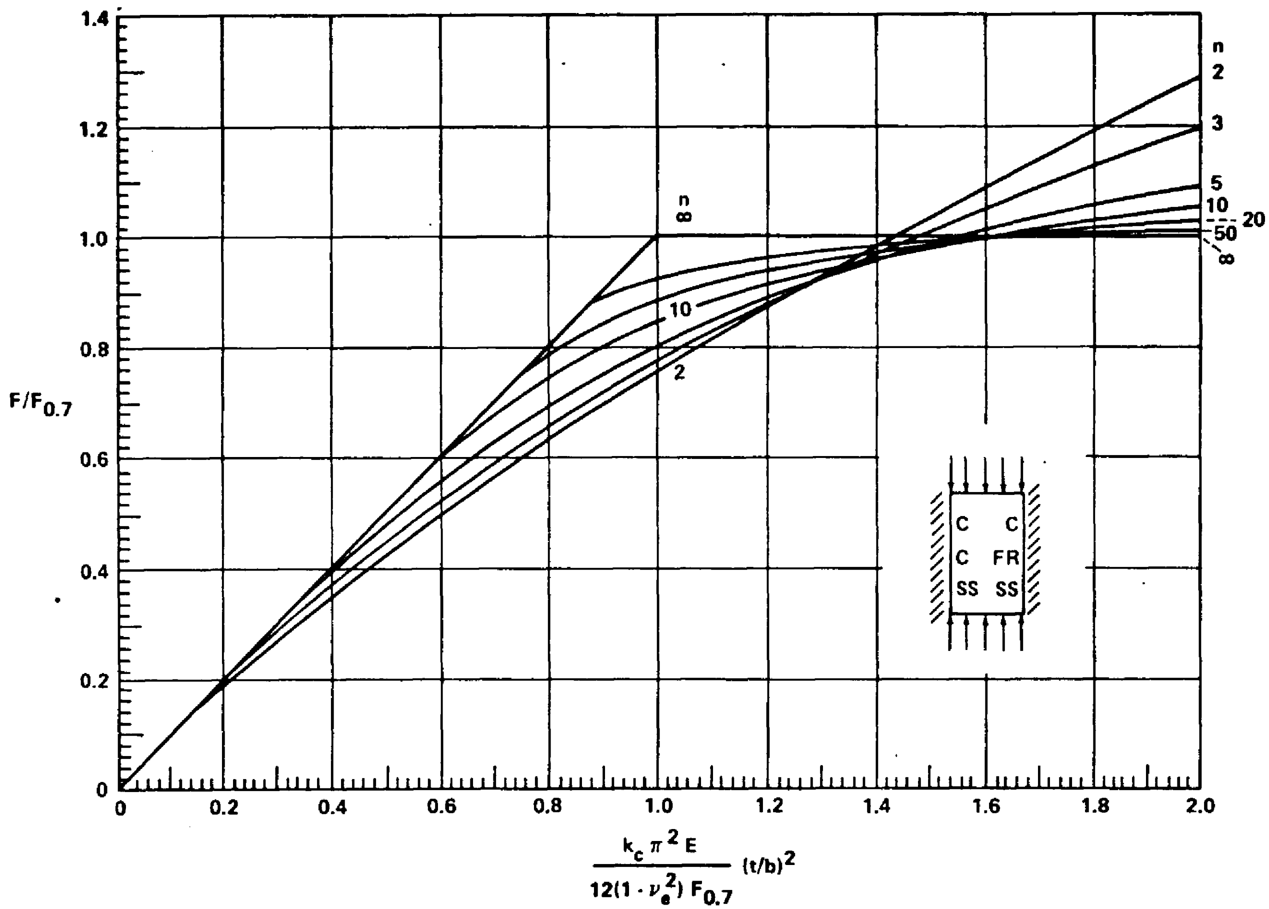


FIGURE C2-10. CHART OF NONDIMENSIONAL COMPRESSIVE BUCKLING STRESS FOR LONG CLAMPED FLANGES AND FOR SUPPORTED PLATES WITH EDGE ROTATIONAL RESTRAINT

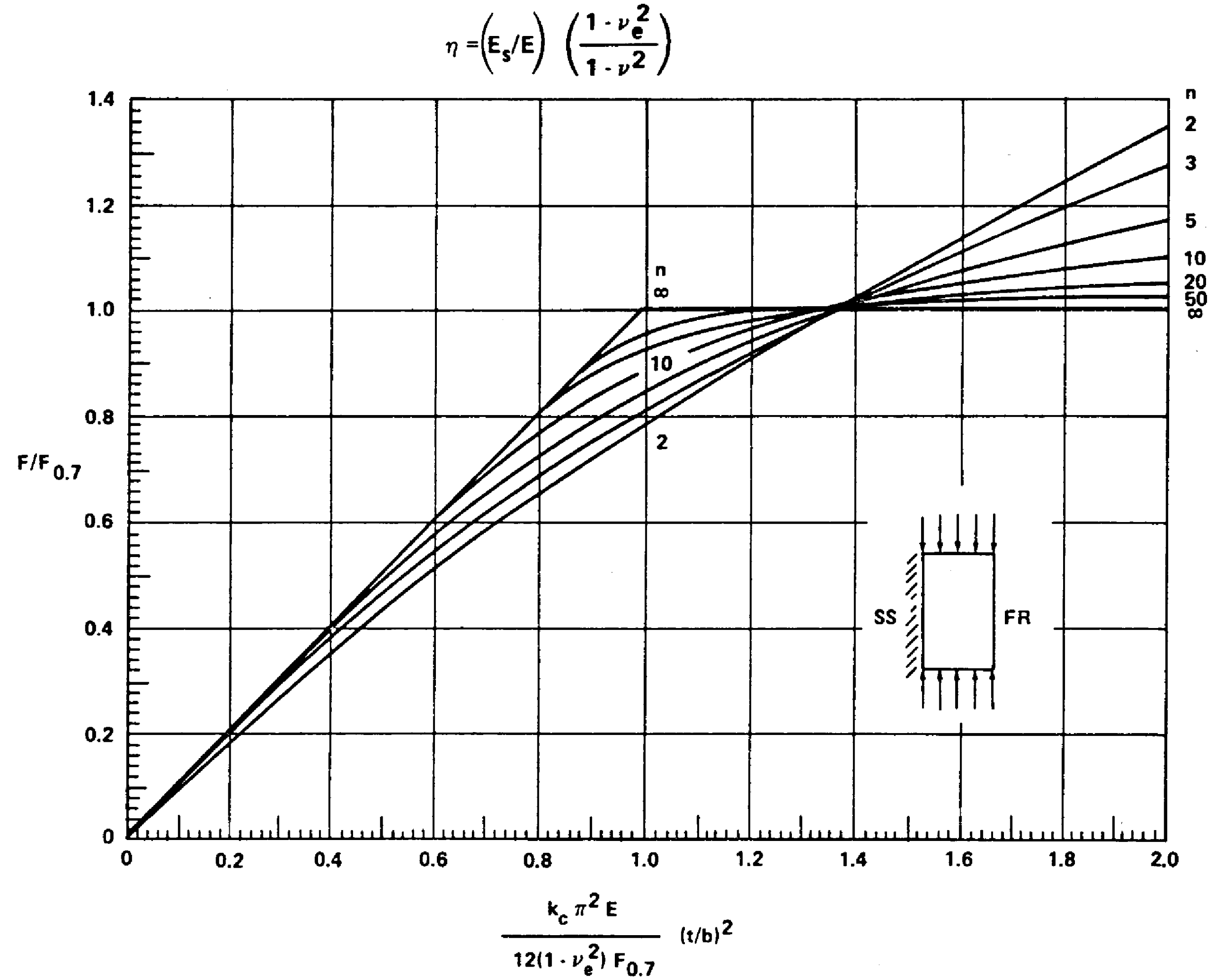


FIGURE C2-11. CHART OF NONDIMENSIONAL COMPRESSIVE BUCKLING STRESS FOR LONG HINGED FLANGES

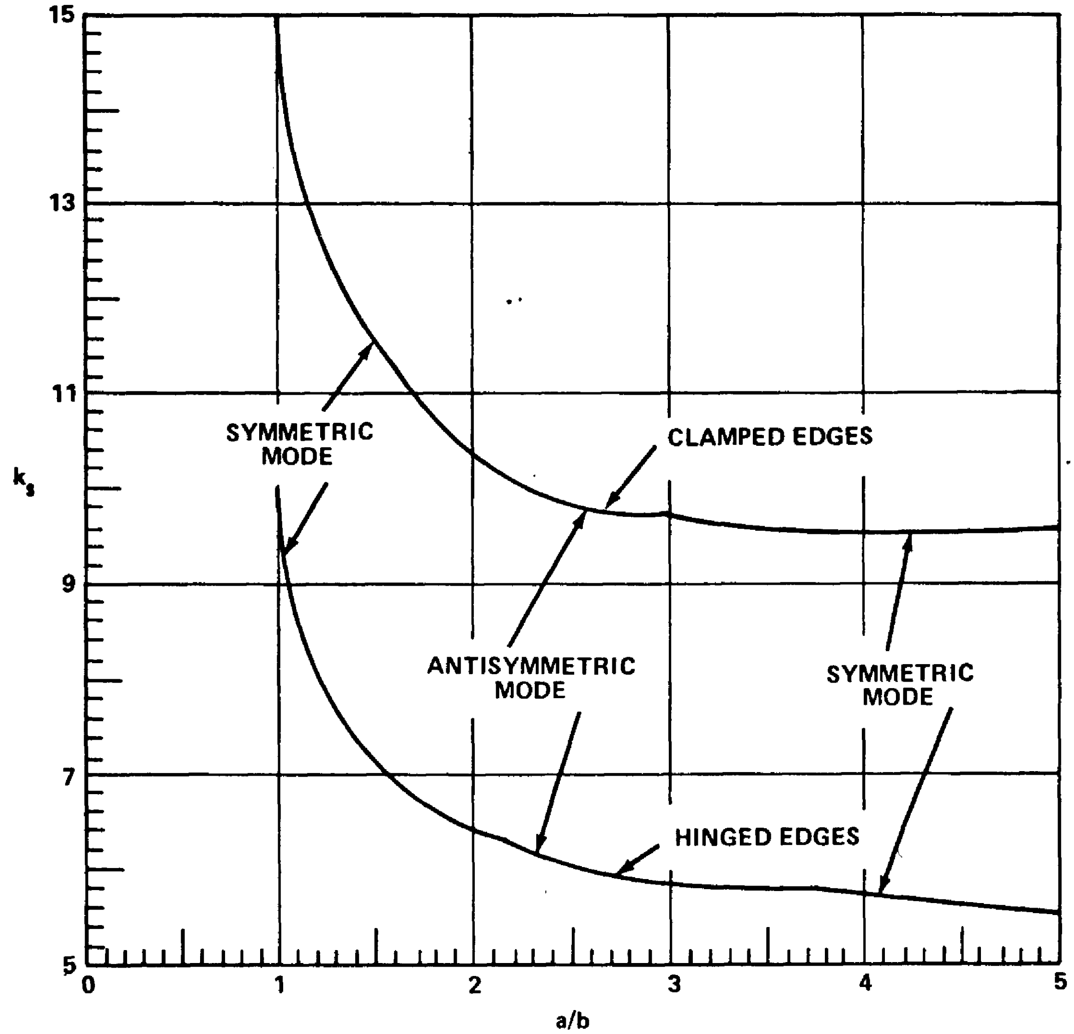


FIGURE C2-12. SHEAR-BUCKLING-STRESS COEFFICIENT OF PLATES AS A FUNCTION OF a/b FOR CLAMPED AND HINGED EDGES

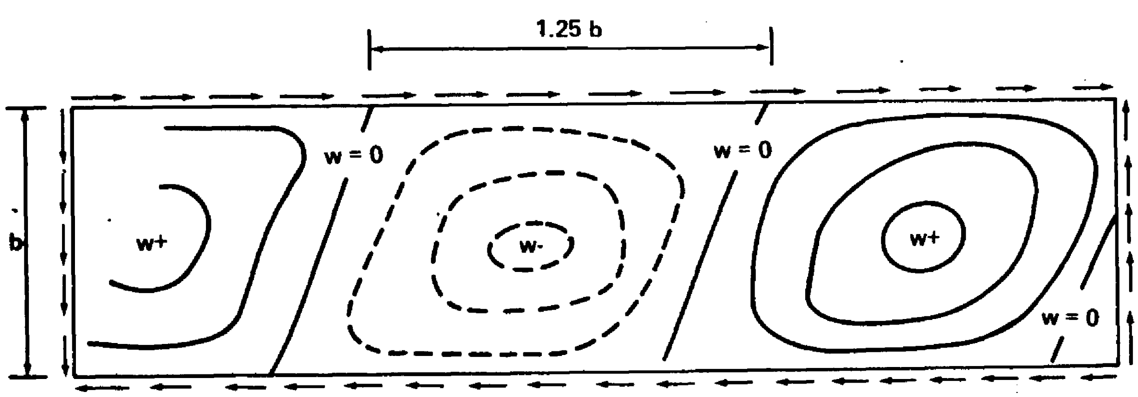


FIGURE C2-13. SHEAR BUCKLING PATTERN FOR RECTANGULAR PLATE

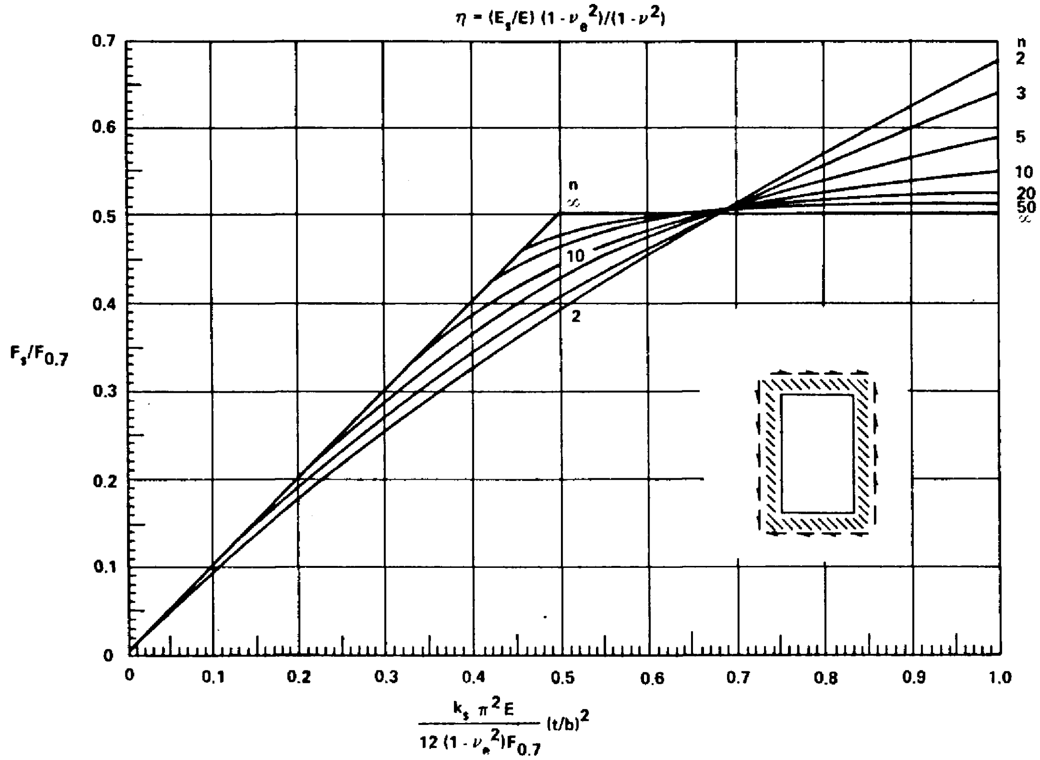


FIGURE C2-14. CHART OF NONDIMENSIONAL SHEAR BUCKLING STRESS FOR PANELS WITH EDGE ROTATIONAL RESTRAINT

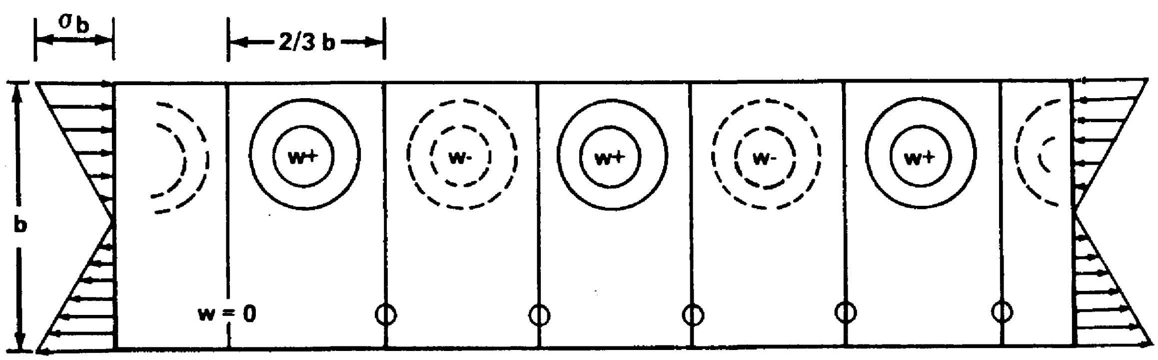


FIGURE C2-15. BUCKLE PATTERN FOR BENDING OF RECTANGULAR PLATE

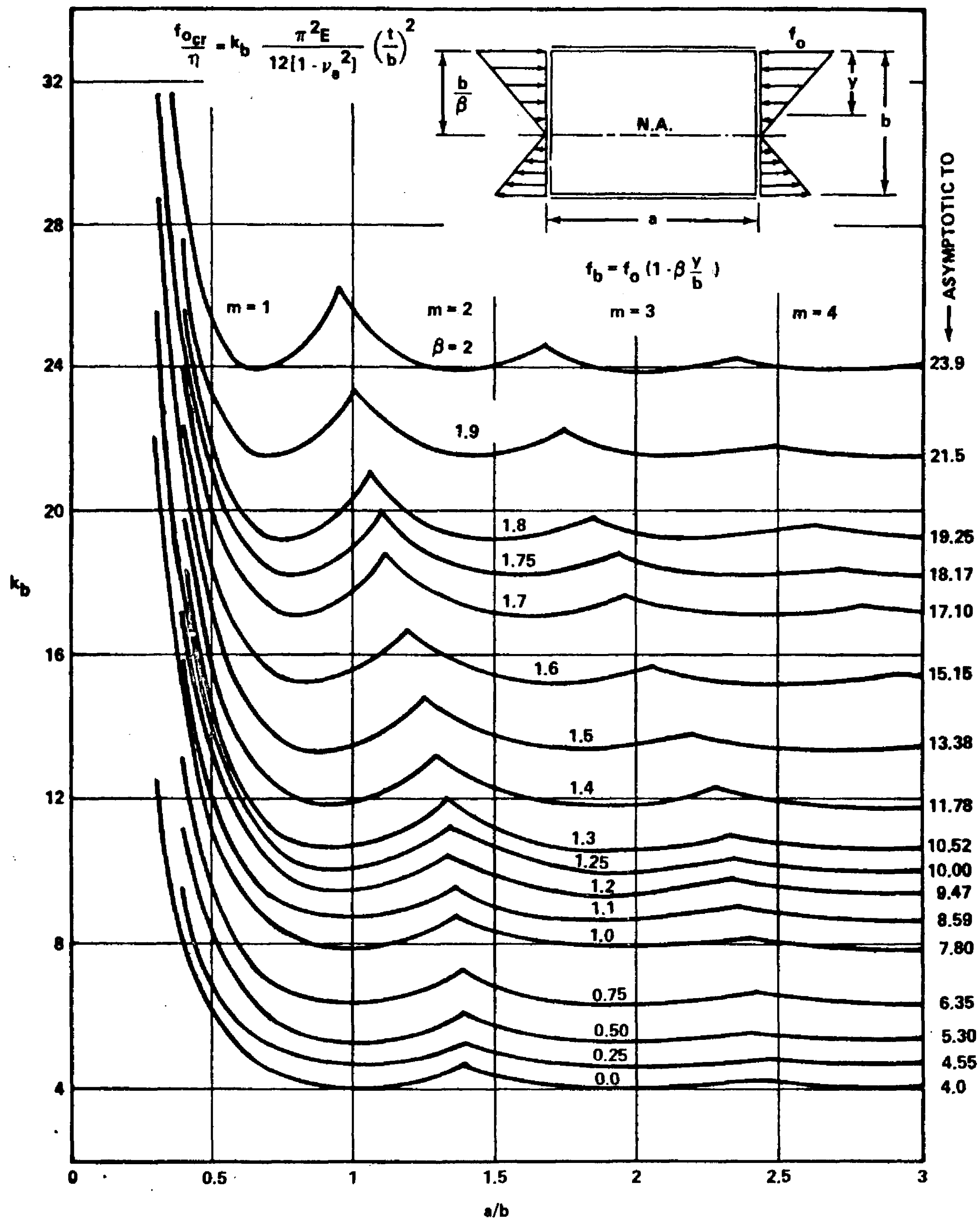


FIGURE C2-16. CRITICAL STRESS COEFFICIENTS FOR A FLAT PLATE IN BENDING IN THE PLANE OF THE PLATE, ALL EDGES SIMPLY SUPPORTED

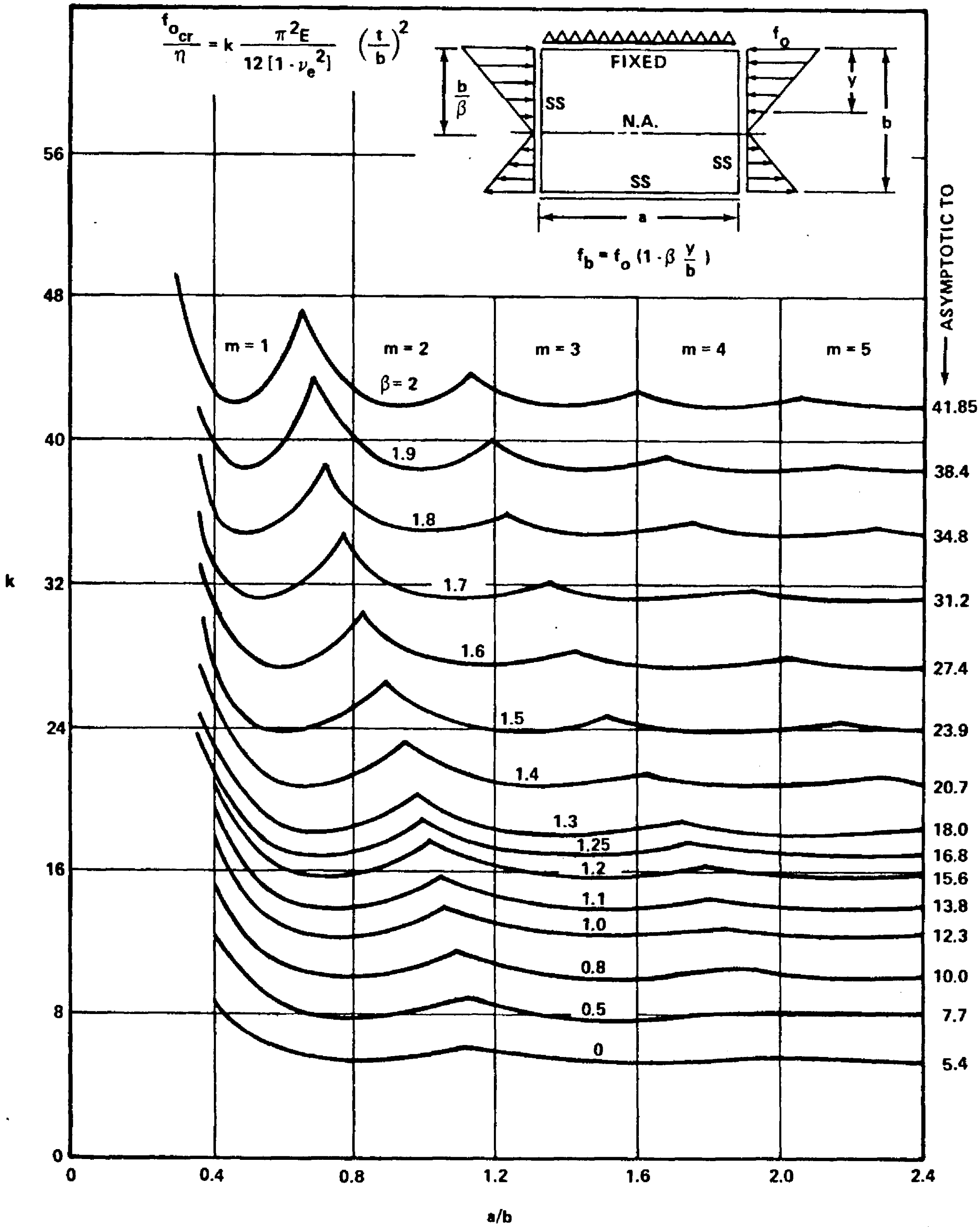


FIGURE C2-17. CRITICAL STRESS COEFFICIENTS FOR A PLATE IN BENDING IN THE PLANE OF THE PLATE, TENSION SIDE SIMPLY SUPPORTED AND COMPRESSION SIDE FIXED

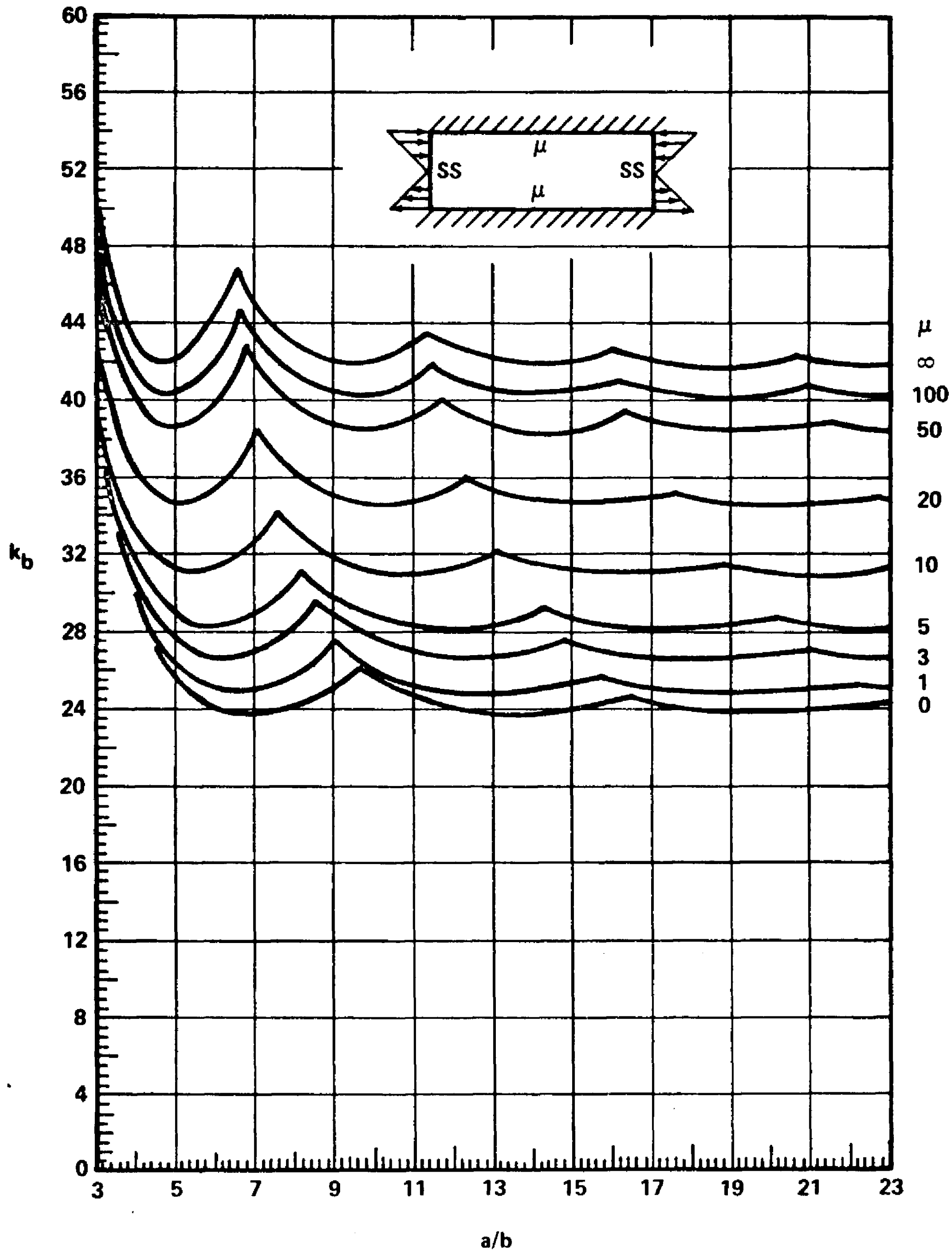


FIGURE C2-18. BENDING-BUCKLING COEFFICIENT OF PLATES AS A FUNCTION OF a/b FOR VARIOUS AMOUNTS OF EDGE ROTATIONAL RESTRAINT

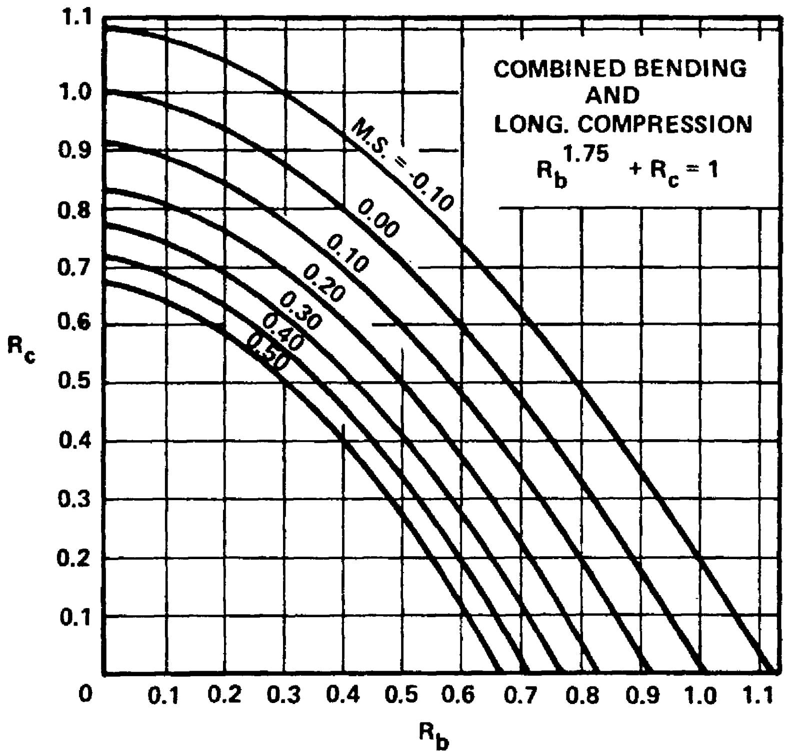


FIGURE C2-19. INTERACTION OF COMBINED BENDING AND LONGITUDINAL COMPRESSION OF PLATES

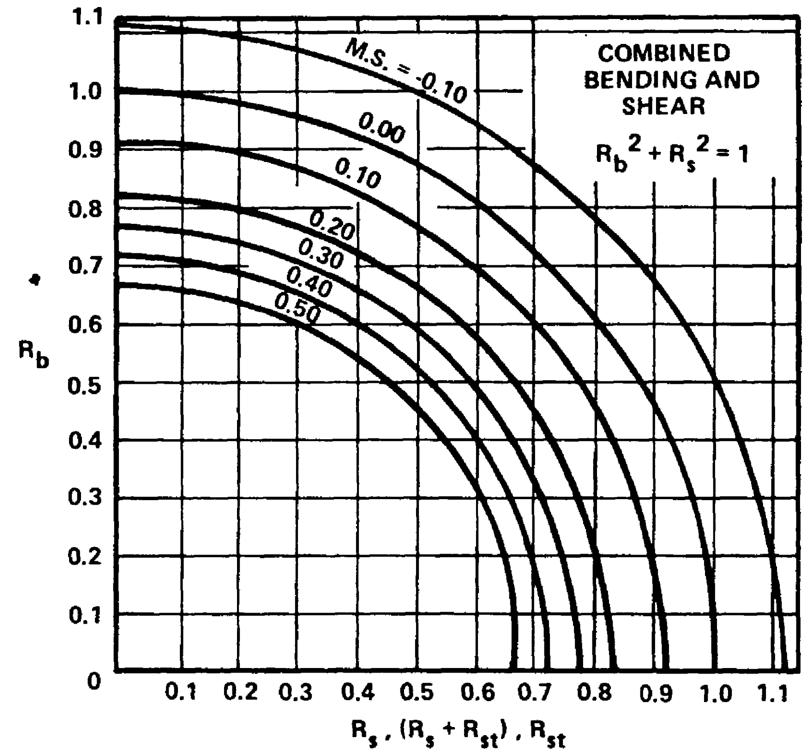


FIGURE C2-20. INTERACTION OF COMBINED BENDING AND SHEAR

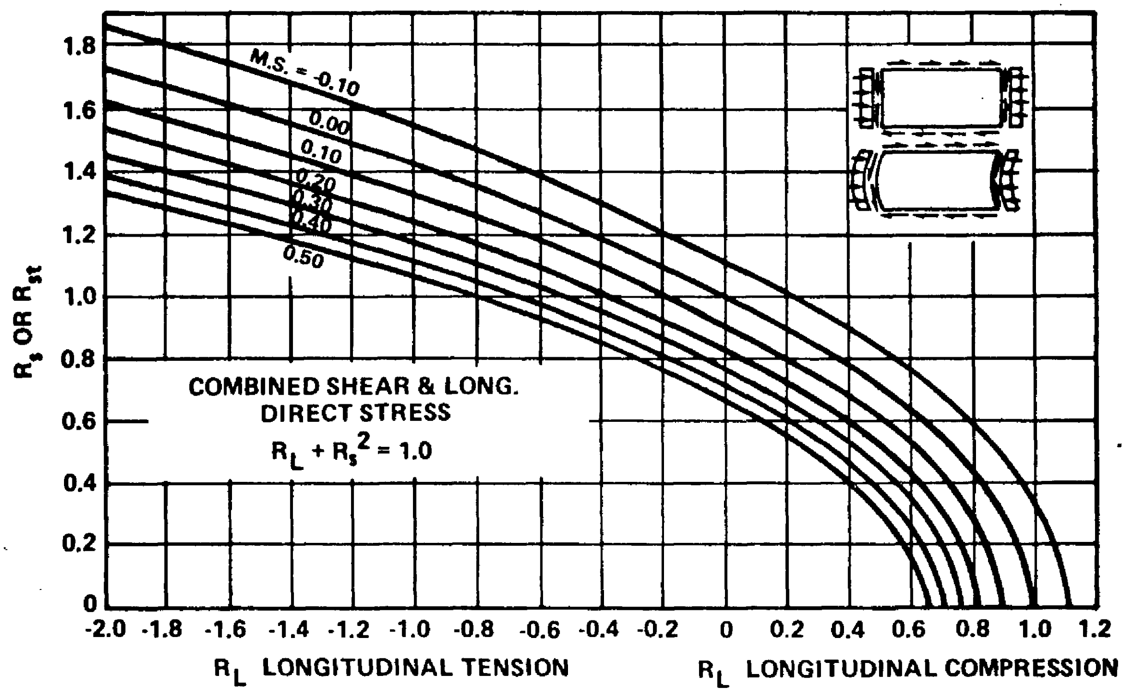


FIGURE C2-21. INTERACTION OF COMBINED SHEAR AND LONGITUDINAL DIRECT STRESS

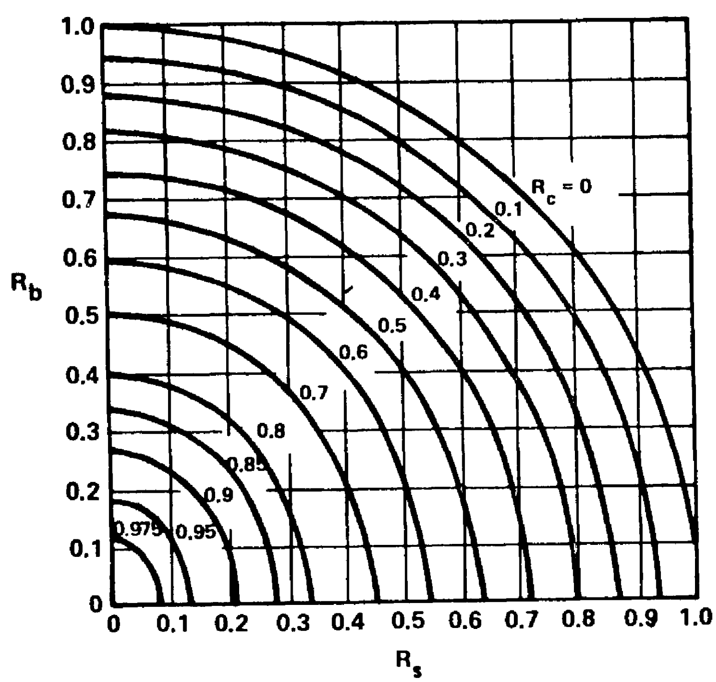


FIGURE C2-22. INTERACTION OF COMBINED COMPRESSION, BENDING, AND SHEAR

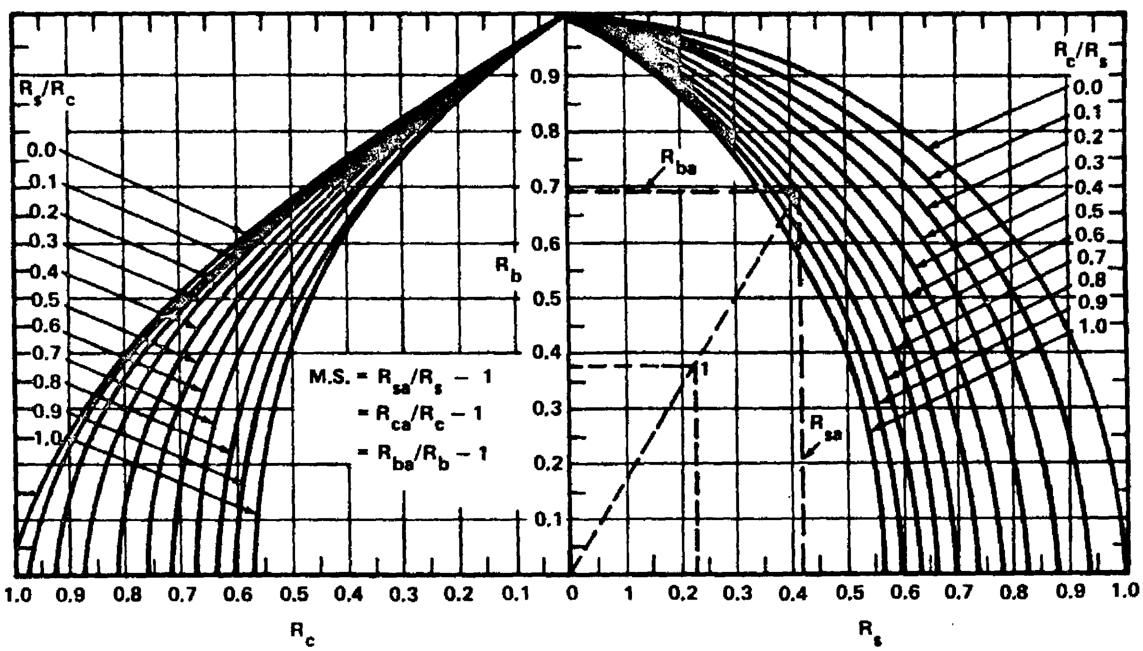


FIGURE C2-23. MARGIN OF SAFETY DETERMINATION FOR COMBINED COMPRESSION BENDING AND SHEAR

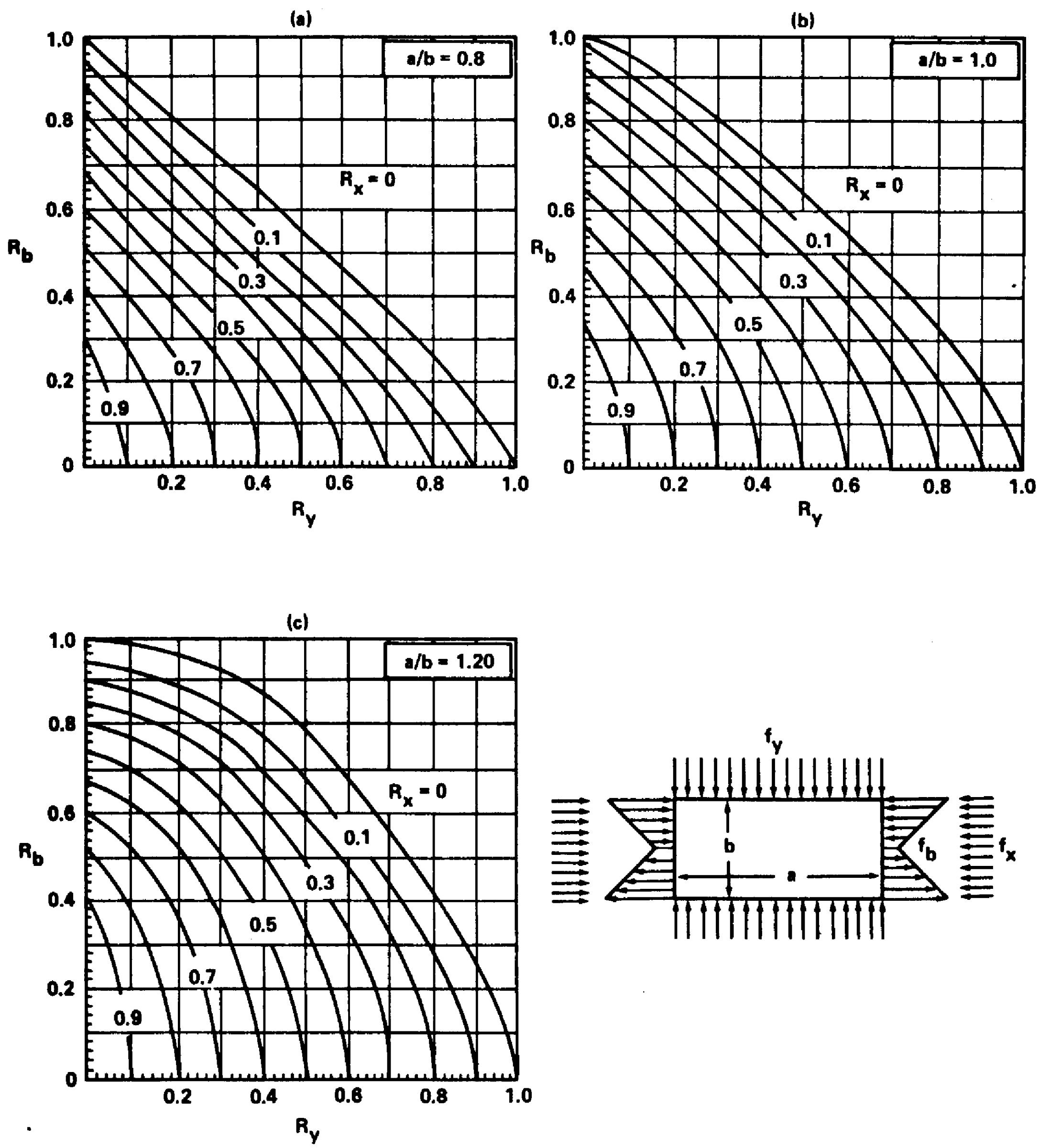


FIGURE C2-24. INTERACTION CURVES FOR SIMPLY SUPPORTED FLAT RECTANGULAR PLATES UNDER COMBINED BIAXIAL COMPRESSION AND LONGITUDINAL BENDING LOADINGS

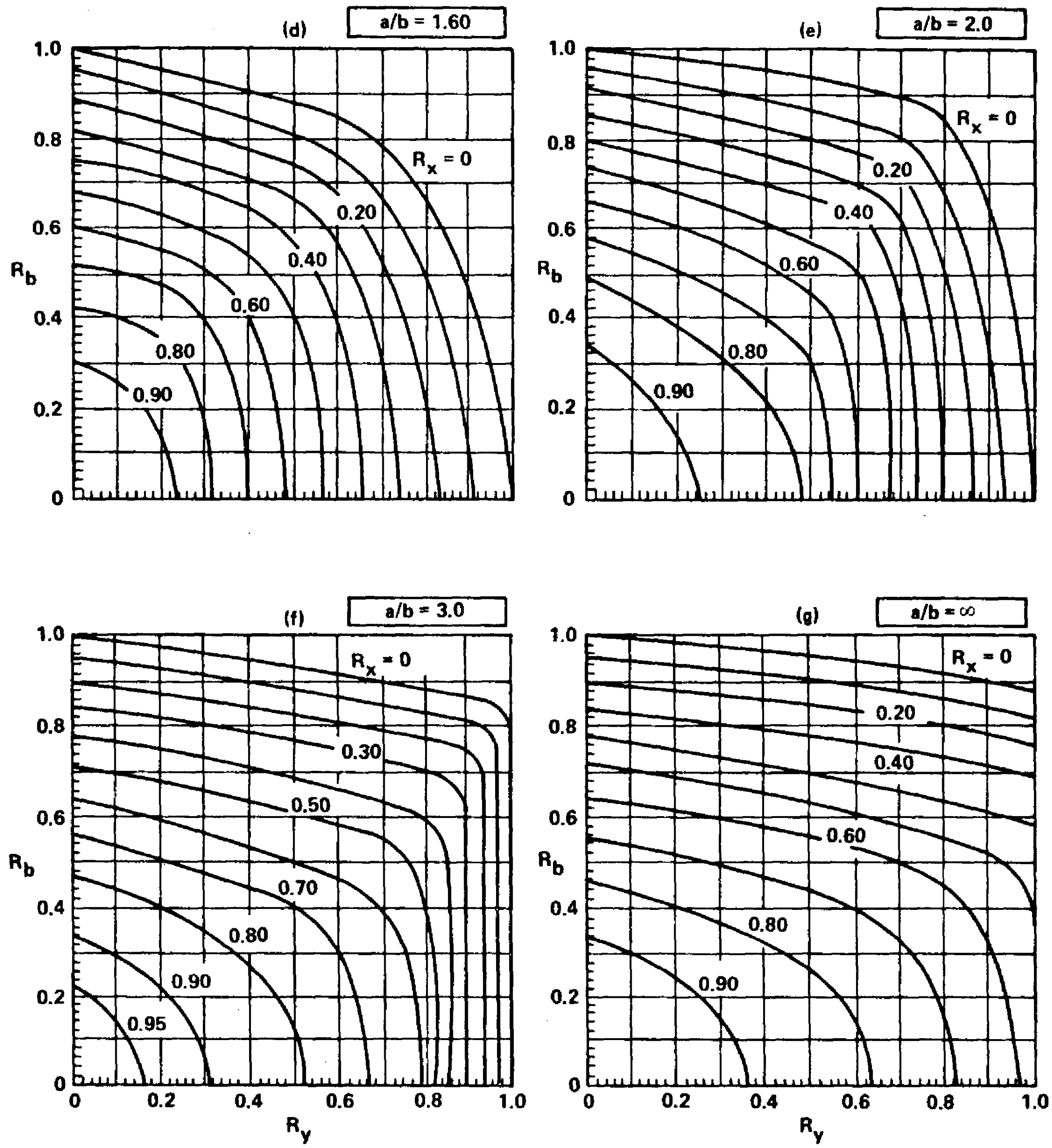


FIGURE C2-24. Concluded

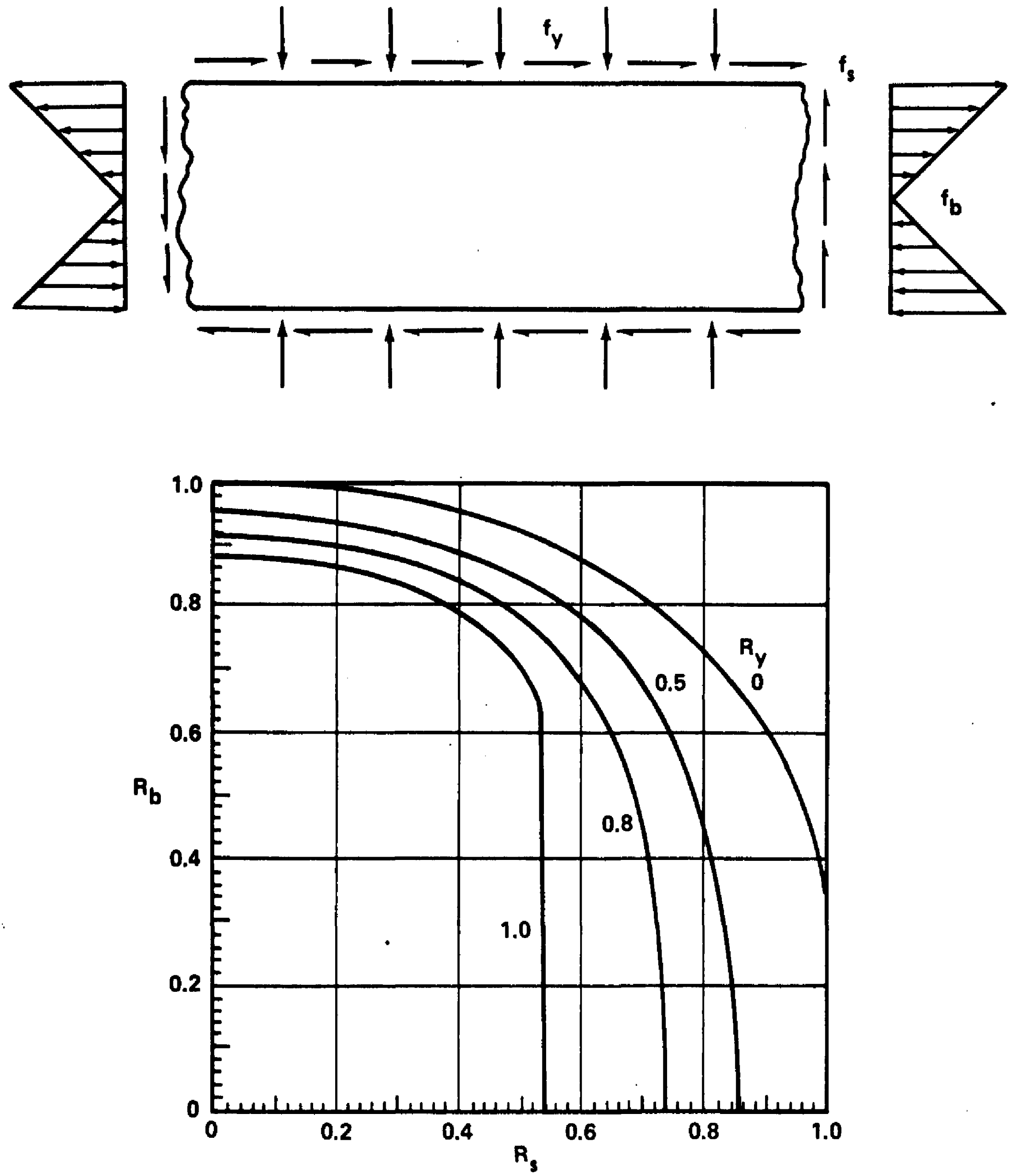
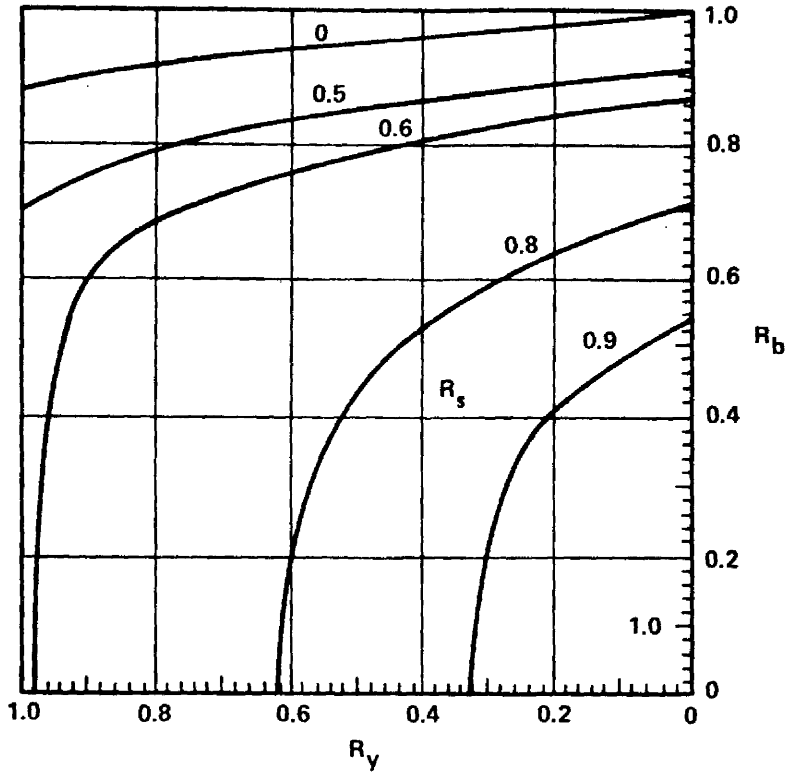


FIGURE C2-25. INTERACTION CURVES FOR SIMPLY SUPPORTED, LONG FLAT PLATES UNDER VARIOUS COMBINATIONS OF SHEAR, BENDING, AND TRANSVERSE COMPRESSION



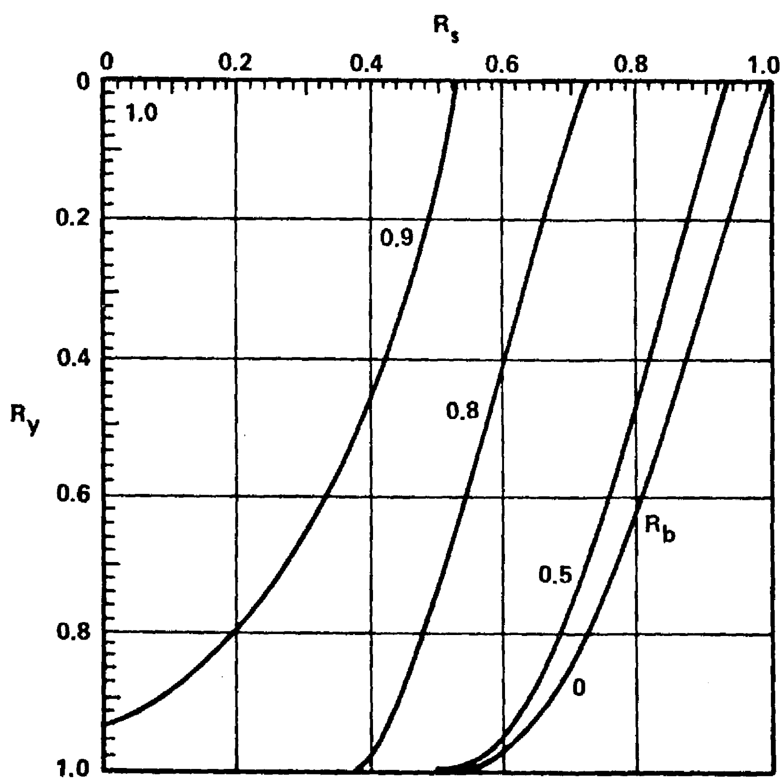


FIGURE C2-25. Concluded

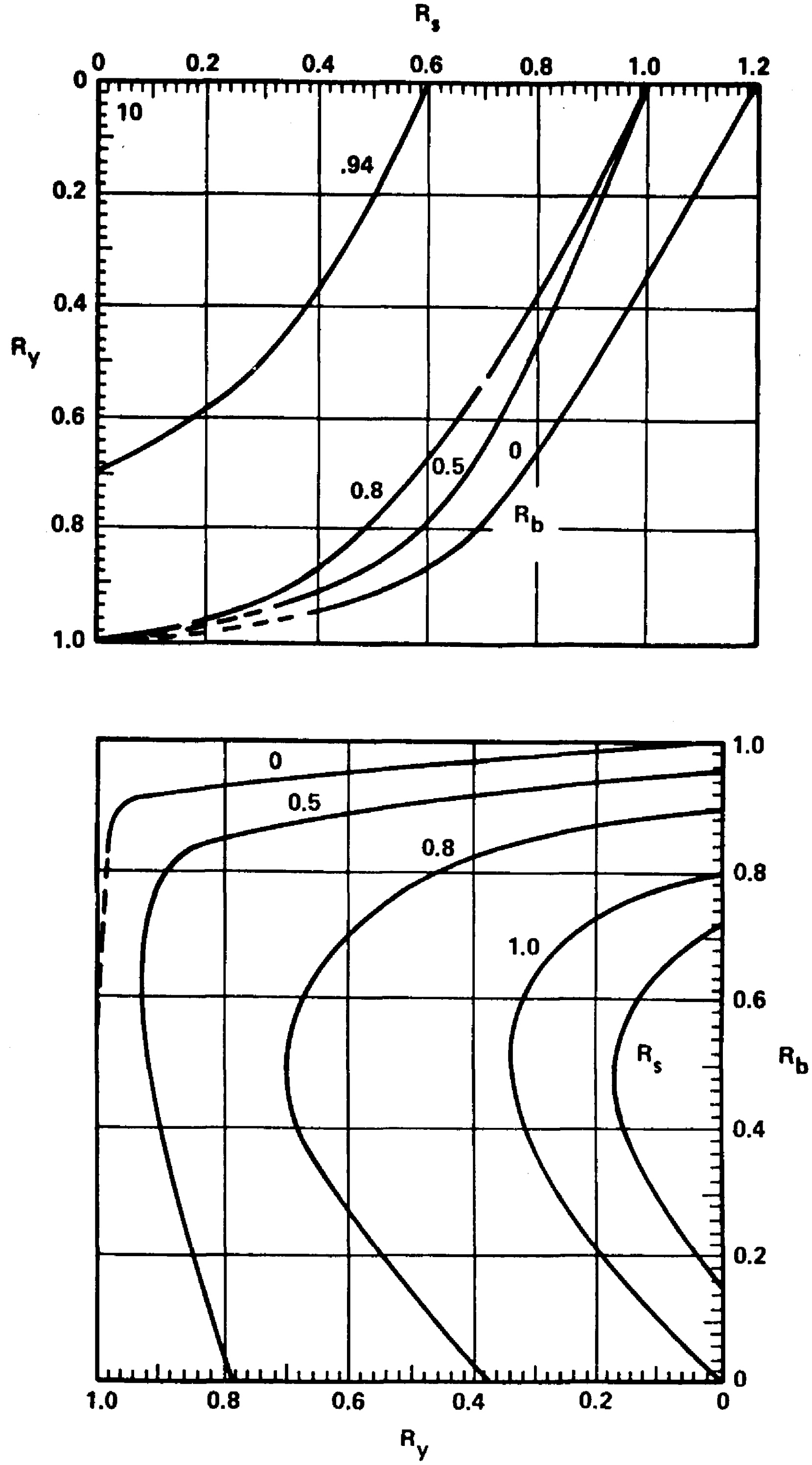
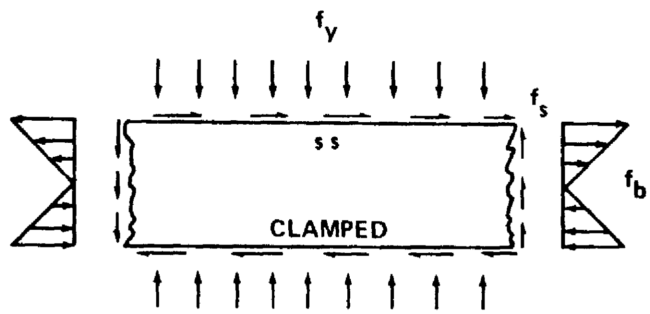


FIGURE C2-26. INTERACTION CURVES FOR UPPER EDGES SIMPLY SUPPORTED, LOWER EDGES CLAMPED, LONG PLATES UNDER VARIOUS COMBINATIONS OF SHEAR, BENDING, AND TRANSVERSE COMPRESSION



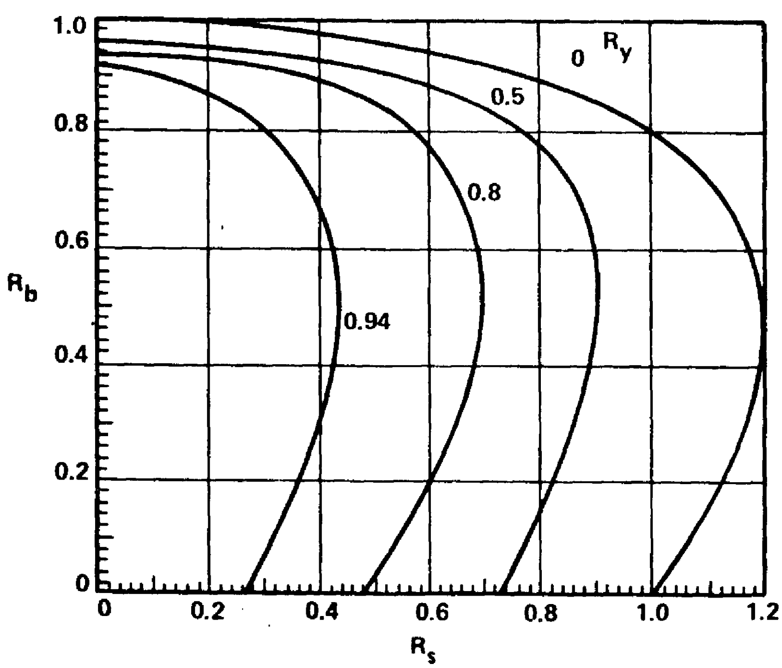


FIGURE C2-26. Concluded

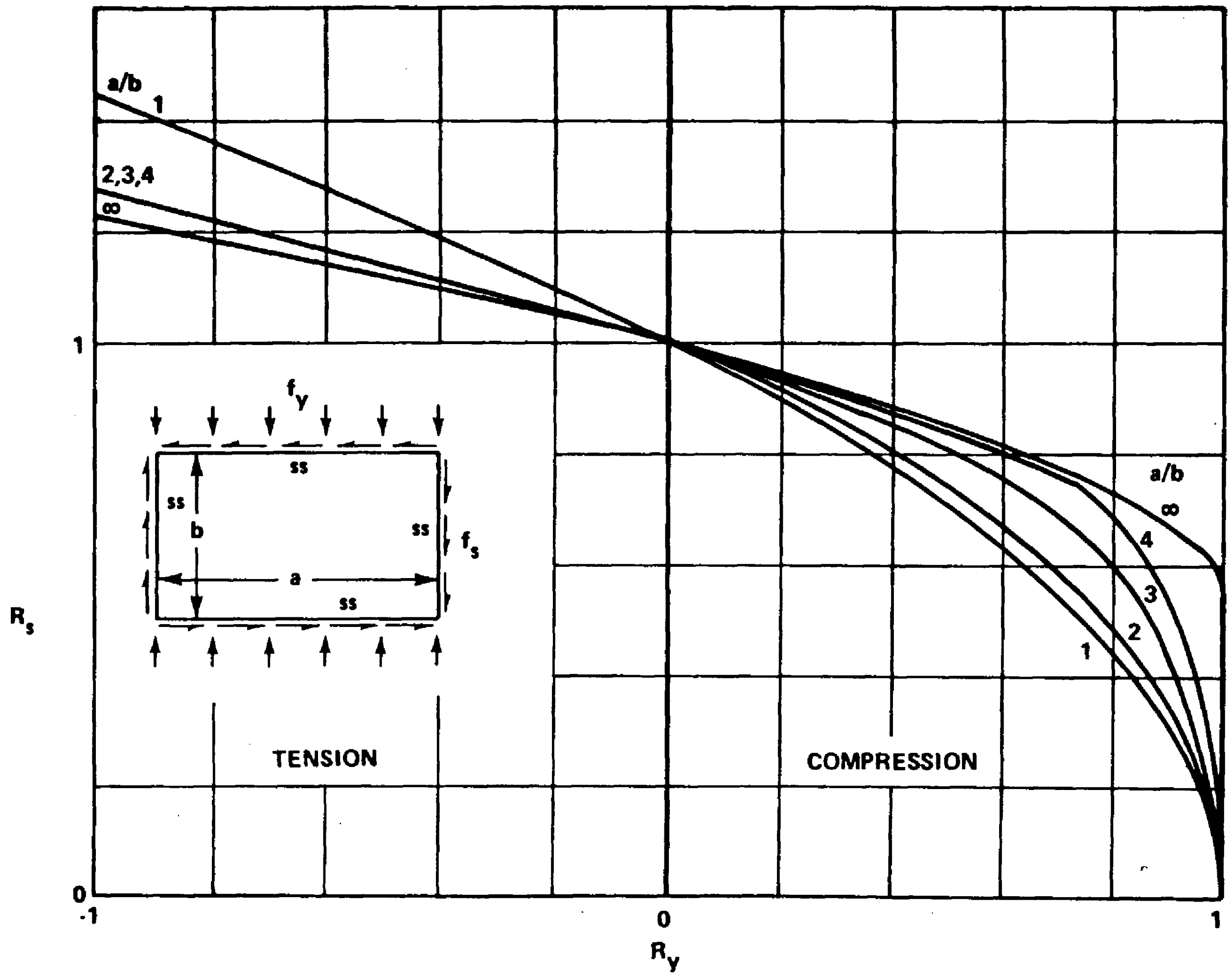


FIGURE C2-27. TRANSITION IN THE FORM OF INTERACTION CURVE FOR SHEAR AND TRANSVERSE DIRECT STRESS FOR A SIMPLY SUPPORTED RECTANGULAR FLAT PLATE AS THE LENGTH-WIDTH RATIO CHANGES FROM 1 TO ∞ IN TERMS OF R_s AND R_y. $\left(R_s = f_s / f_{s_{cr}},\ R_y = f_y / f_{y_{cr}}\right)$

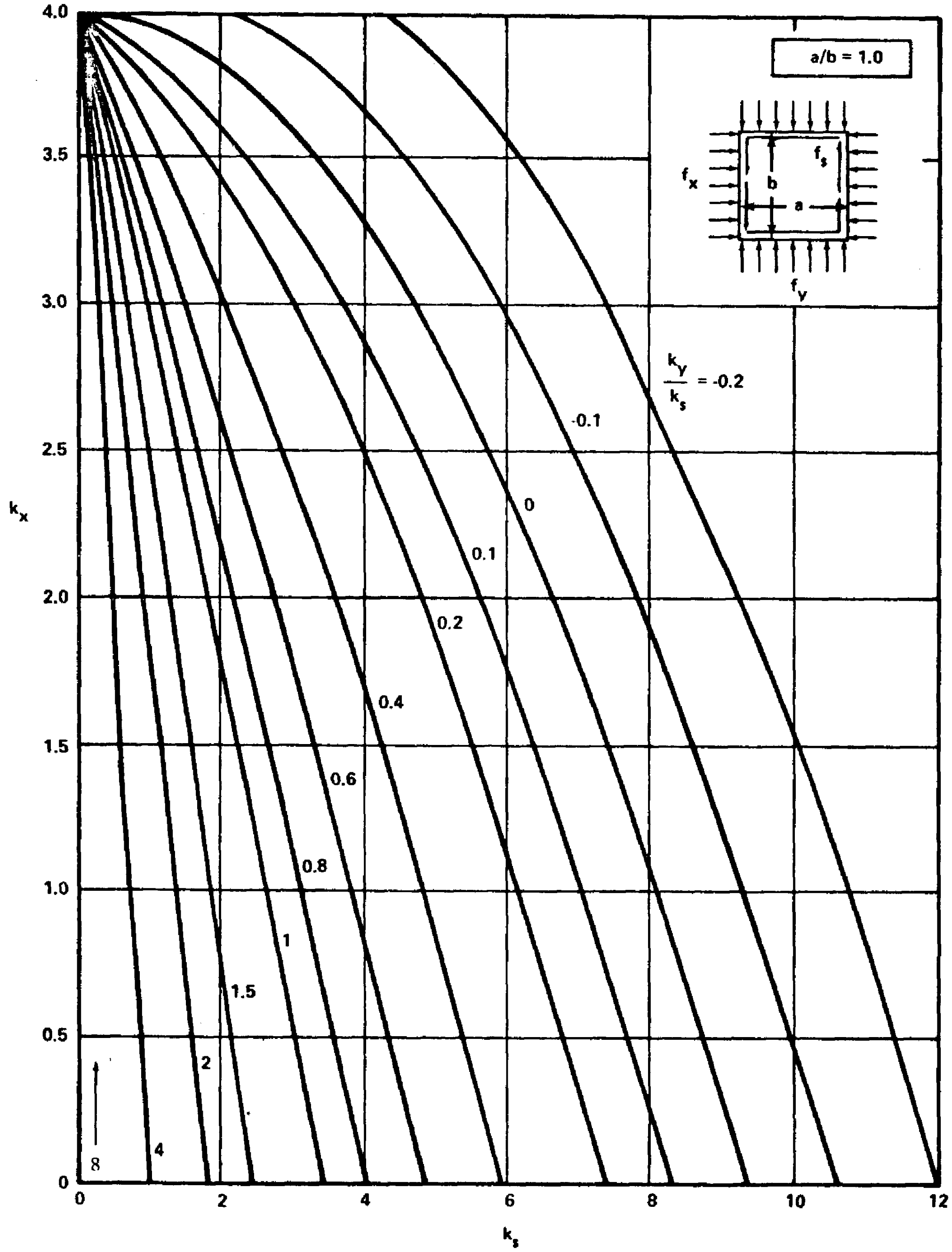


FIGURE C2-28. CRITICAL STRESS COEFFICIENTS FOR SIMPLY SUPPORTED FLAT PLATES UNDER LONGITUDINAL COMPRESSION, TRANSVERSE COMPRESSION, AND SHEAR

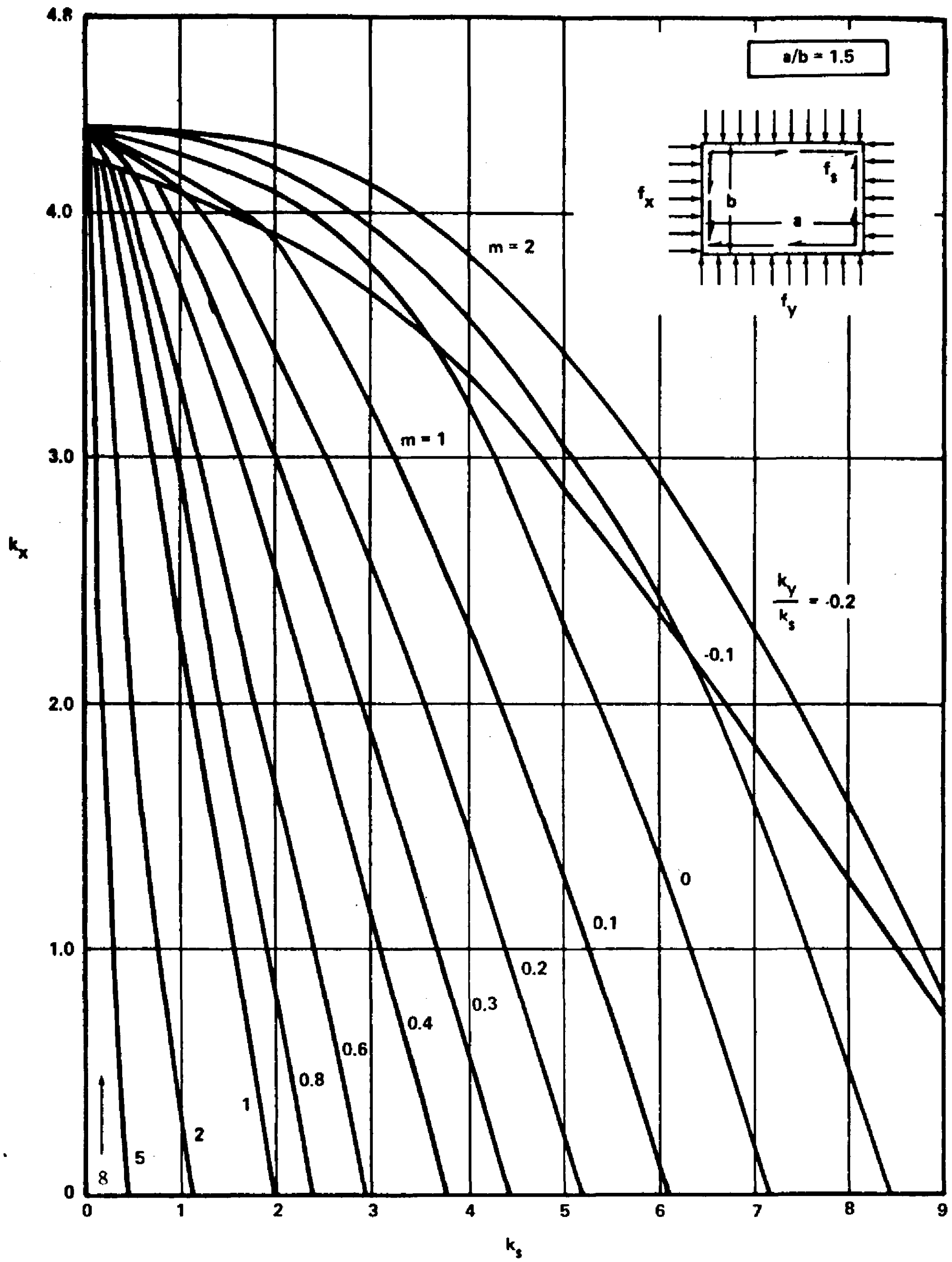


FIGURE C2-29. CRITICAL STRESS COEFFICIENTS FOR SIMPLY SUPPORTED FLAT PLATES UNDER LONGITUDINAL COMPRESSION, TRANSVERSE COMPRESSION, AND SHEAR

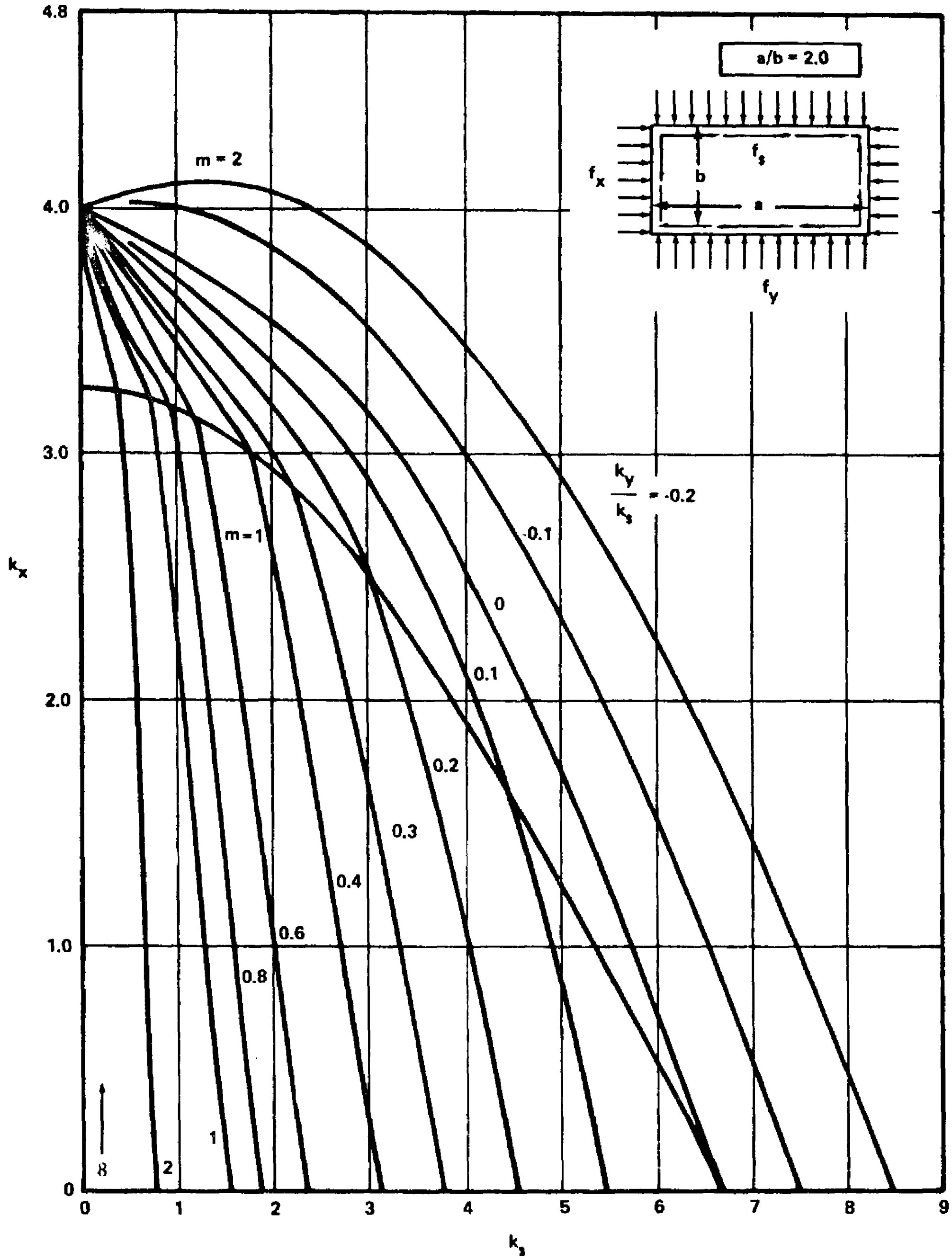


FIGURE C2-30. CRITICAL STRESS COEFFICIENTS FOR SIMPLY SUPPORTED FLAT PLATES UNDER LONGITUDINAL COMPRESSION, TRANSVERSE COMPRESSION, AND SHEAR

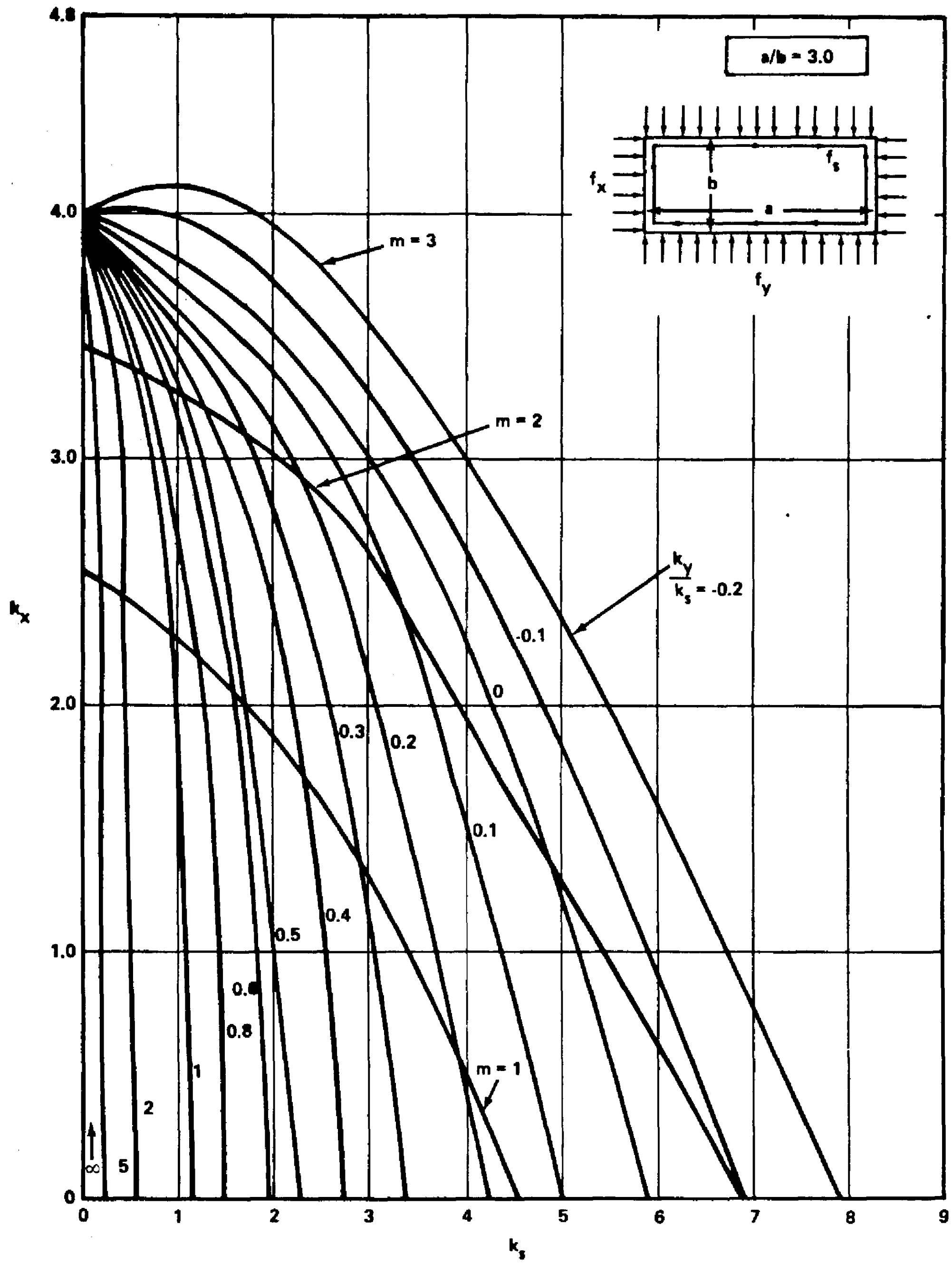


FIGURE C2-31. CRITICAL STRESS COEFFICIENTS FOR SIMPLY SUPPORTED FLAT PLATES UNDER LONGITUDINAL COMPRESSION, TRANSVERSE COMPRESSION, AND SHEAR

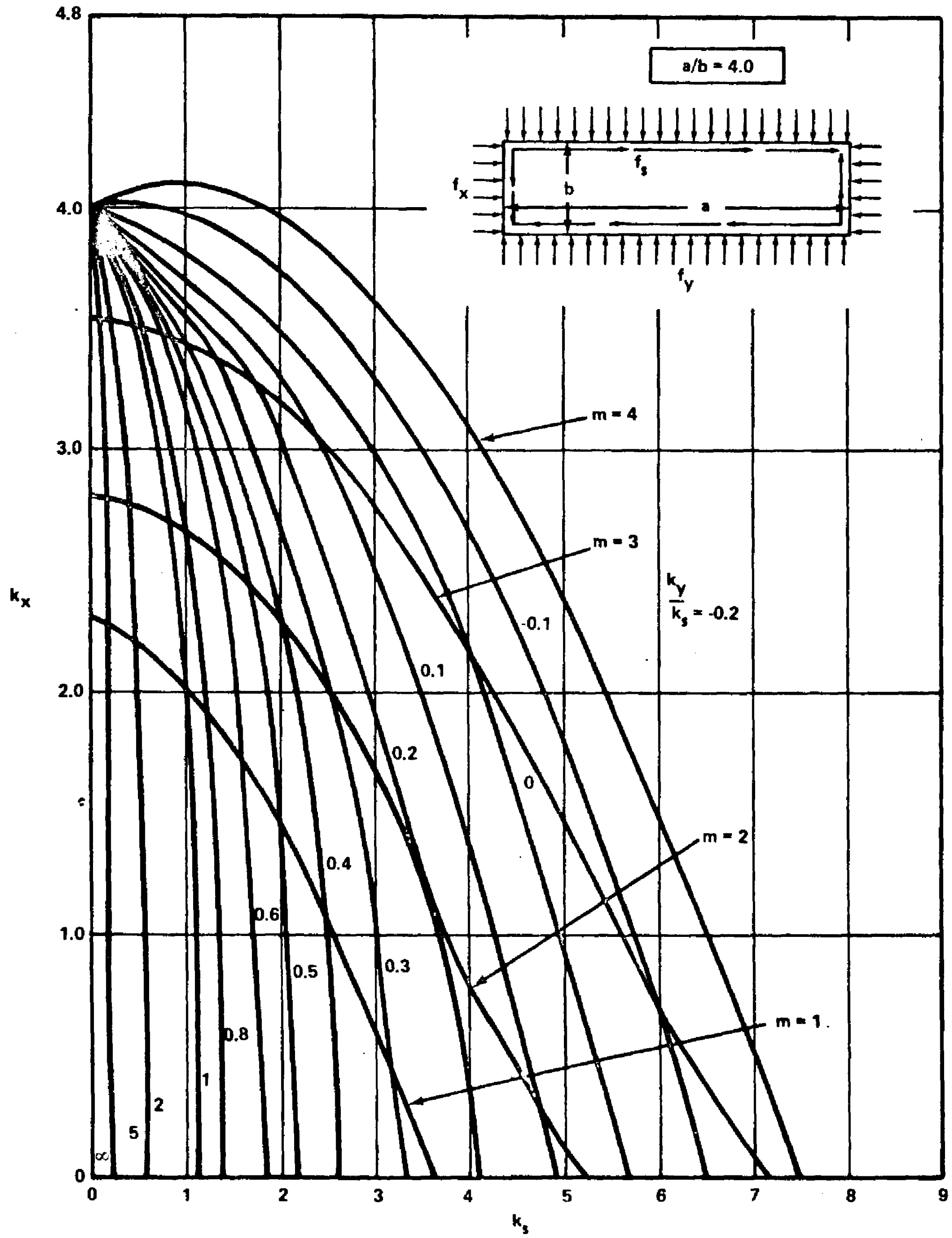


FIGURE C2-32. CRITICAL STRESS COEFFICIENTS FOR SIMPLY SUPPORTED FLAT PLATES UNDER LONGITUDINAL COMPRESSION, TRANSVERSE COMPRESSION, AND SHEAR

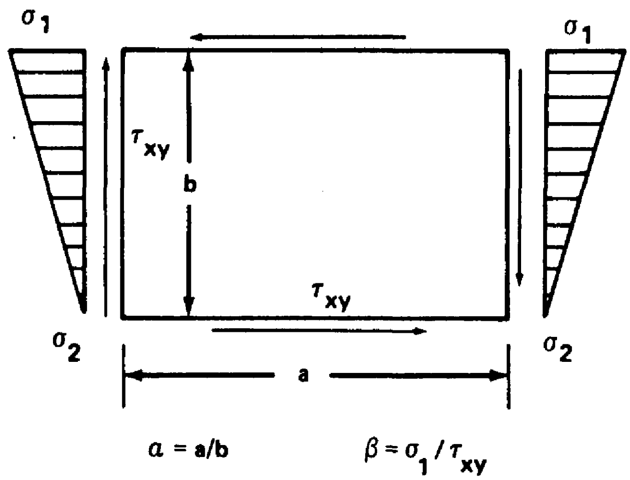


FIGURE C2-33. RECTANGULAR PLATE UNDER COMBINED SHEAR AND NONUNIFORM LONGITUDINAL COMPRESSION

$$\beta = N_A/N_B; \; g = \log_e \beta; \; N_x/N_A = e^{-gx/a}; \; q/N_A = (gb/2a)e^{-gx/a}; \; \text{AND } t_x/t_A = e^{-gx/3a}$$

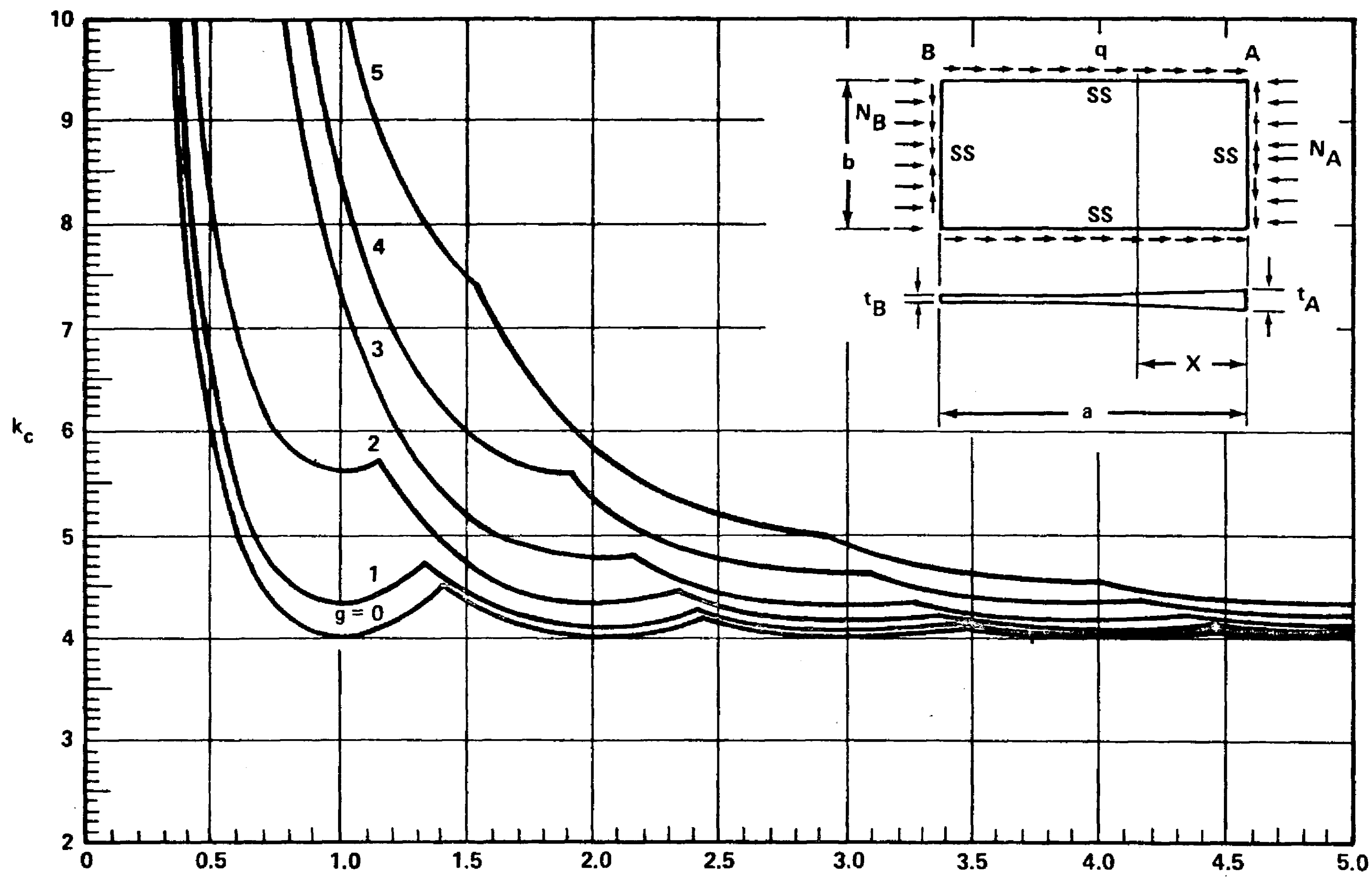


FIGURE C2-34. COMPRESSIVE-BUCKLING-STRESS COEFFICIENT FOR A SIMPLY SUPPORTED RECTANGULAR FLAT PLATE OF MINIMUM WEIGHT (Thickness and loading vary exponentially along length.)

$$F_{av} = \frac{k_{c_{av}} \pi^2 E}{12(1 - \nu_e^2)} (t/b)^2$$

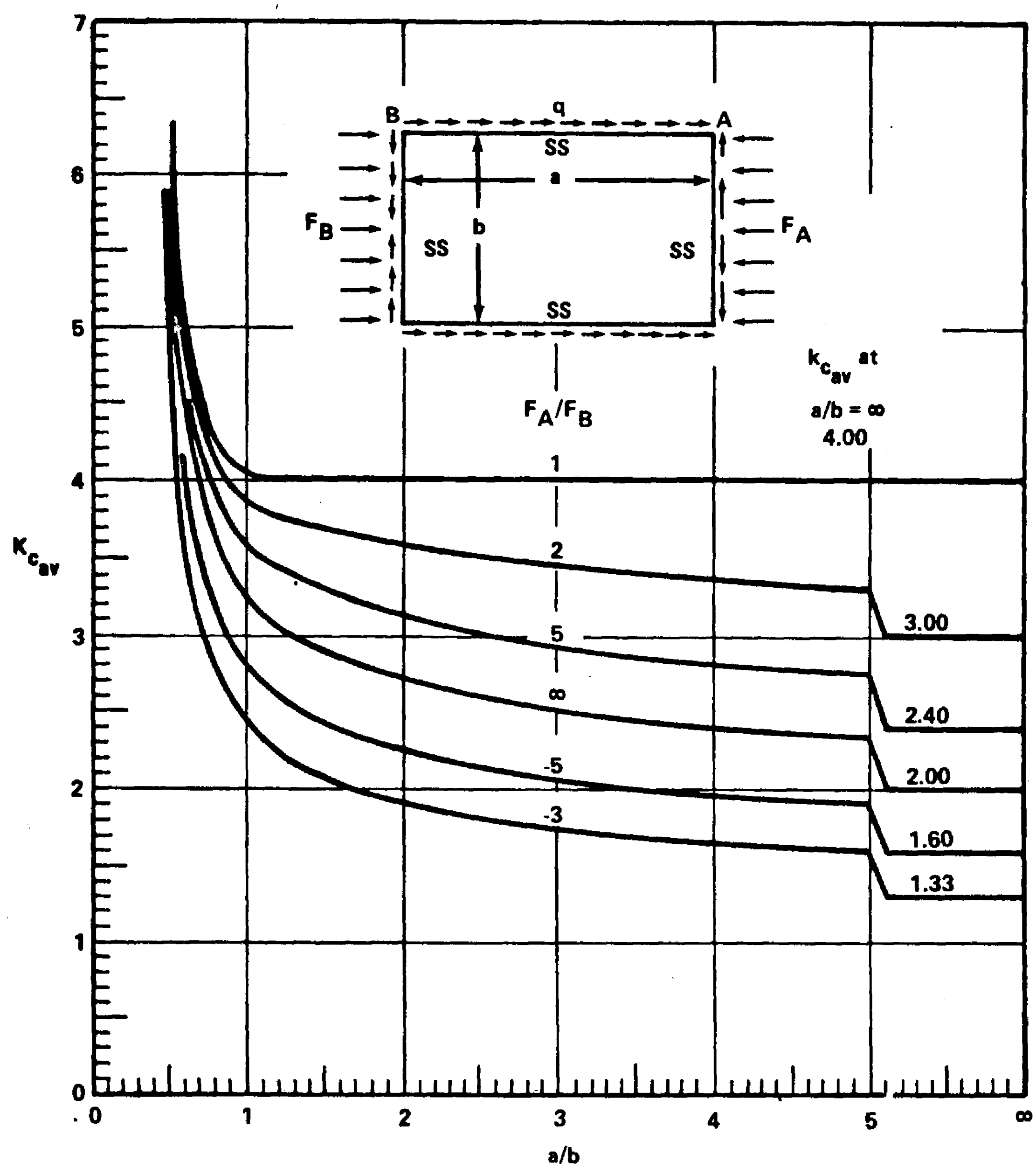
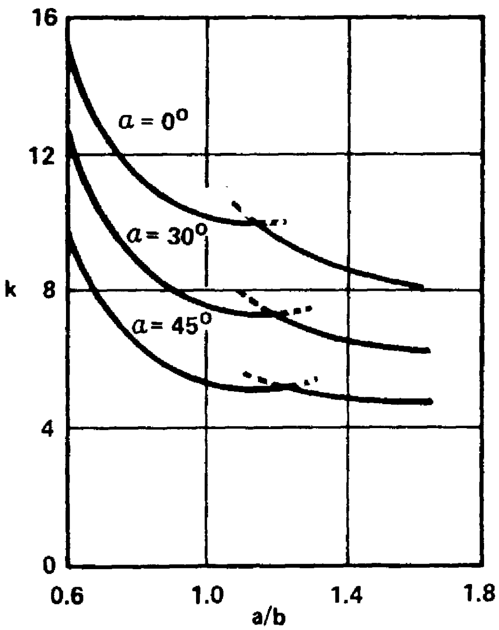
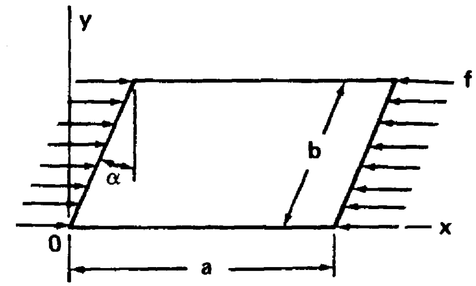


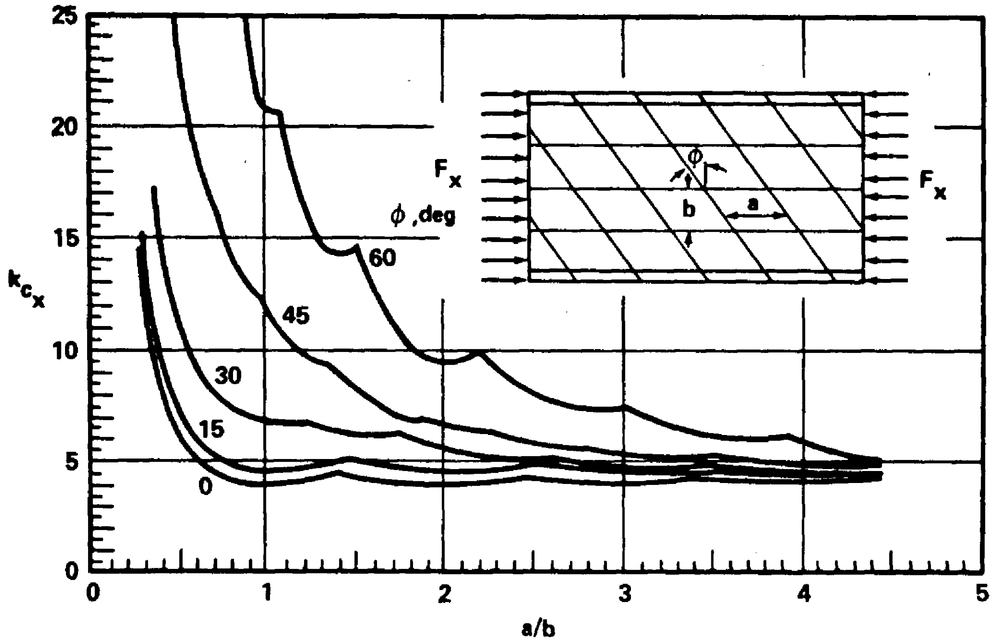
FIGURE C2-35. AVERAGE COMPRESSIVE-BUCKLING-STRESS COEFFICIENT FOR RECTANGULAR FLAT PLATE OF CONSTANT THICKNESS WITH LINEARLY VARYING AXIAL LOAD



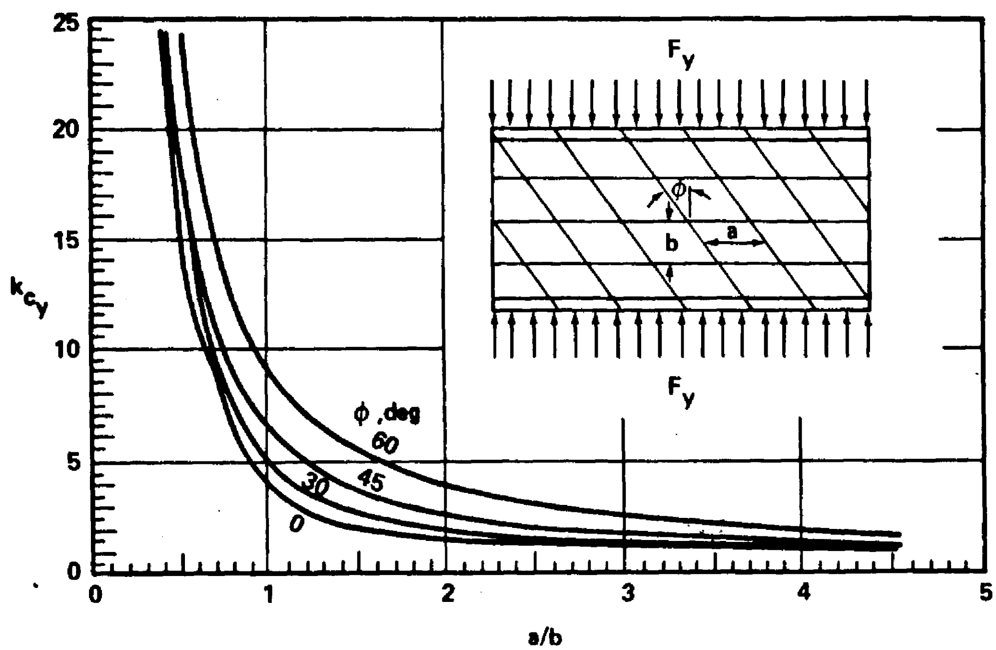


$$\frac{f_{cr}}{\eta} = \frac{k}{\cos^4 \alpha} \quad \frac{\pi^2 E}{12(1 - \nu_e^2)} \left[t/b\right]^2$$

FIGURE C2-36. BUCKLING COEFFICIENTS OF CLAMPED OBLIQUE FLAT PLATES IN COMPRESSION



(a) LOADING IN x-DIRECTION



(b) LOADING IN y-DIRECTION

FIGURE C2-37. COMPRESSIVE-BUCKLING COEFFICIENTS FOR FLAT SHEET ON NONDEFLECTING SUPPORTS DIVIDED INTO PARALLELOGRAM-SHAPED PANELS
(All panels sides are equal.)

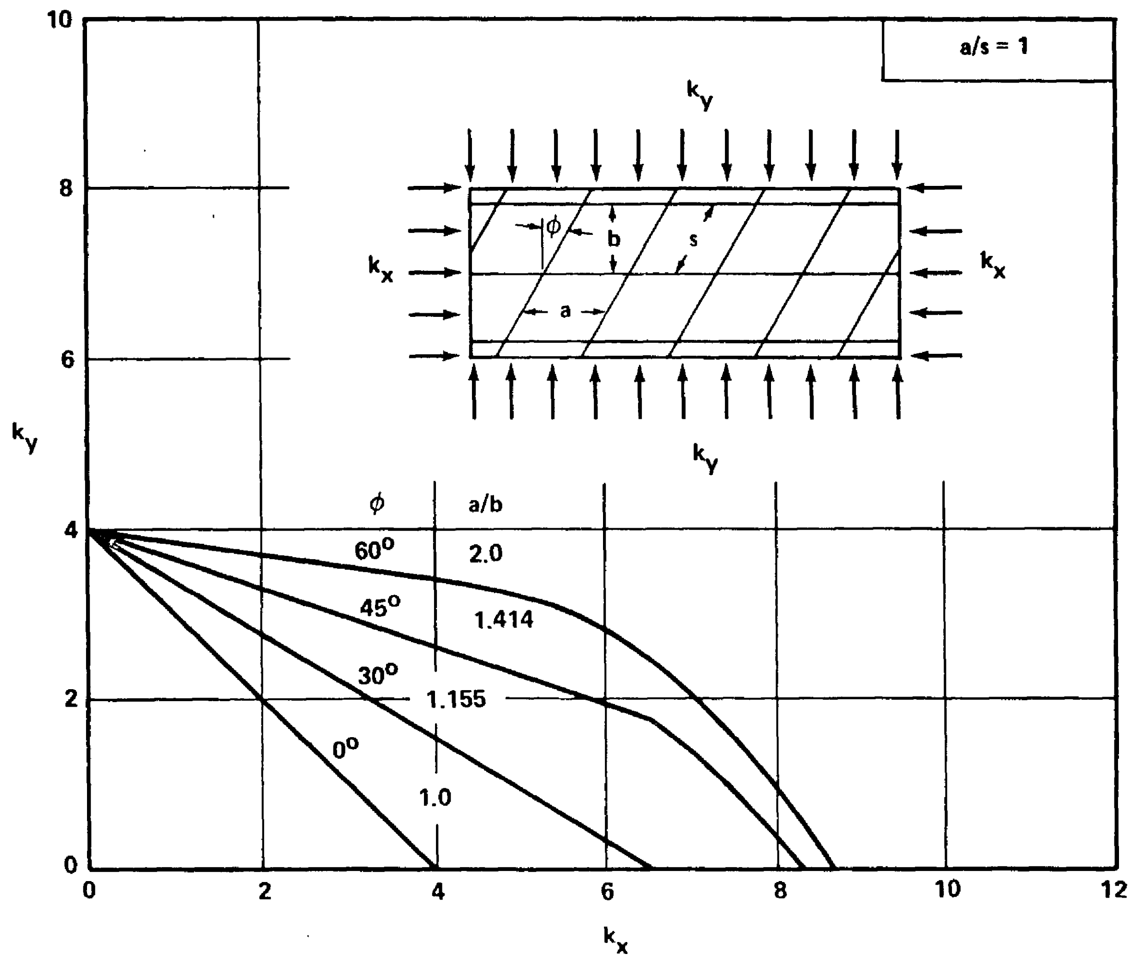


FIGURE C2-38. INTERACTION CURVES FOR COMBINED AXIAL AND TRANSVERSE LOADING OF SKEW PANELS

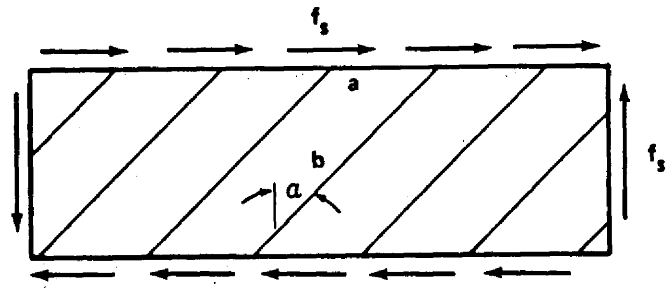
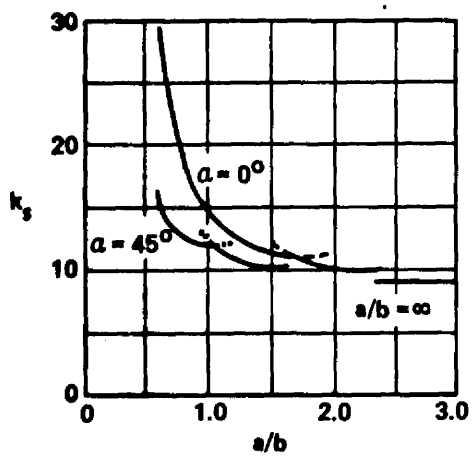
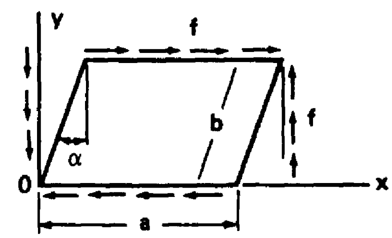


FIGURE C2-39. SHEAR LOADING OF PARALLELOGRAM PLATE





$$\frac{f_{cr}}{\eta} = k \frac{1}{\cos^2 \alpha} \frac{\pi^2 E}{12(1-\nu_e^2)} \left[\frac{t}{b}\right]^2$$

FIGURE C2-40. BUCKLING COEFFICIENTS OF CLAMPED OBLIQUE FLAT PLATES IN SHEAR

$$\frac{f_{cr}}{\eta} = k \frac{\pi^2 E}{12(1-\nu_e^2)} \left[t/b\right]^2$$

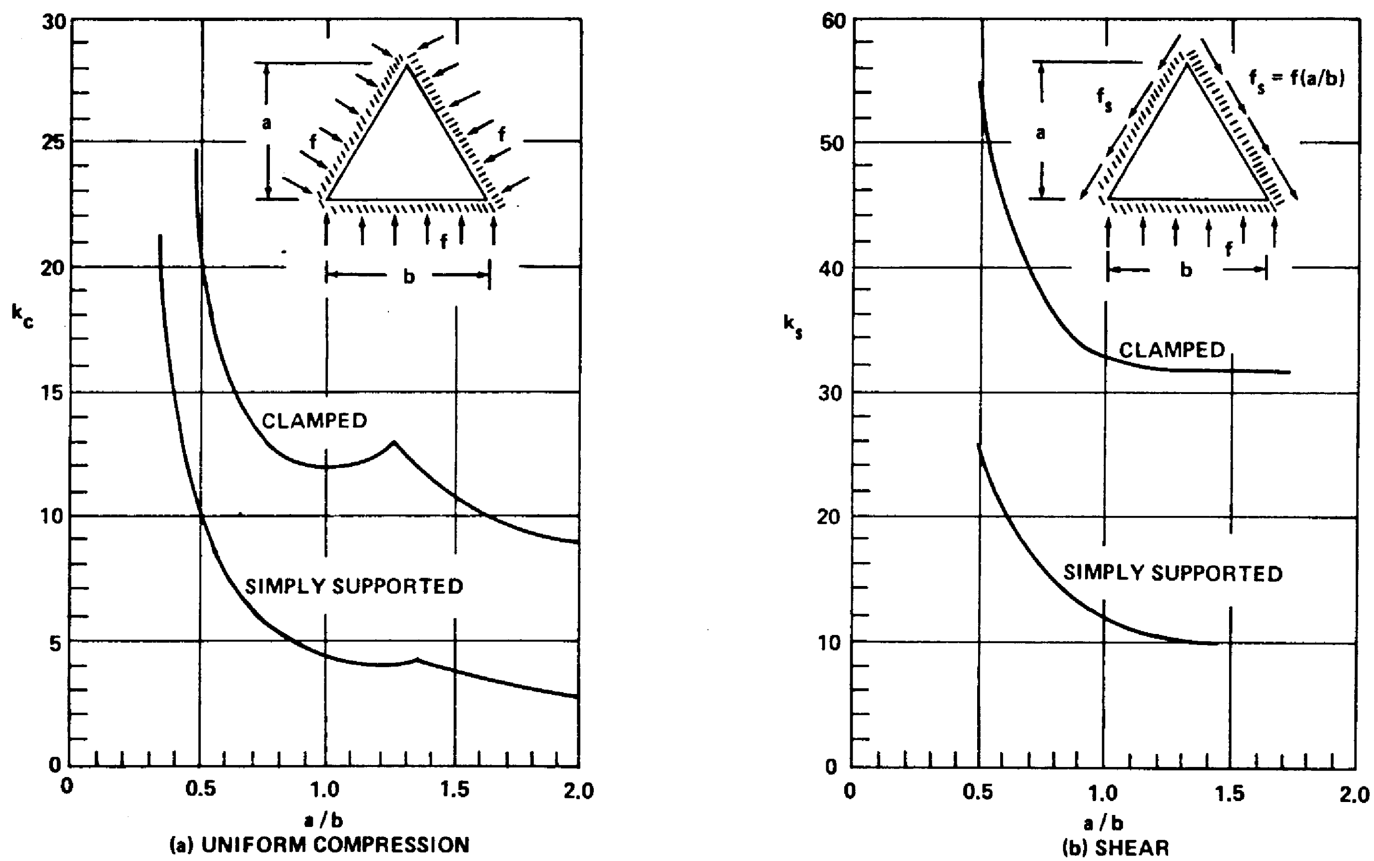
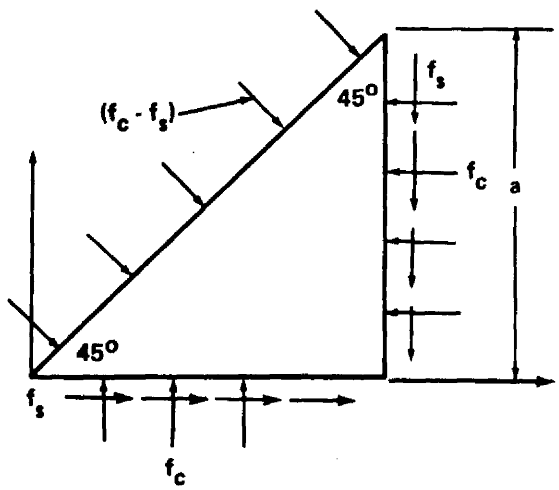


FIGURE C2-41. BUCKLING COEFFICIENTS FOR ISOSCELES TRIANGULAR PLATES



$$\frac{f_{cr}}{\eta} = k \frac{\pi^2 E}{12(1 - \nu_e^2)} \; t^2/a^2$$

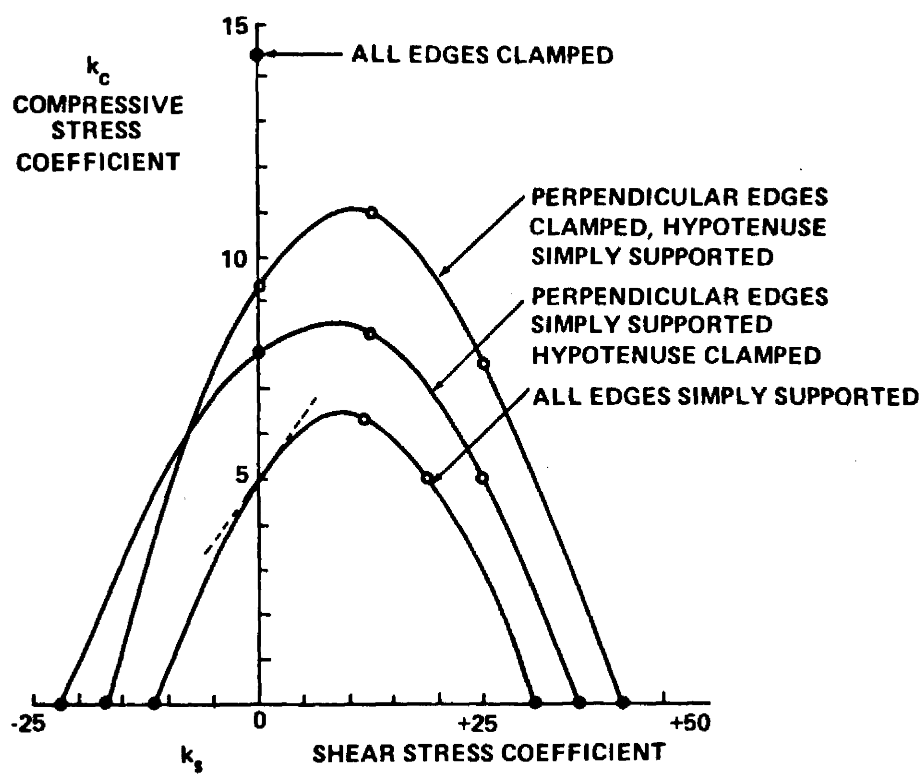


FIGURE C2-42. INTERACTION CURVES FOR BUCKLING OF RIGHT-ANGLED ISOSCELES TRIANGULAR PLATE

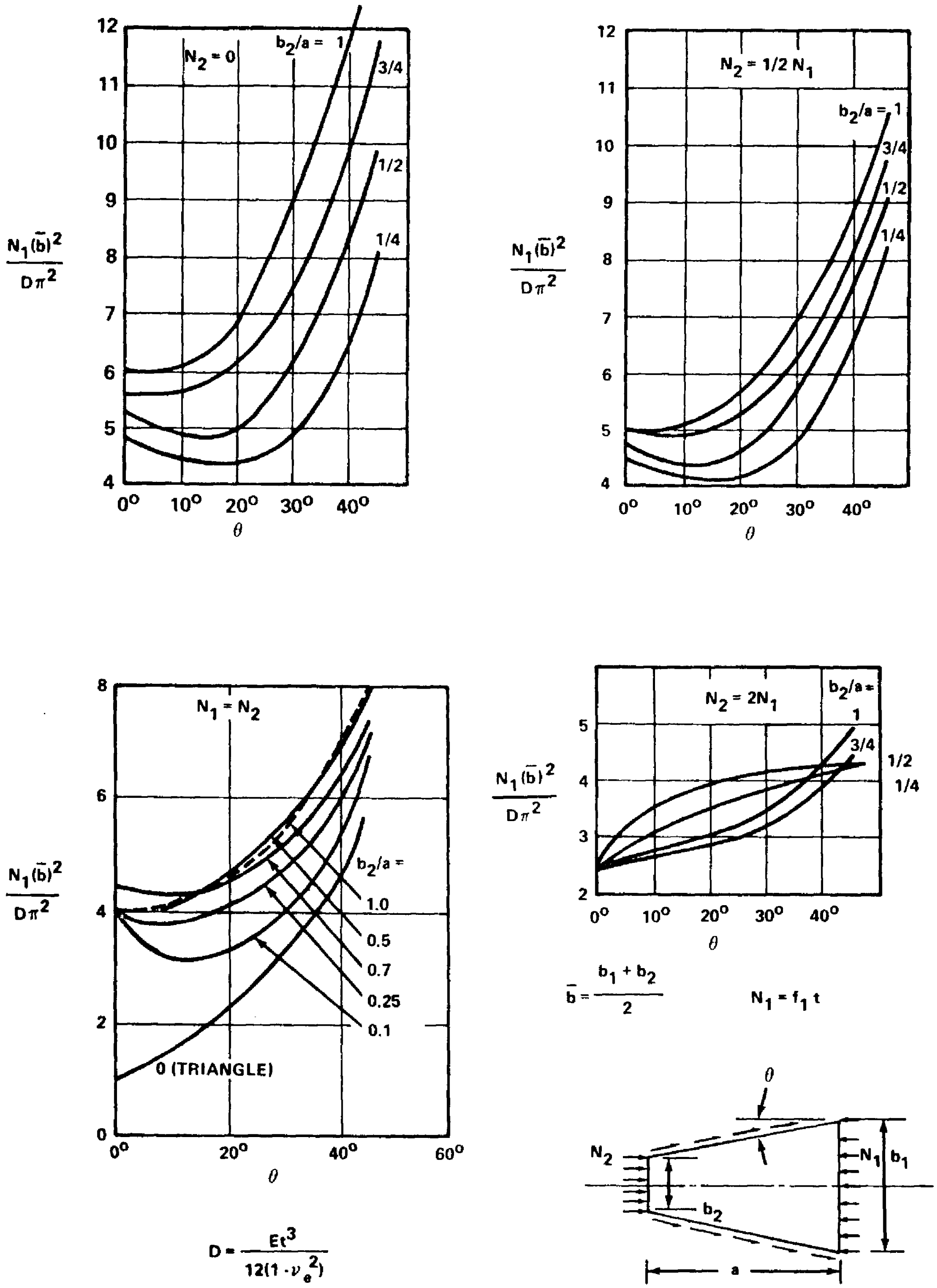


FIGURE C2-43. BUCKLING CURVES FOR TRAPEZOIDAL PLATES

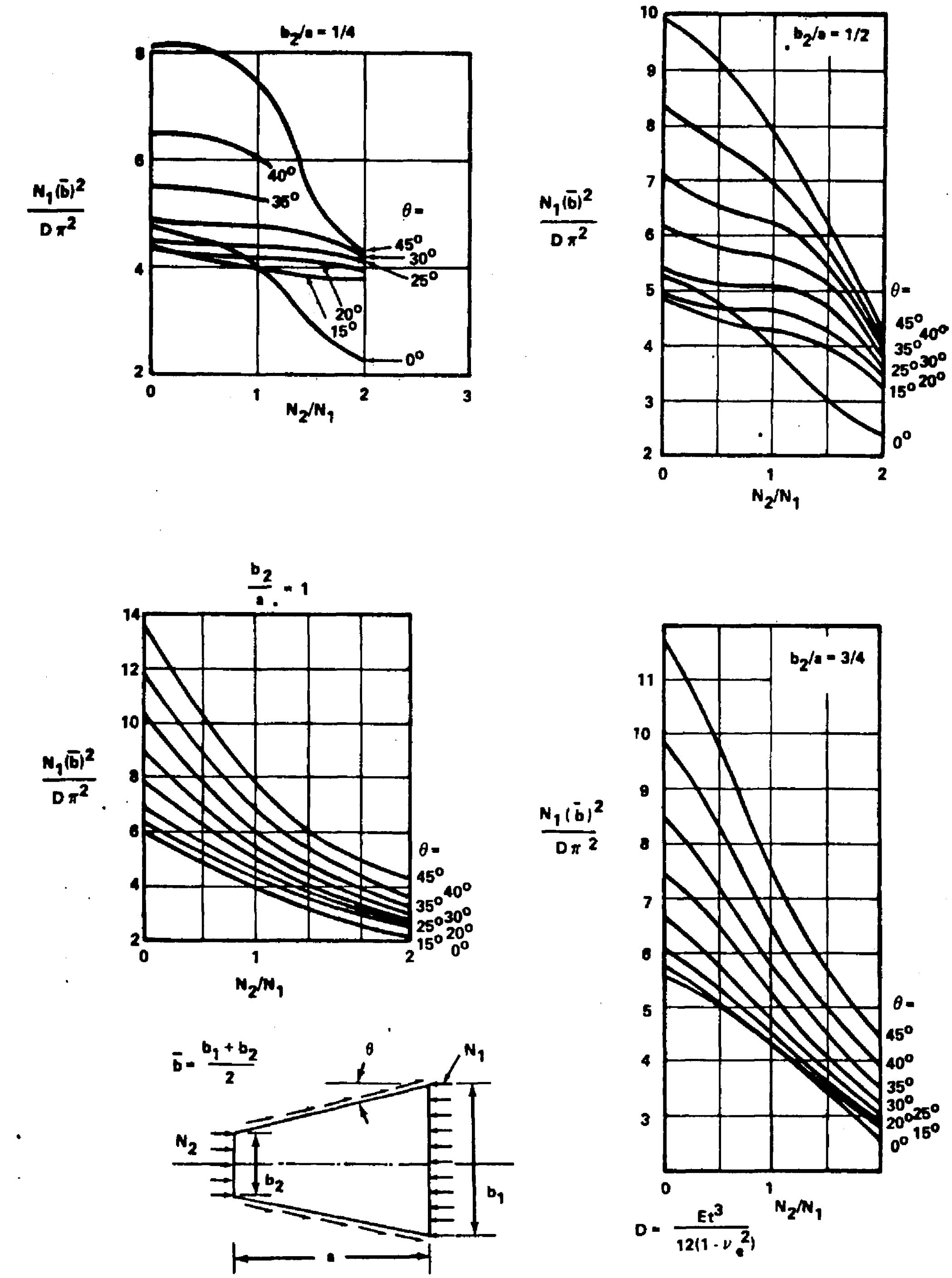


FIGURE C2-44. BUCKLING CURVES FOR TRAPEZOIDAL PLATES

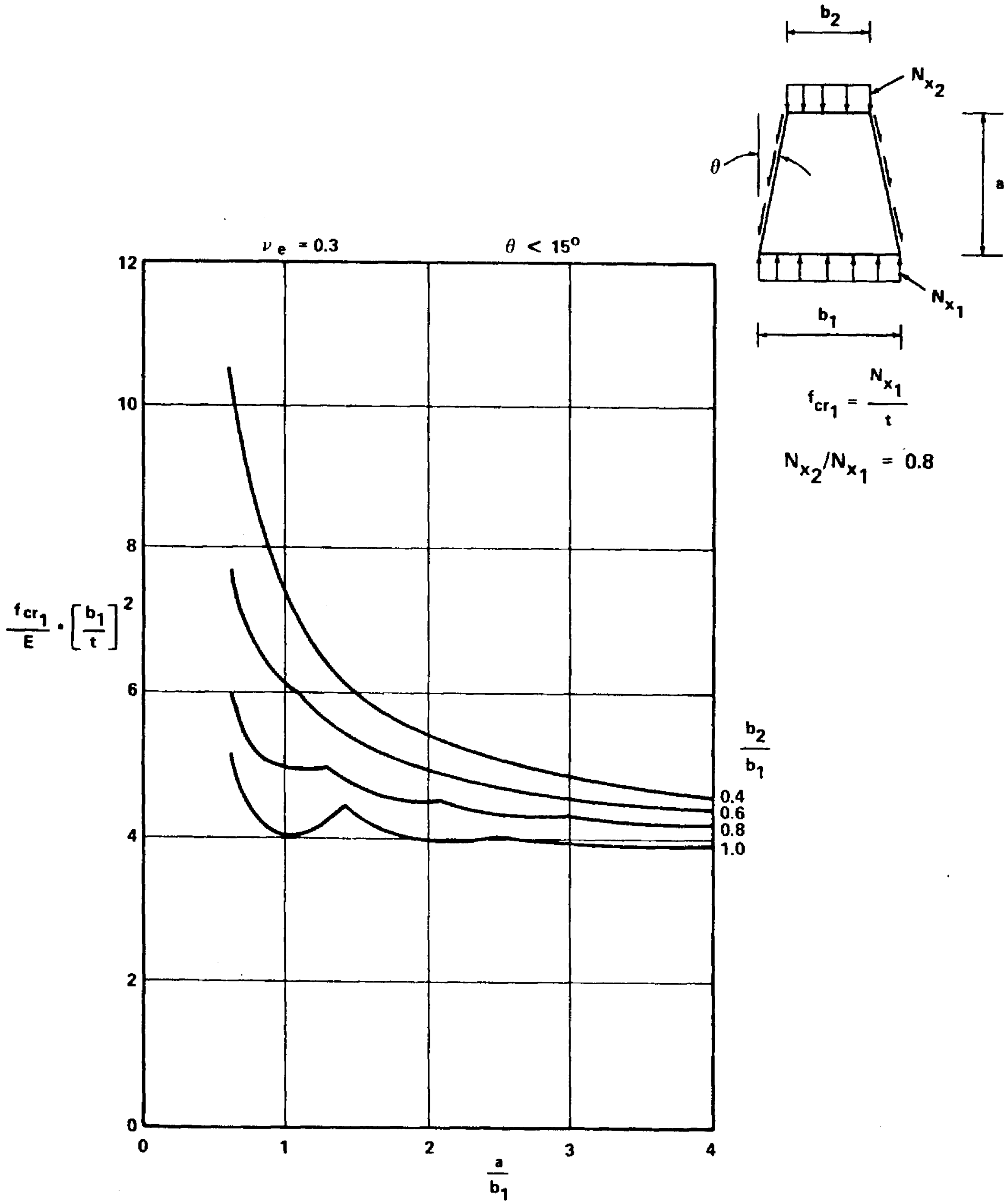


FIGURE C2-45. BUCKLING STRESS DIAGRAM (Sides and ends simply-supported. No stress normal to sides.)

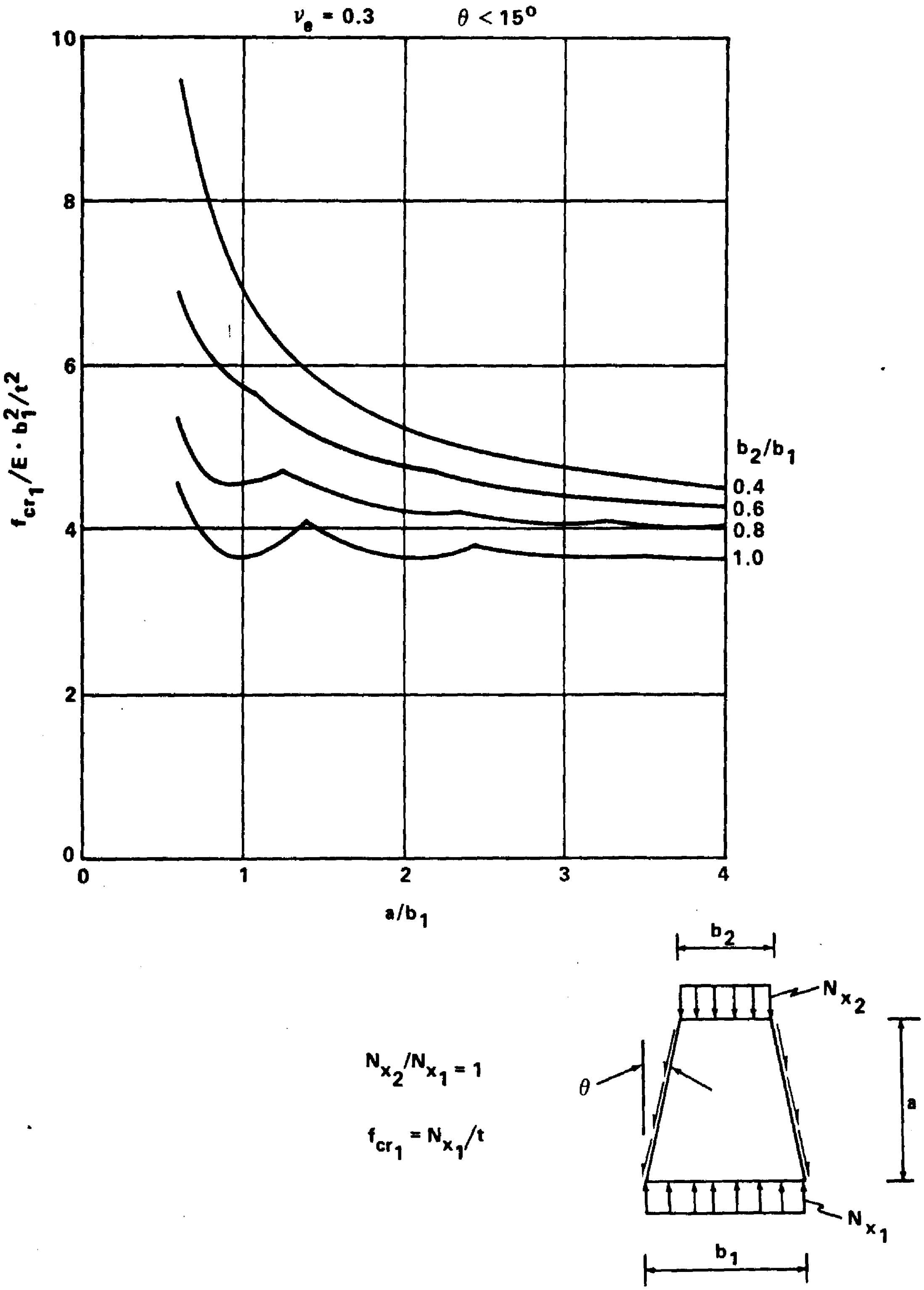


FIGURE C2-46. BUCKLING STRESS DIAGRAM (Sides and ends simply-supported. No stress normal to sides.)

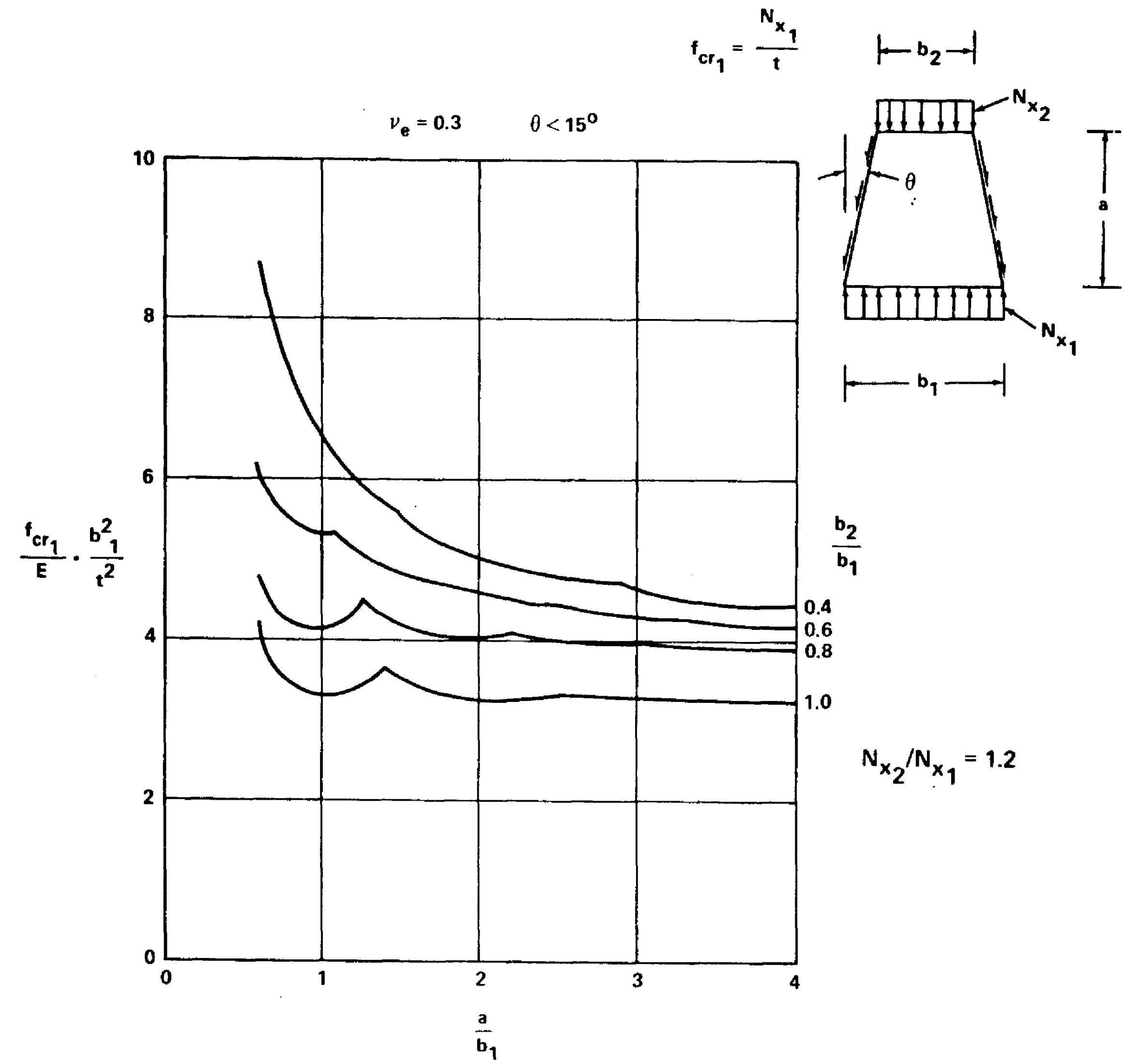


FIGURE C2-47. BUCKLING STRESS DIAGRAM (Sides and ends simply-supported. No stress normal to sides.)

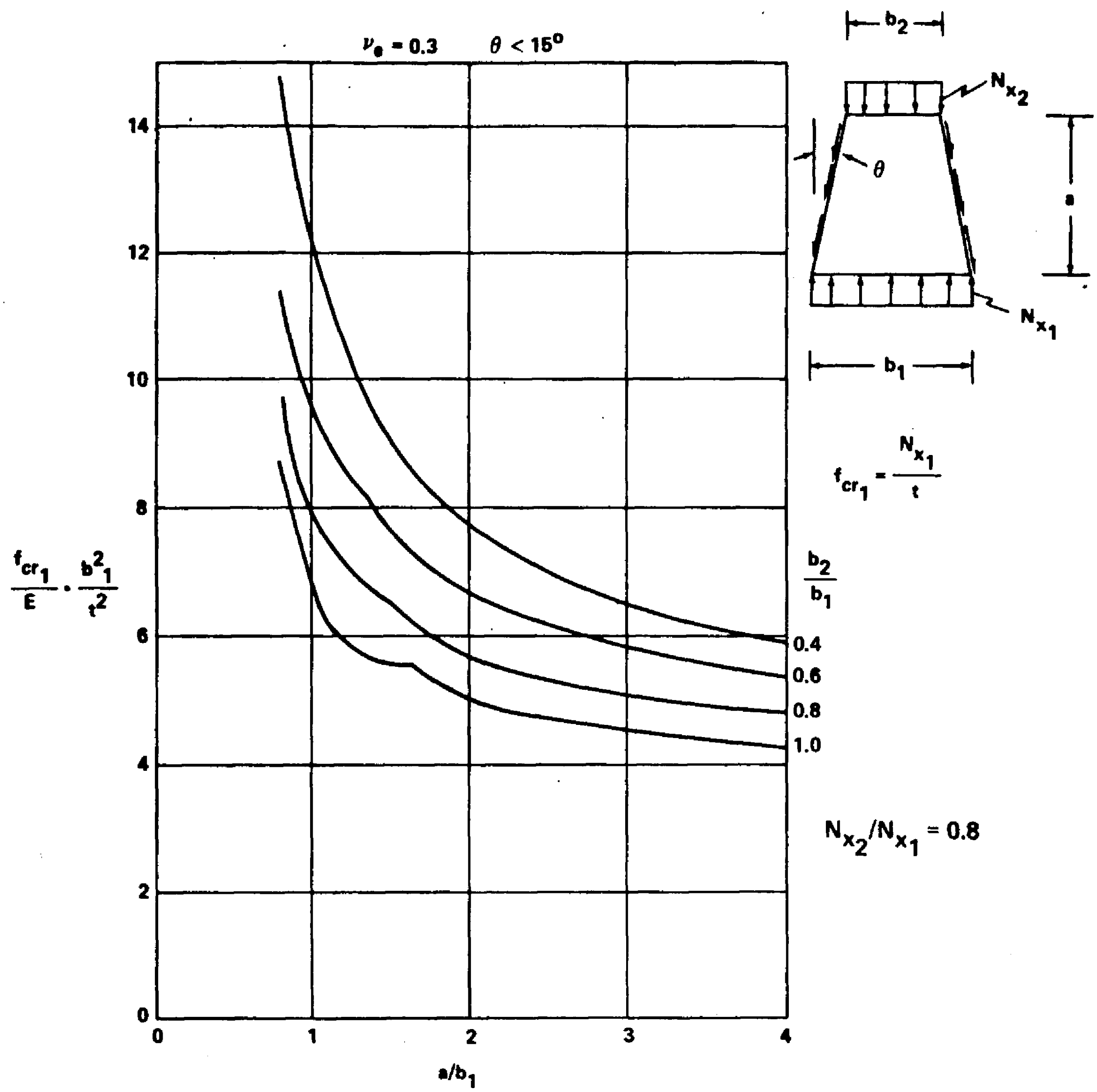


FIGURE C2-48. BUCKLING STRESS DIAGRAM (Sides simply-supported. Ends clamped. No stress normal to sides.)

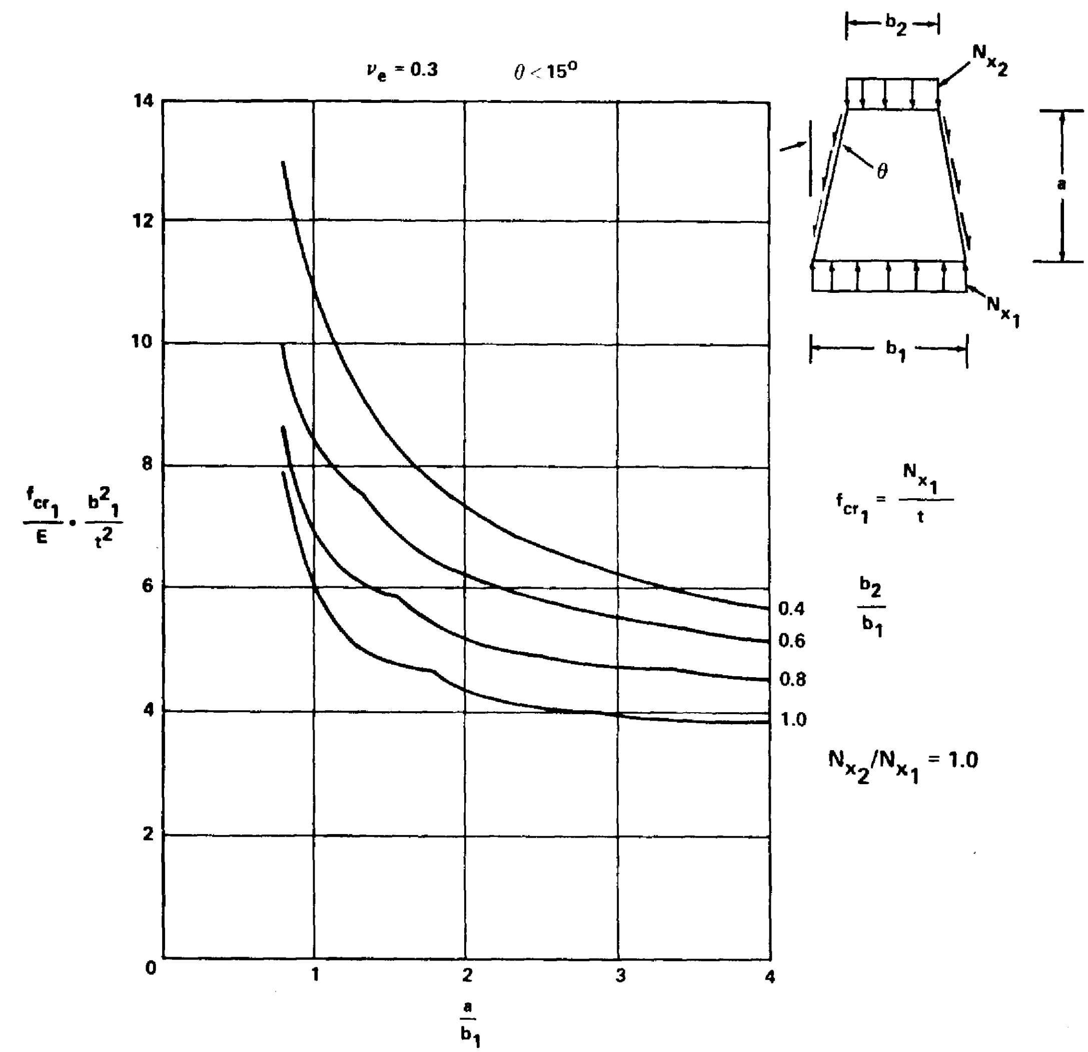


FIGURE C2-49. BUCKLING STRESS DIAGRAM (Sides simply-supported. Ends clamped. No stress normal to sides.)

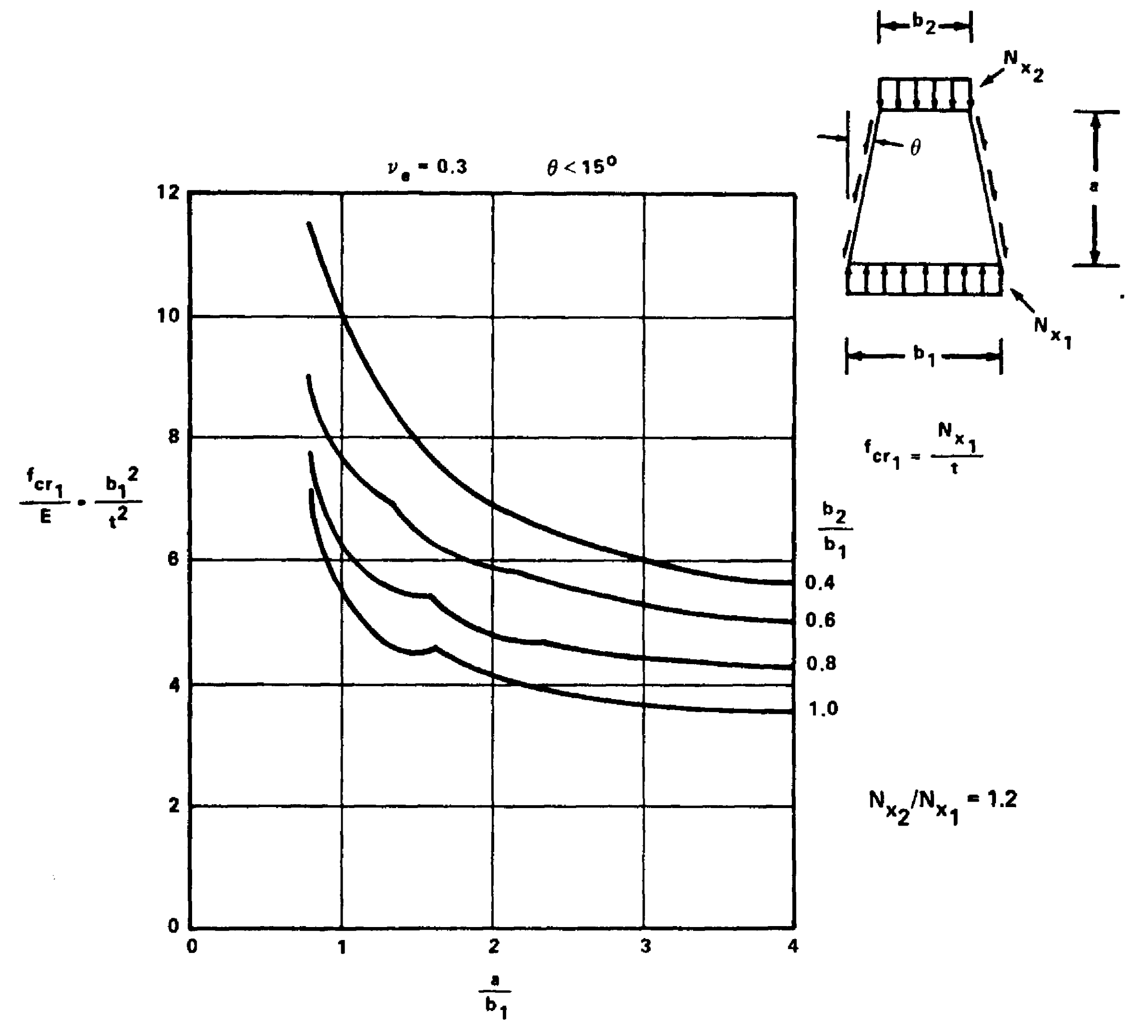


FIGURE C2-50. BUCKLING STRESS DIAGRAM (Sides simply-supported. Ends clamped. No stress normal to sides.)

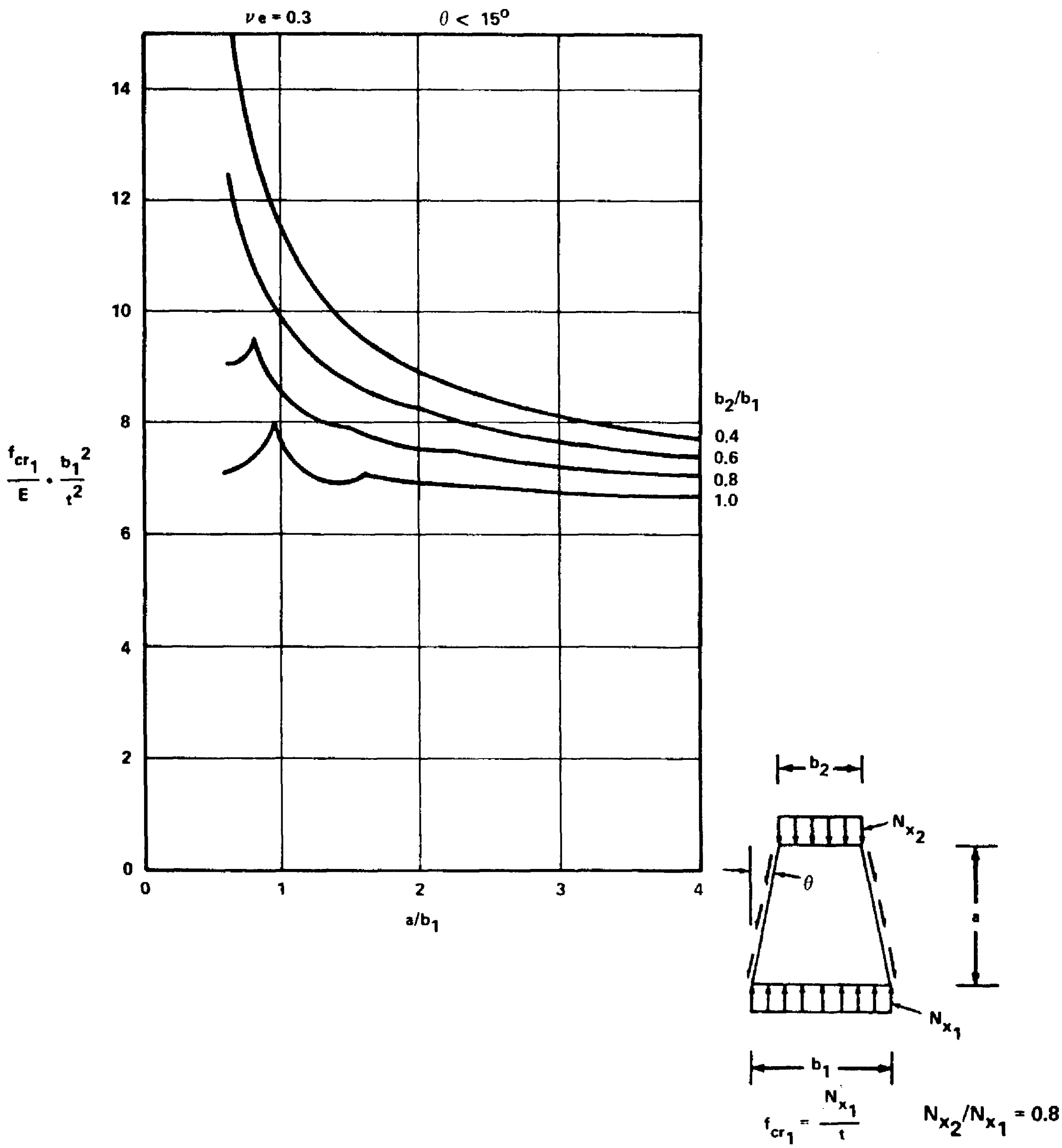


FIGURE C2-51. BUCKLING STRESS DIAGRAM (Sides clamped. Ends simply-supported. No stress normal to sides.)

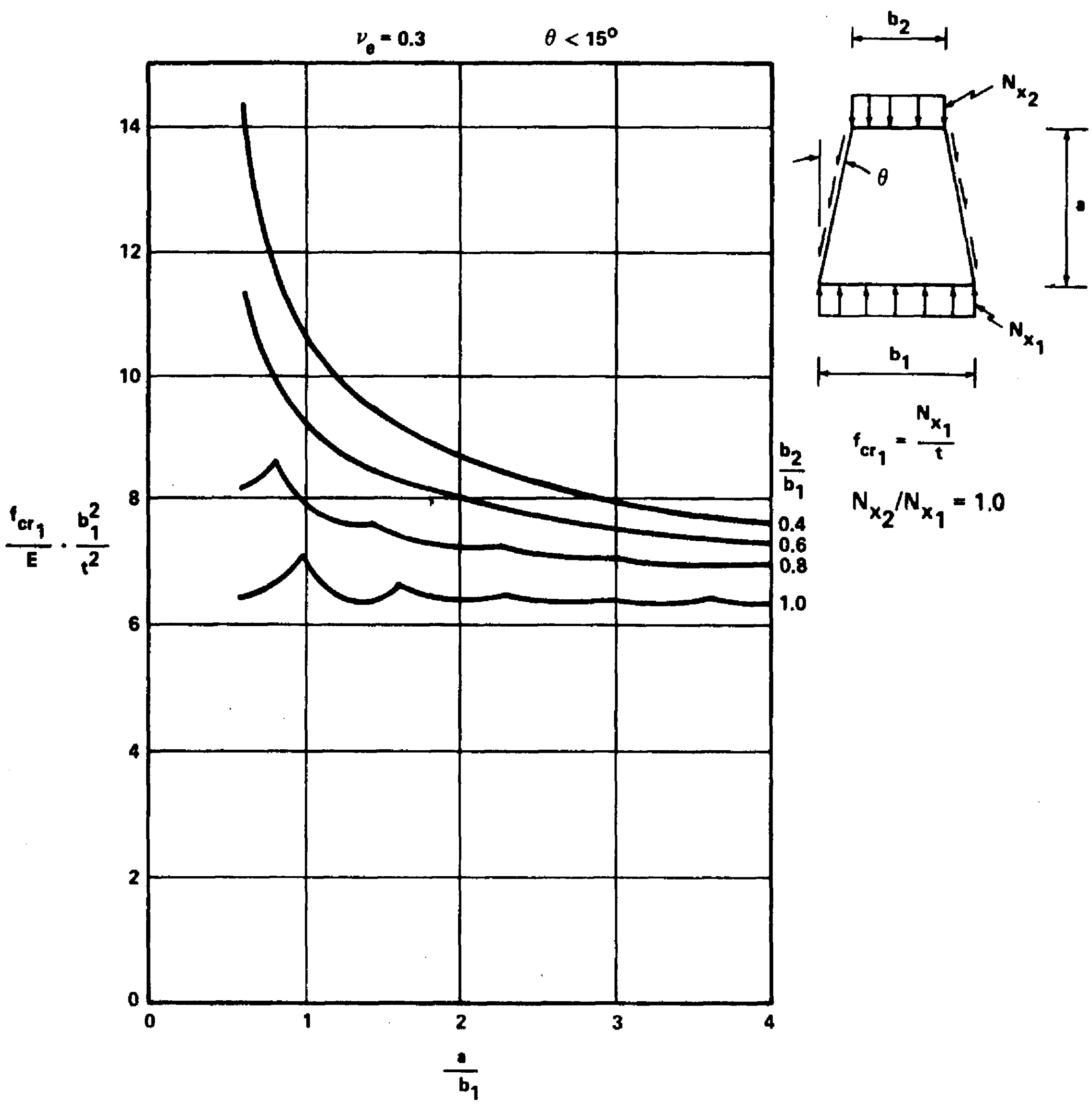


FIGURE C2-52. BUCKLING STRESS DIAGRAM (Sides clamped. Ends simply-supported. No stress normal to sides.)

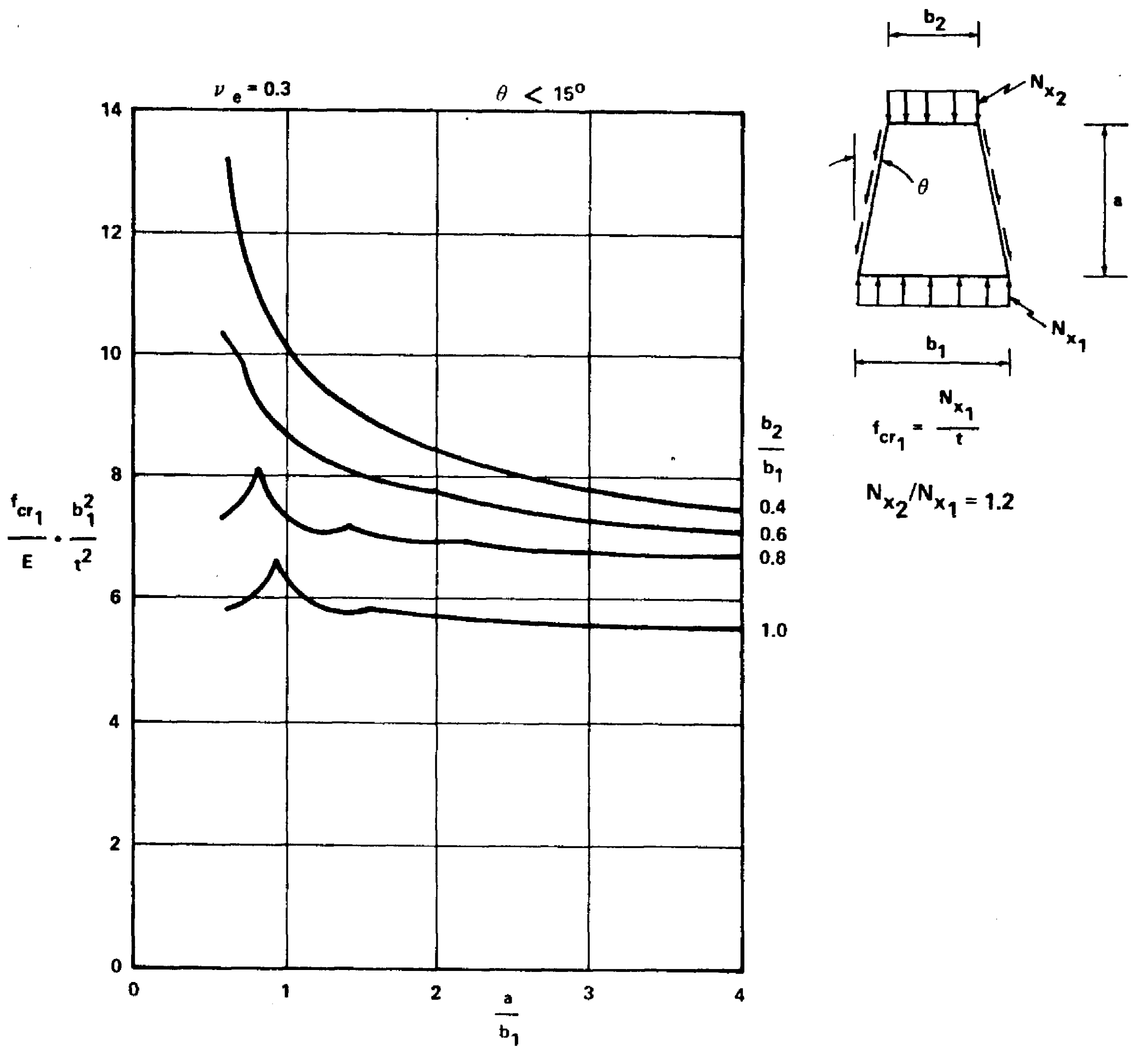


FIGURE C2-53. BUCKLING STRESS DIAGRAM (Sides clamped. Ends simply-supported. No stress normal to sides.)

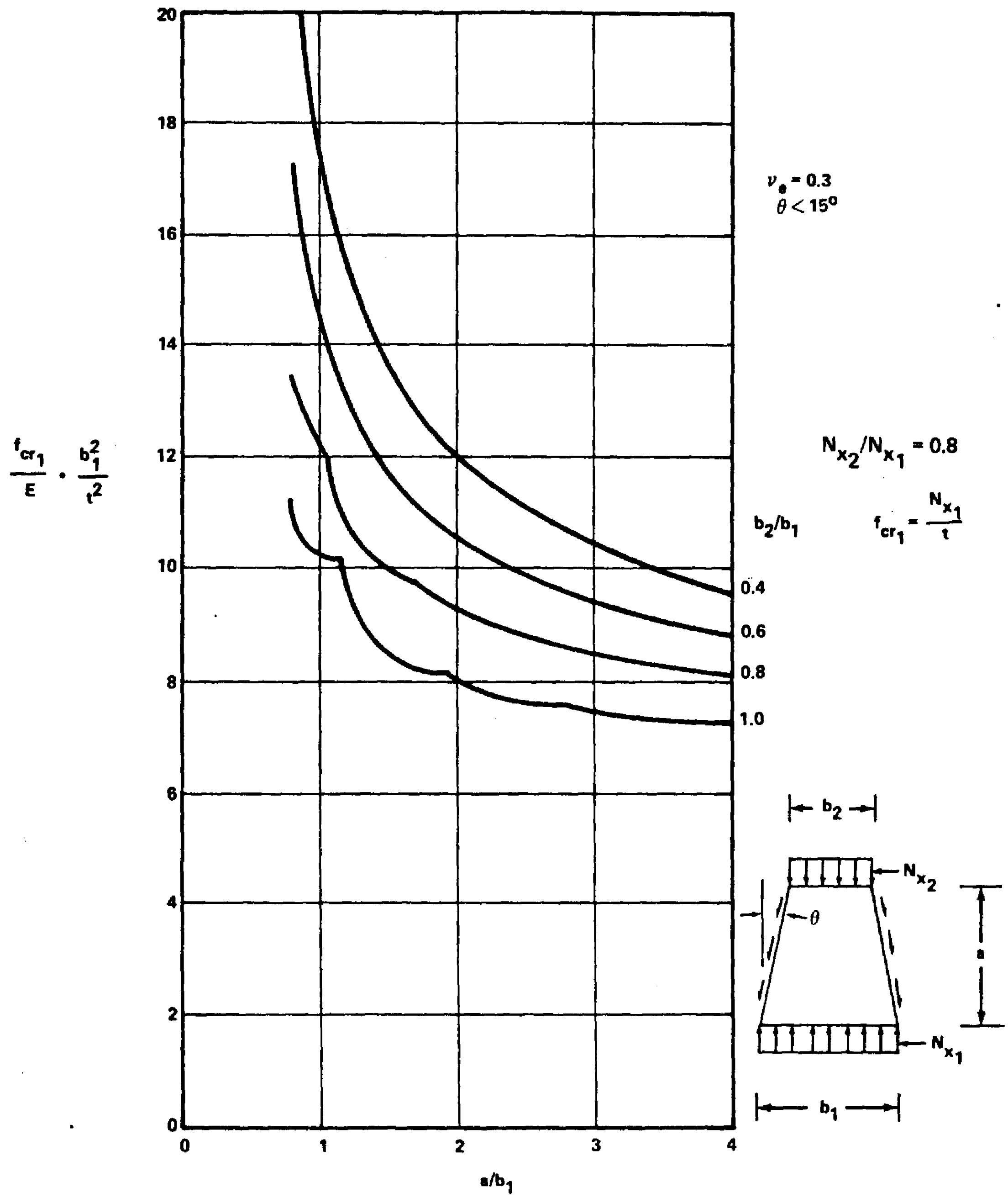


FIGURE C2-54. BUCKLING STRESS DIAGRAM (Sides and ends clamped. No stress normal to sides.)

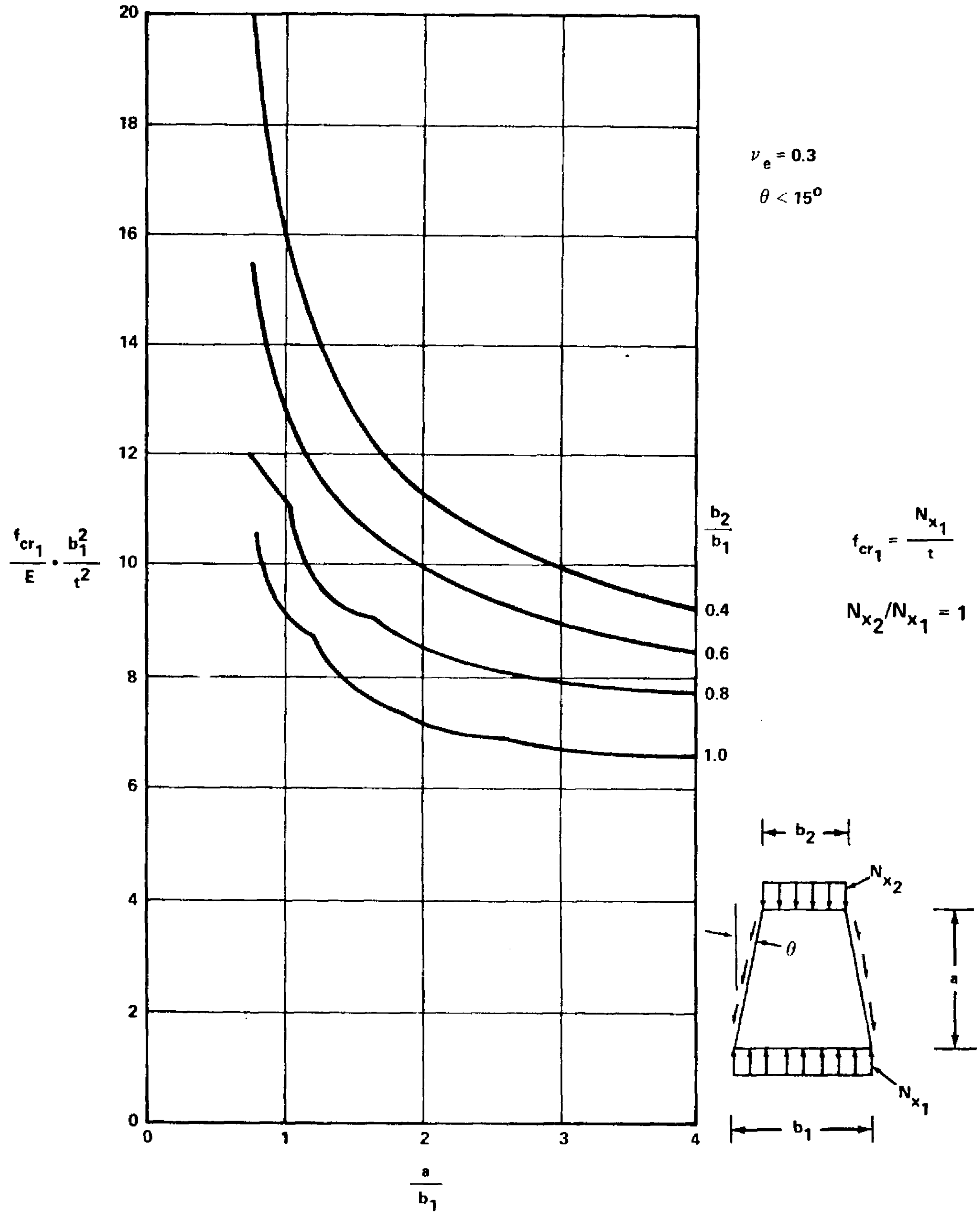


FIGURE C2-55. BUCKLING STRESS DIAGRAM (Sides and ends clamped. No stress normal to sides.)

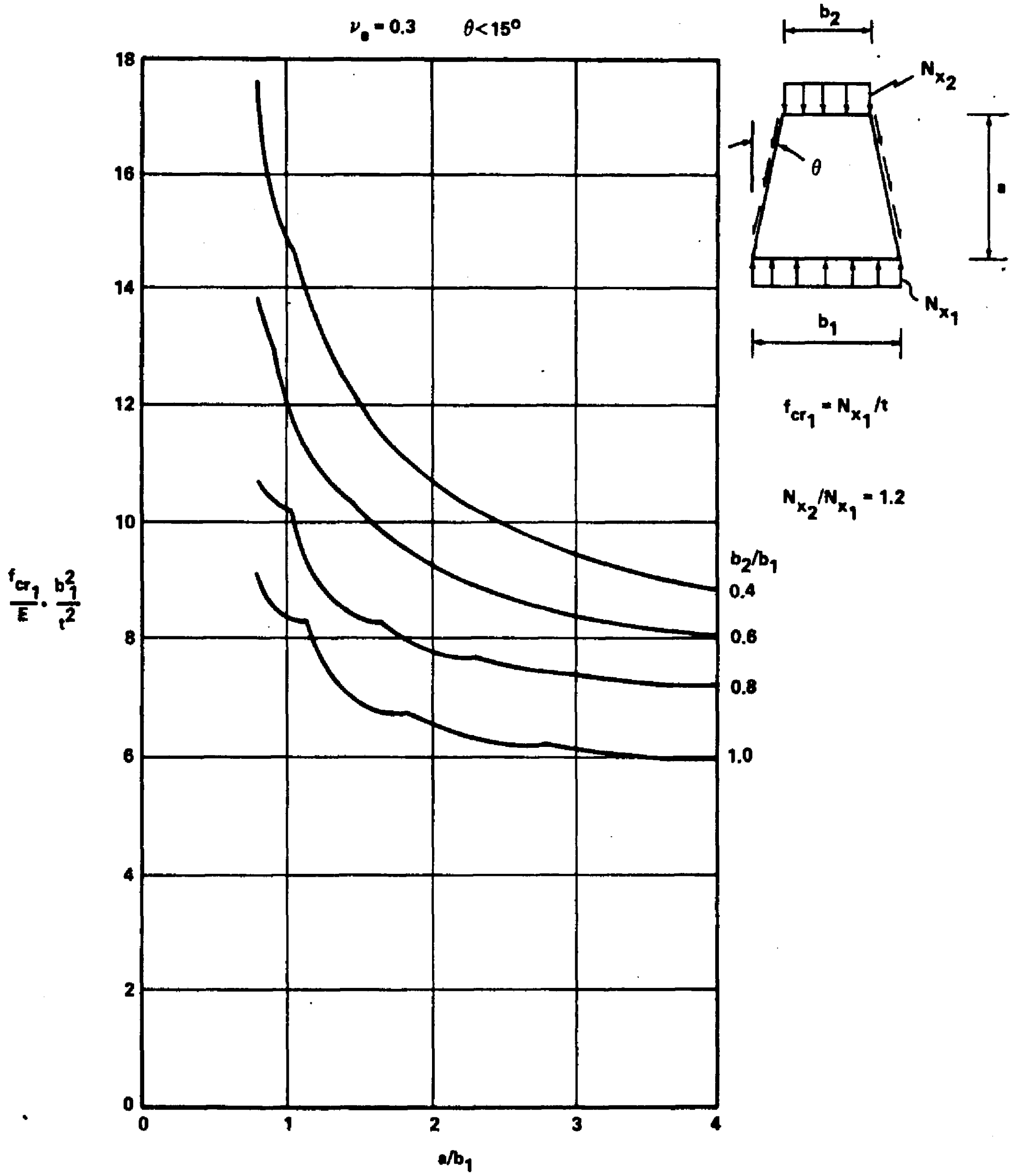


FIGURE C2-56. BUCKLING STRESS DIAGRAM (Sides and ends clamped. No stress normal to sides.)

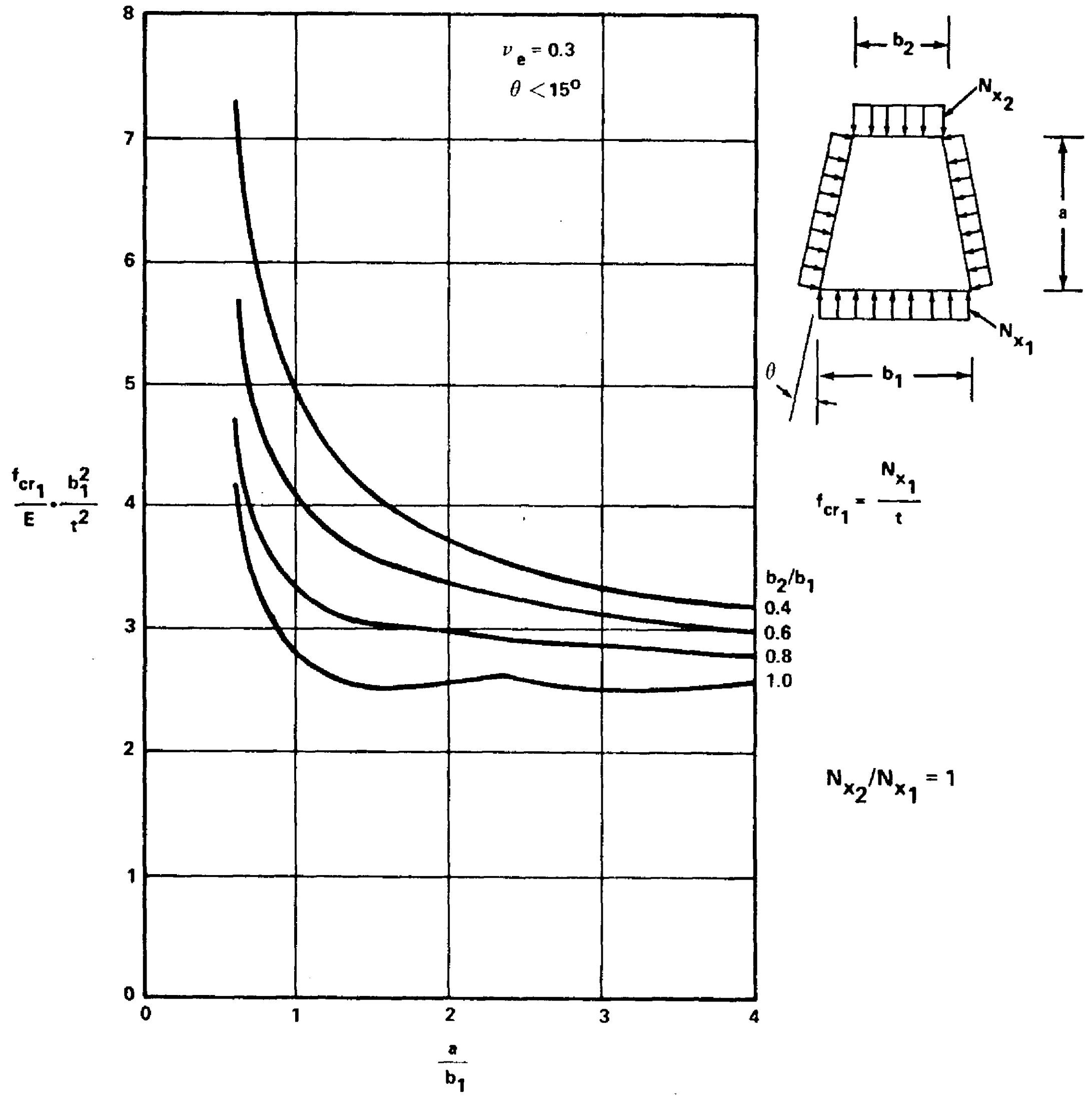


FIGURE C2-57. BUCKLING STRESS DIAGRAM (Sides and ends simply-supported. No displacement of the sides normal to the direction of taper.)

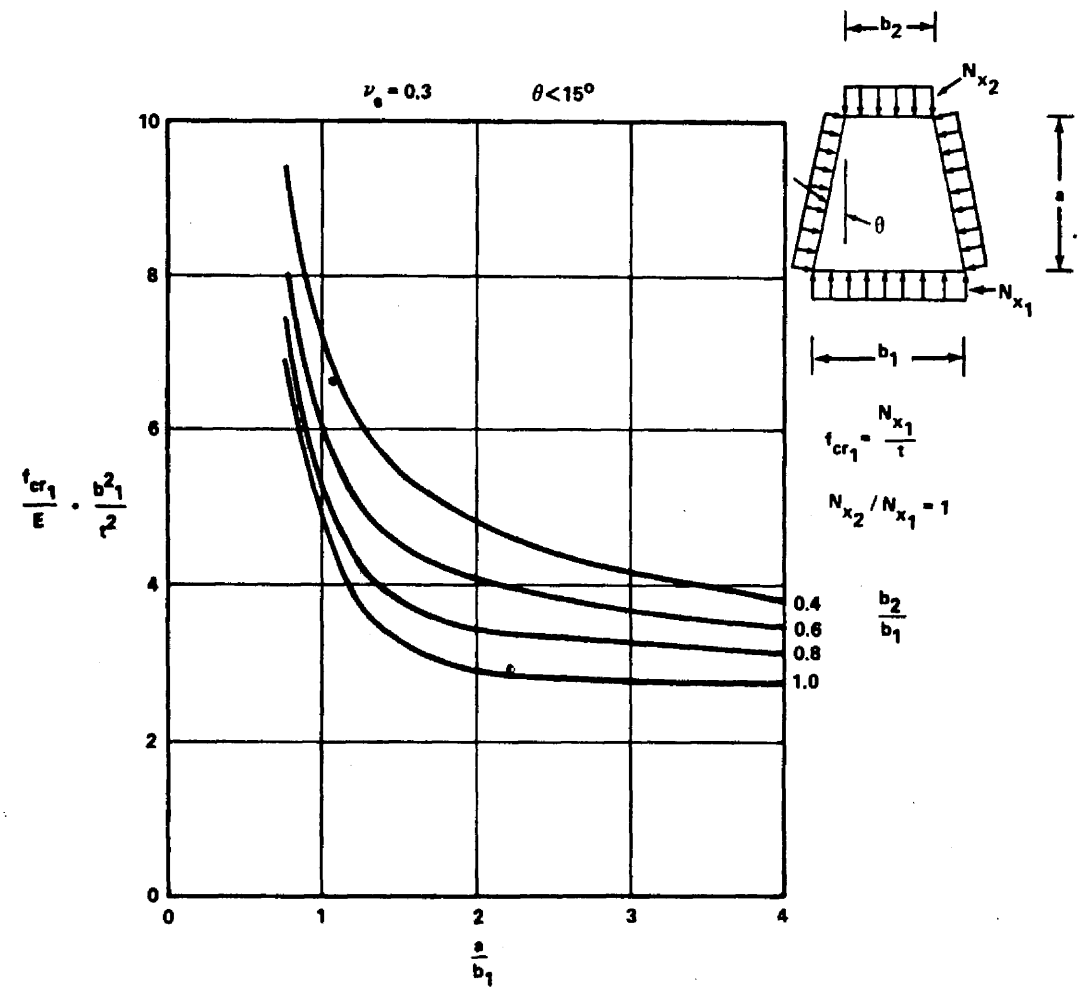


FIGURE C2-58. BUCKLING STRESS DIAGRAM (Sides simply-supported. Ends clamped. No displacement of the sides normal to the direction of taper.)

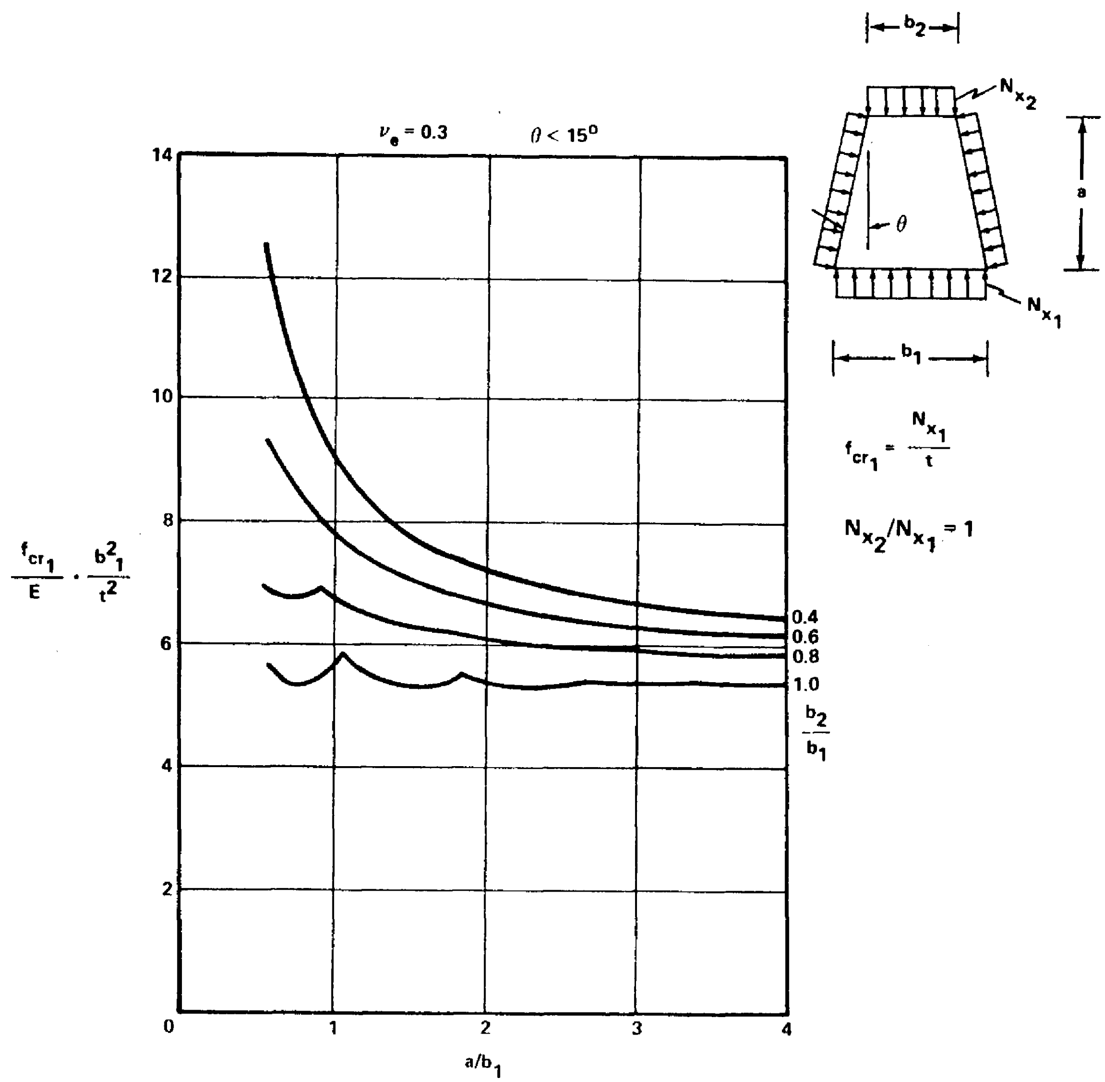


FIGURE C2-59. BUCKLING STRESS DIAGRAM (Sides clamped. Ends simply-supported. No displacement of the sides normal to the direction of taper.)

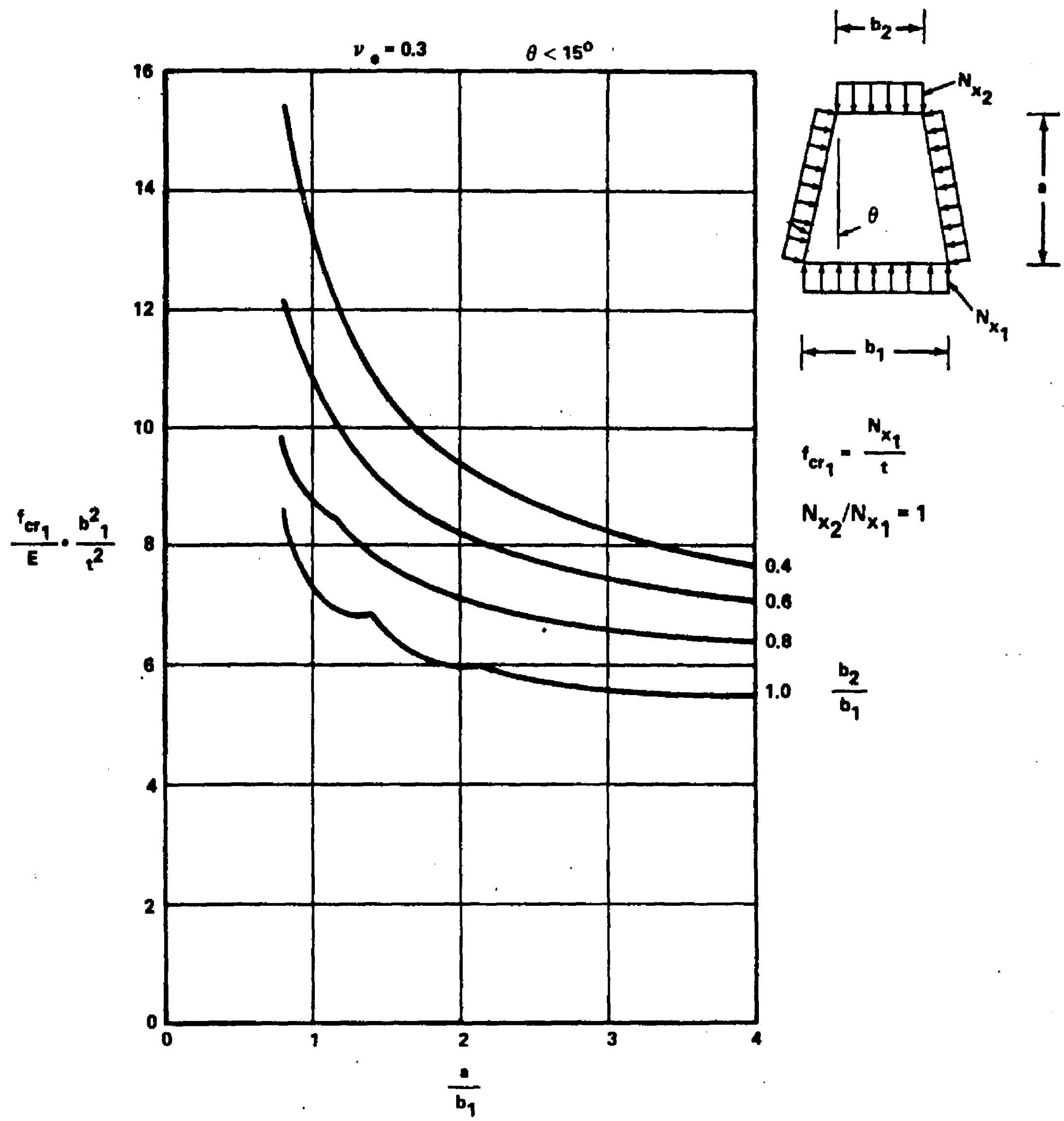
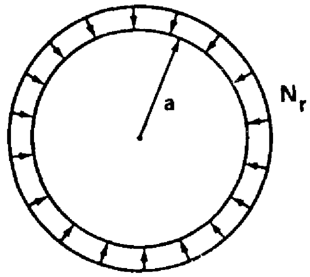
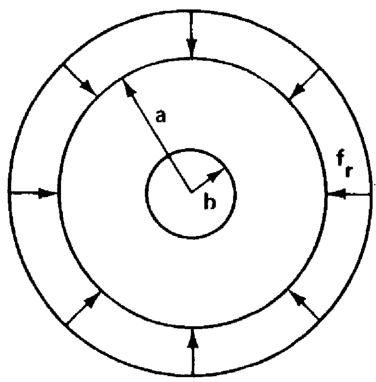


FIGURE C2-60. BUCKLING STRESS DIAGRAM (Sides and ends clamped. No displacement of the sides normal to the direction of taper.)



$$f_r = \frac{N_r}{t}$$

FIGURE C2-61. CIRCULAR PLATE SUBJECTED TO RADIAL LOAD



$$\frac{f_{r_{cr}}}{\eta} = k \frac{E}{12(1-\nu_e^2)} \frac{t^2}{a^2}$$

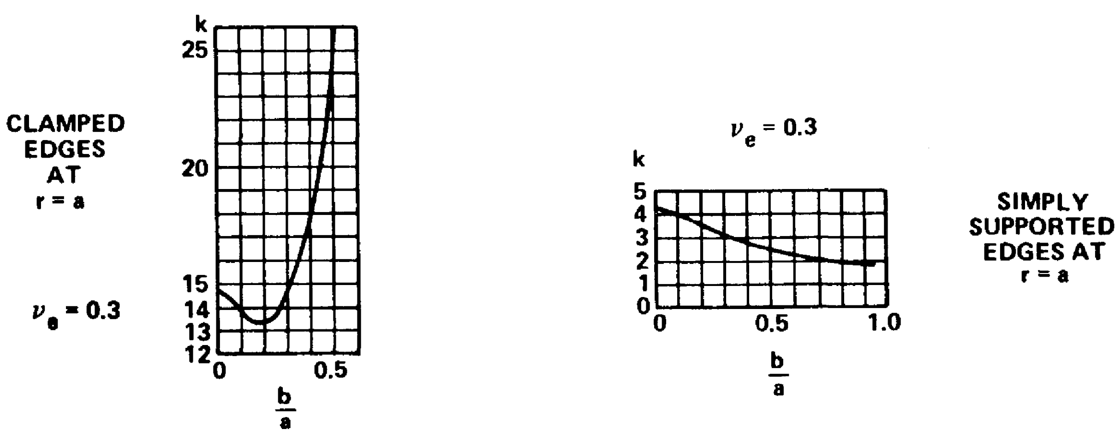


FIGURE C2-62. BUCKLING COEFFICIENTS FOR ANNULAR PLATE

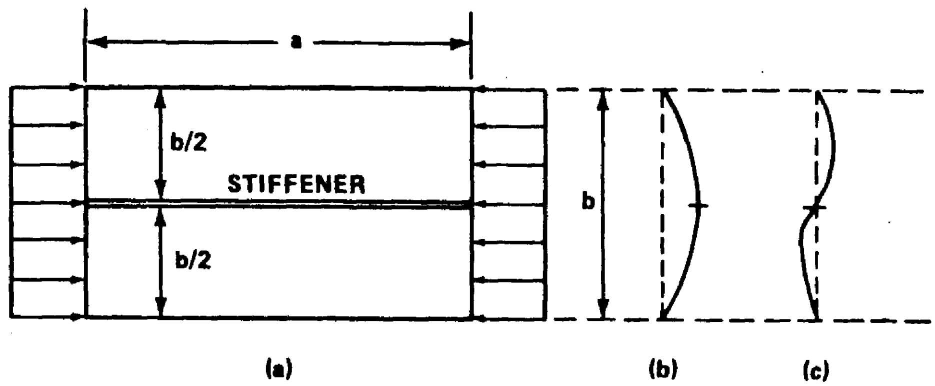


FIGURE C2-63. RECTANGULAR PLATE WITH CENTRAL LONGITUDINAL STIFFENER UNDER COMPRESSIVE LOAD

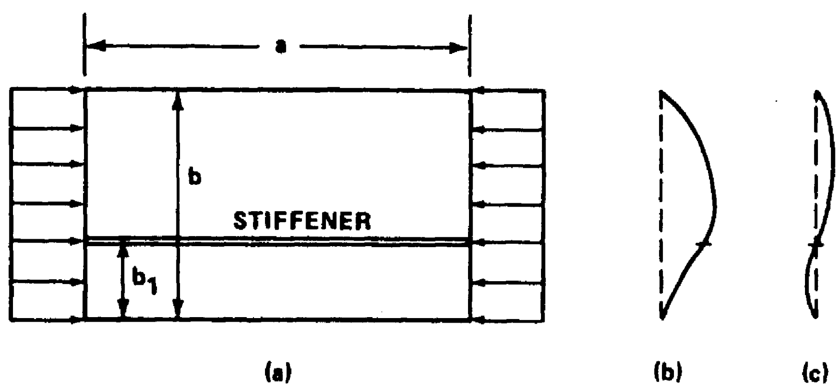


FIGURE C2-64. RECTANGULAR PLATE WITH ONE STIFFENER ECCENTRICALLY LOCATED UNDER COMPRESSION

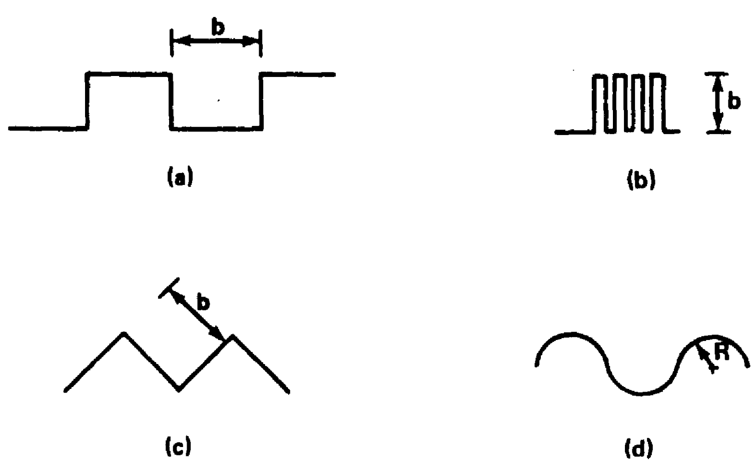


FIGURE C2-65. TYPICAL CORRUGATIONS

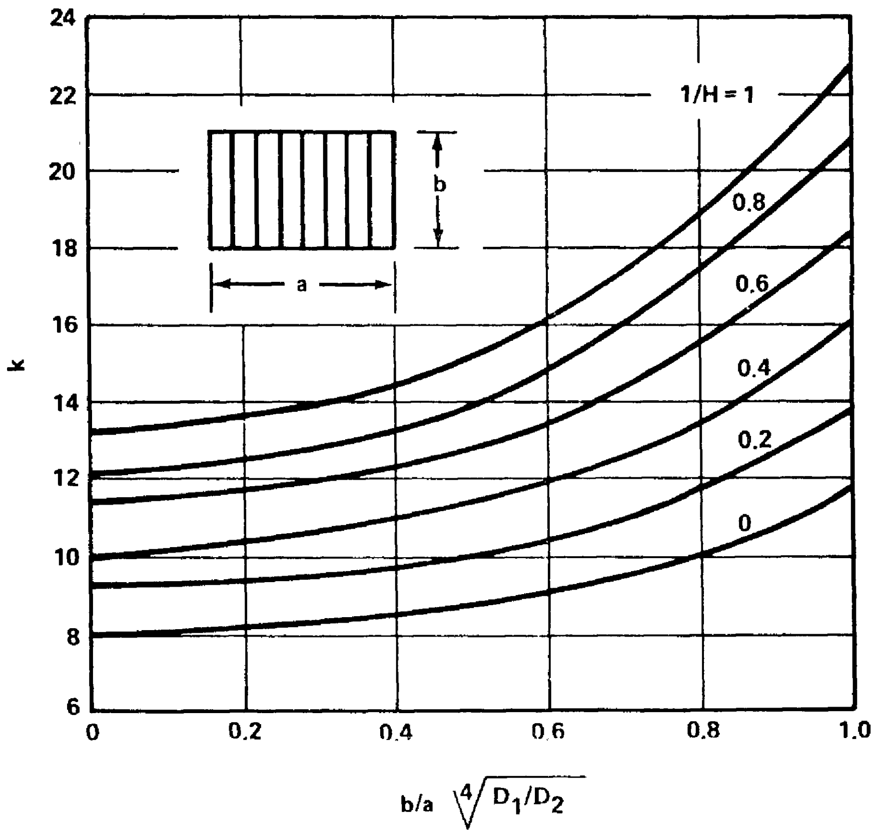


FIGURE C2-66. SHEAR BUCKLING COEFFICIENTS FOR FLAT SIMPLY SUPPORTED CORRUGATED PLATES WHEN H > 1

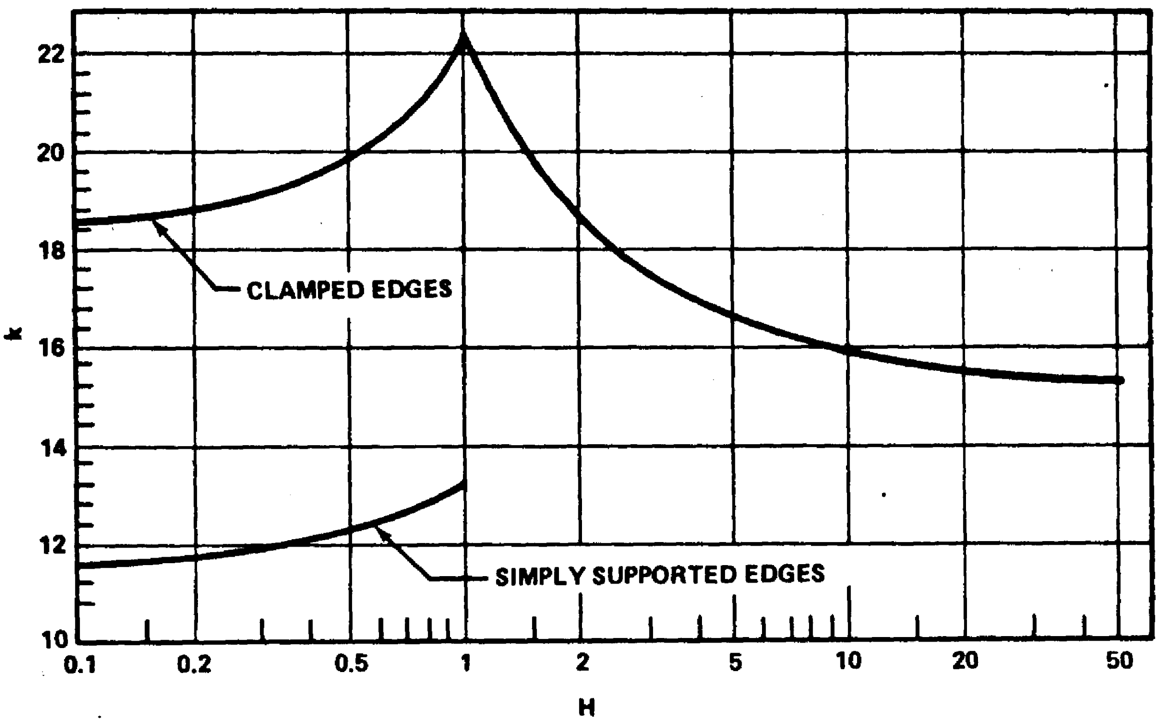
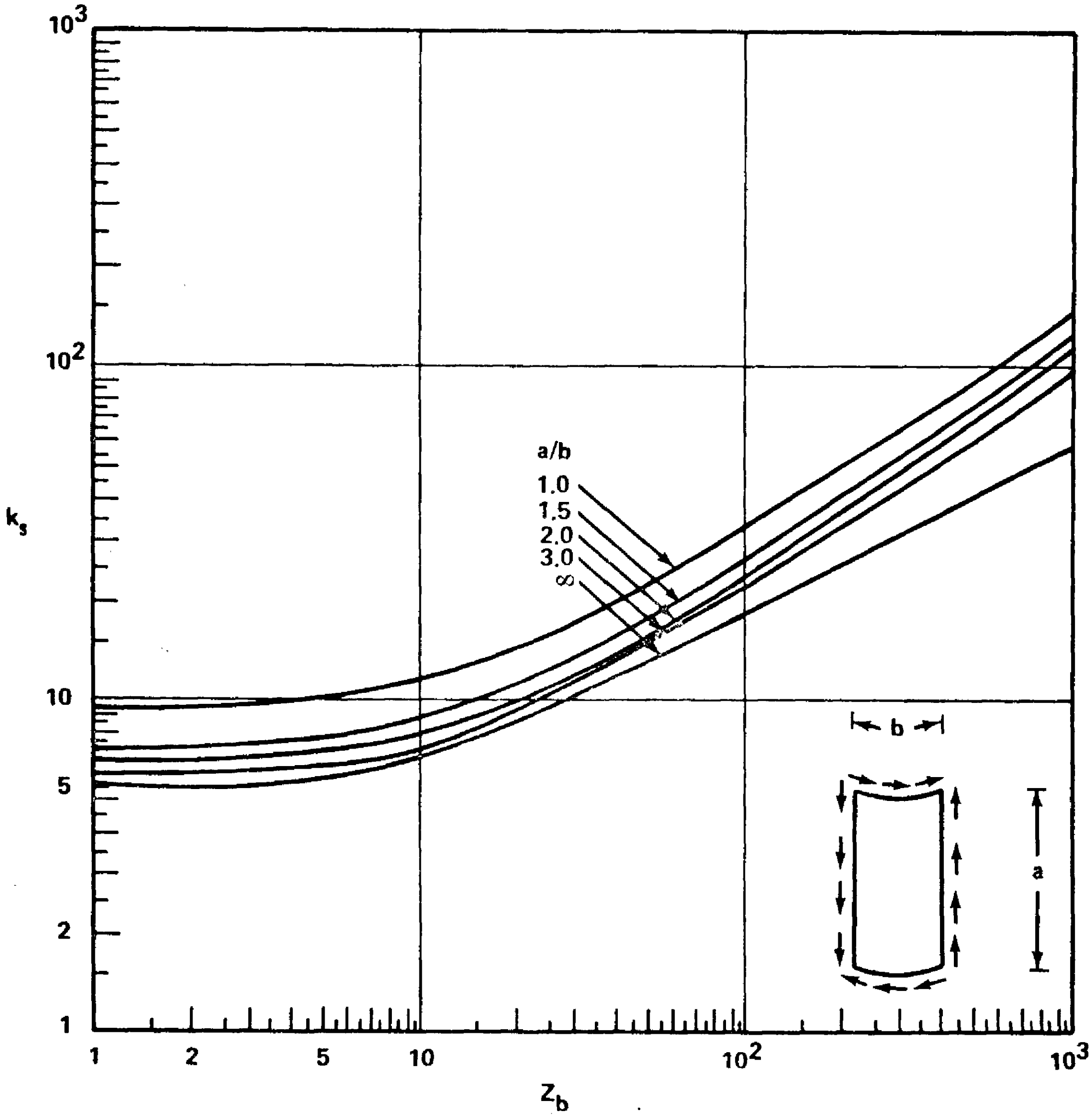


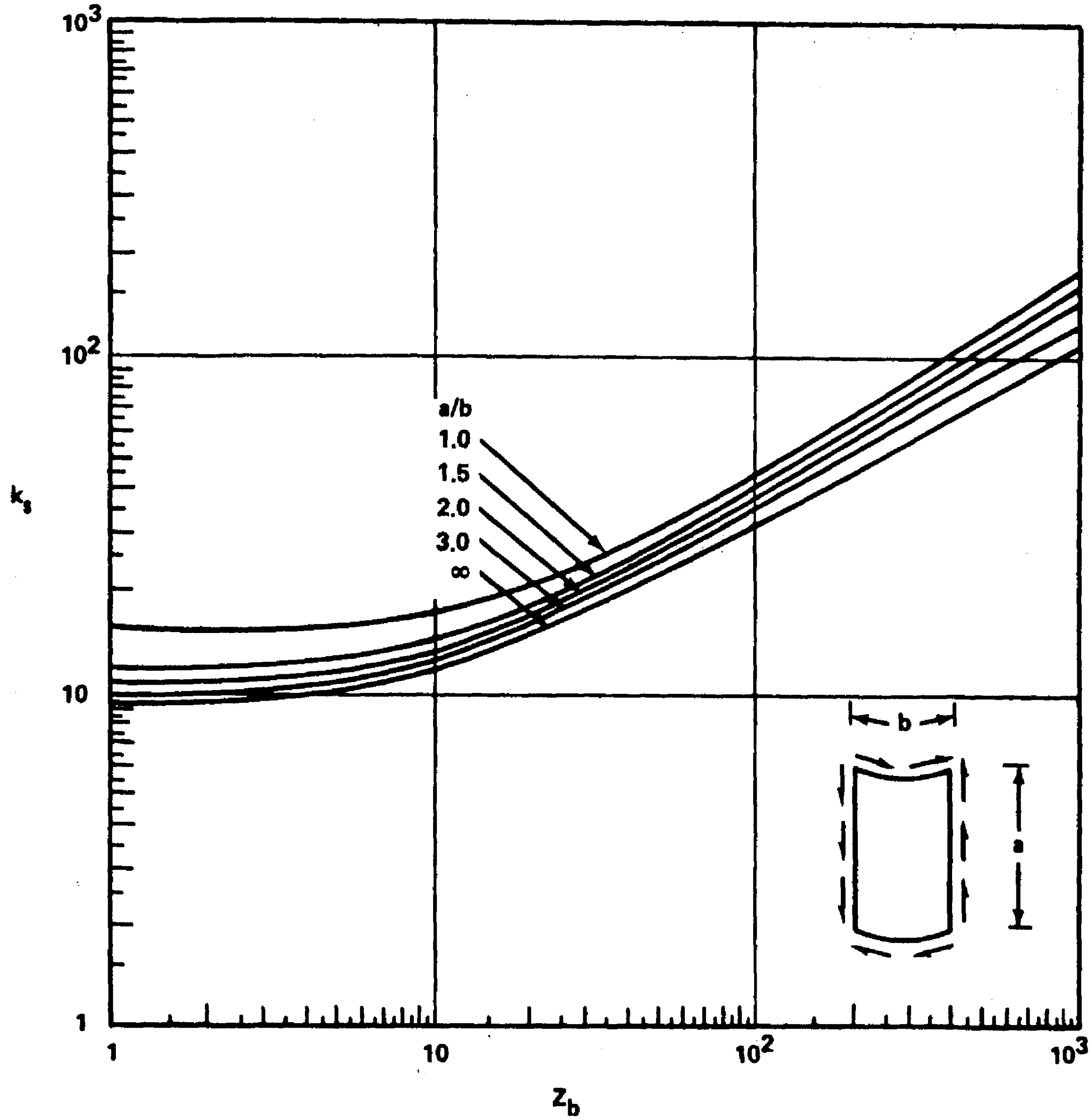
FIGURE C2-67. SHEAR BUCKLING COEFFICIENTS FOR FLAT INFINITELY LONG CORRUGATED PLATES: SIMPLY SUPPORTED EDGES, H<1 AND CLAMPED EDGES

$$F_{s_{cr}} = \frac{k_s \pi^2 E}{12(1 - \nu_e^2)} (t/b)^2 \; ; \; Z_b = b^2/rt \; (1 - \nu_e^2)^{1/2}$$



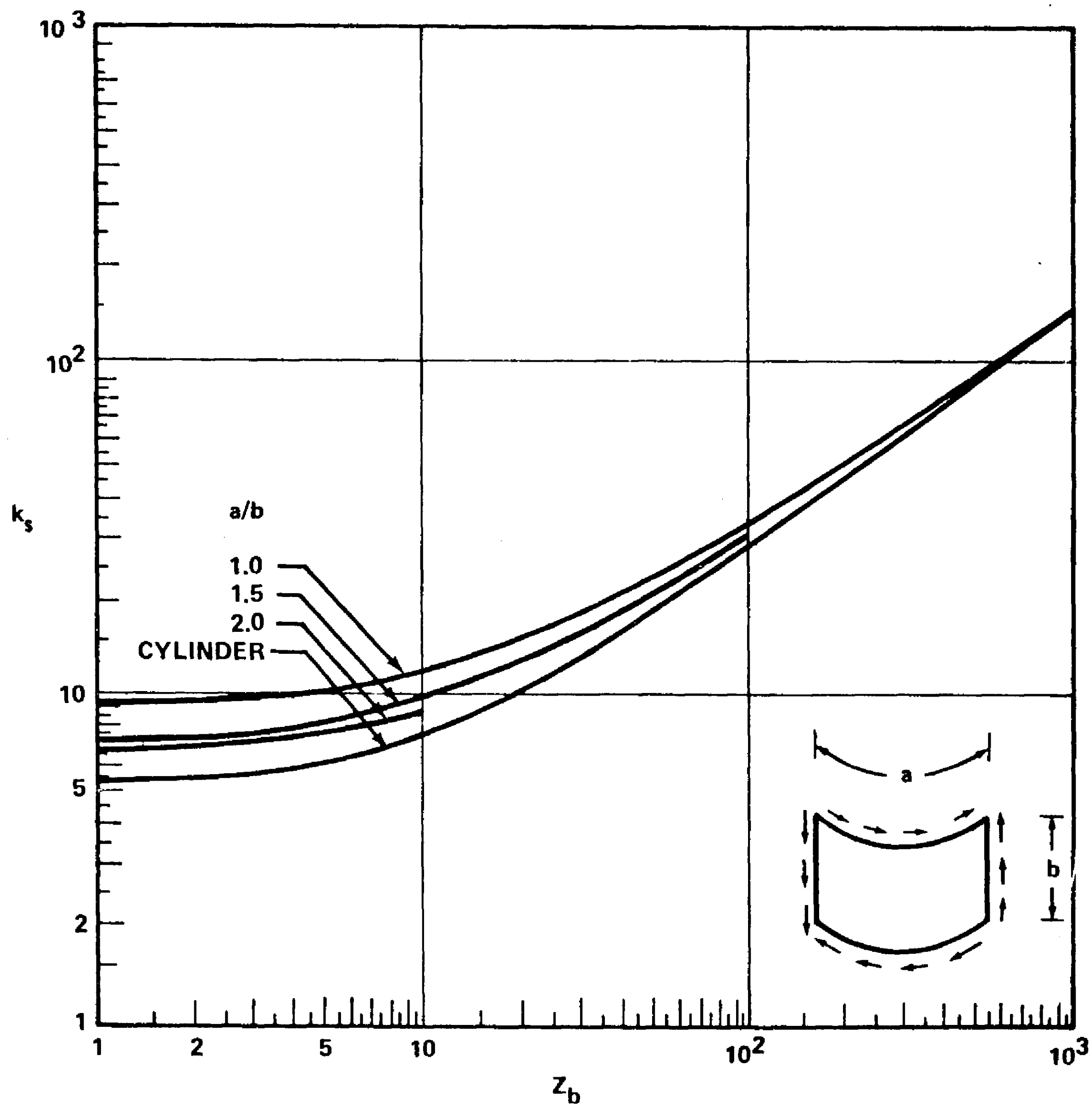
(a) LONG SIMPLY SUPPORTED PLATES

FIGURE C2-68. SHEAR BUCKLING COEFFICIENTS FOR VARIOUS CURVED PLATES



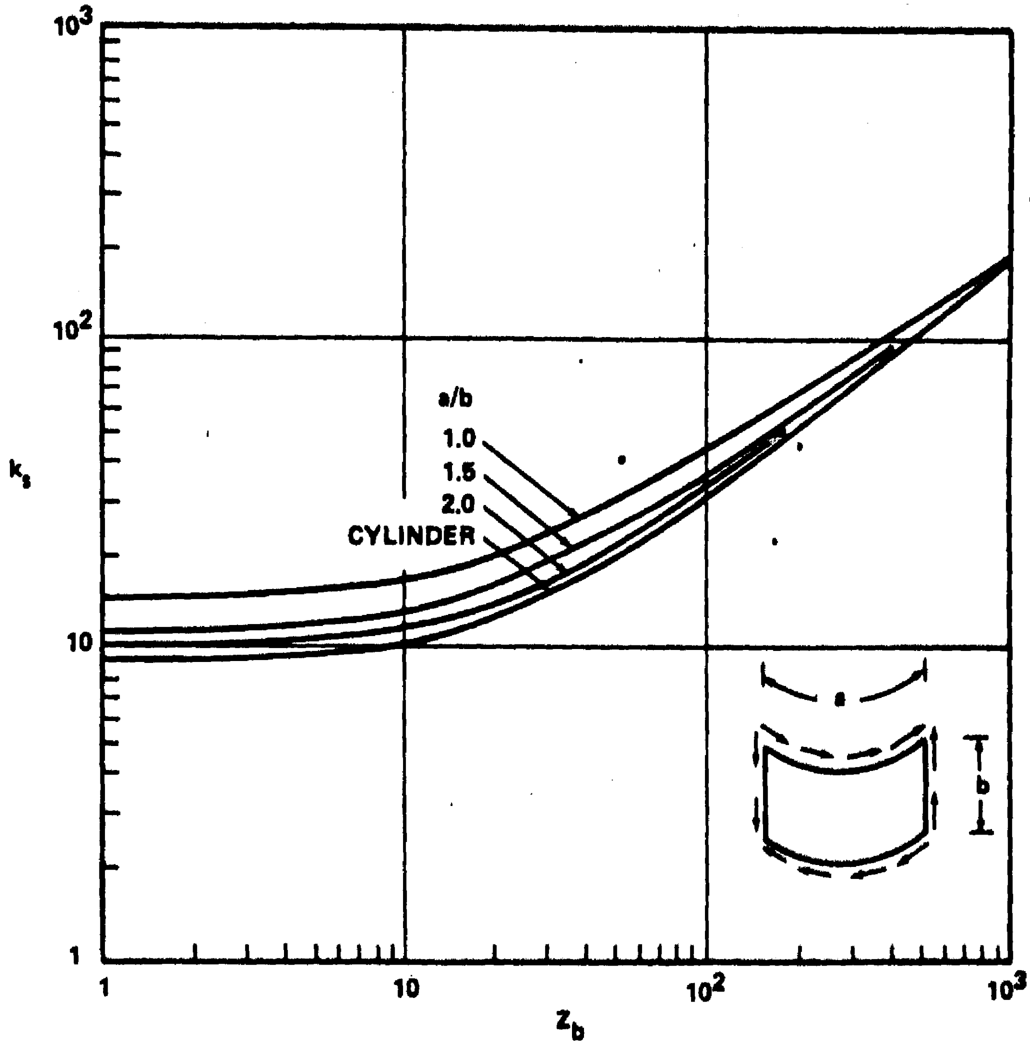
(b) LONG CLAMPED PLATES

FIGURE C2-68. (Continued)



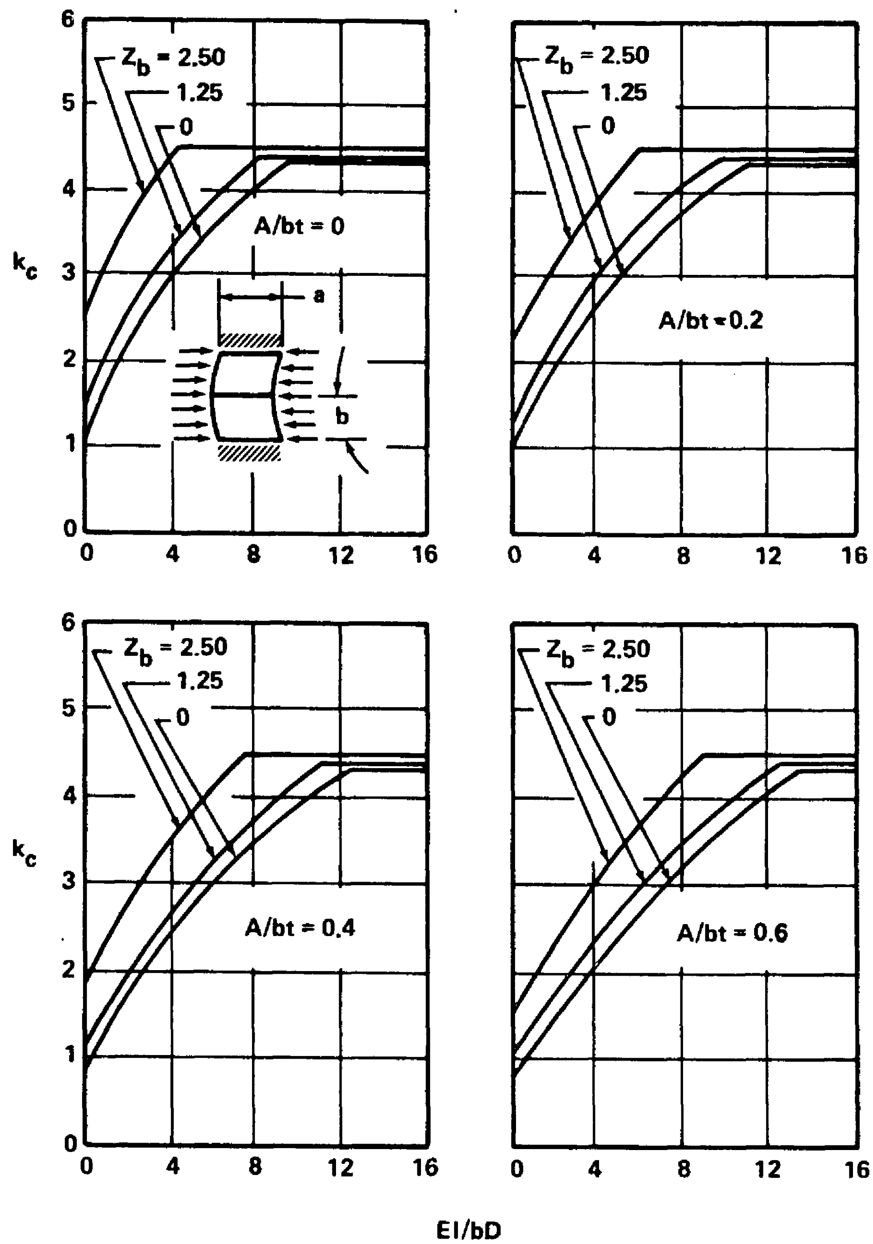
(c) WIDE, SIMPLY SUPPORTED PLATES

FIGURE C2-68. (Continued)



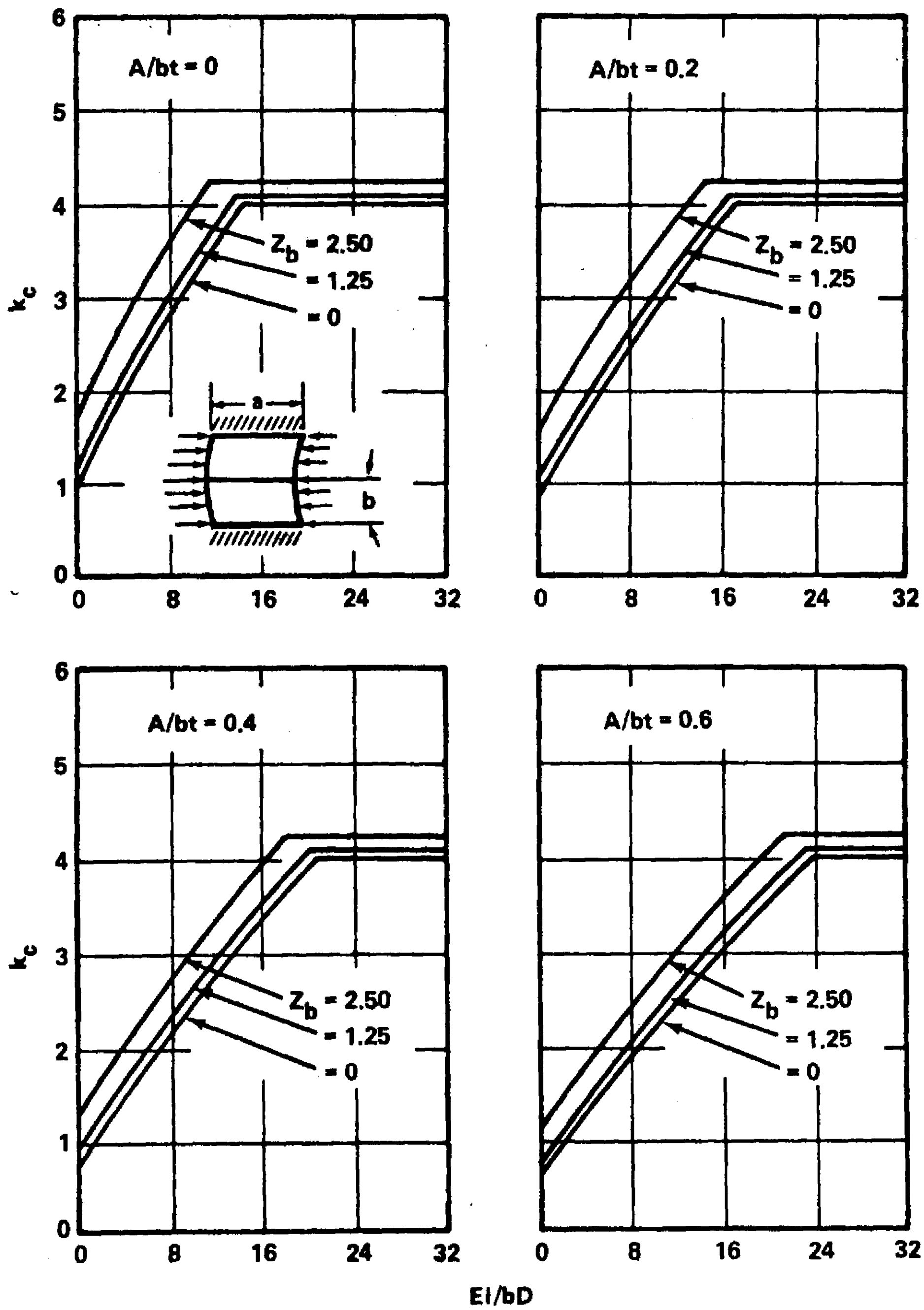
(d) WIDE CLAMPED PLATES

FIGURE C2-68. (Concluded)



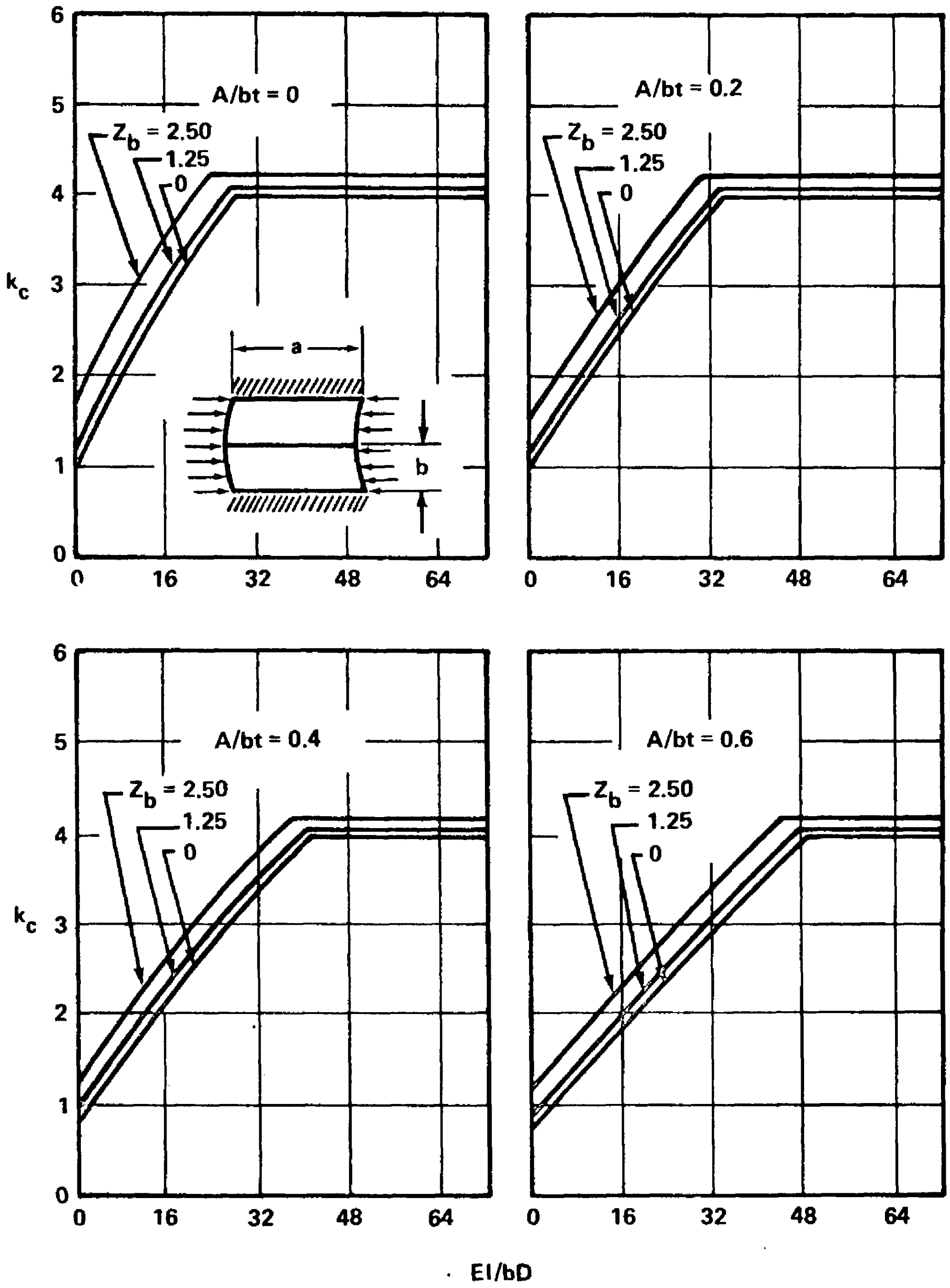
(a) a/b = 4/3

FIGURE C2-69. COMPRESSIVE-BUCKLING COEFFICIENTS FOR SIMPLY SUPPORTED CURVED PLATES WITH CENTER AXIAL STIFFENER



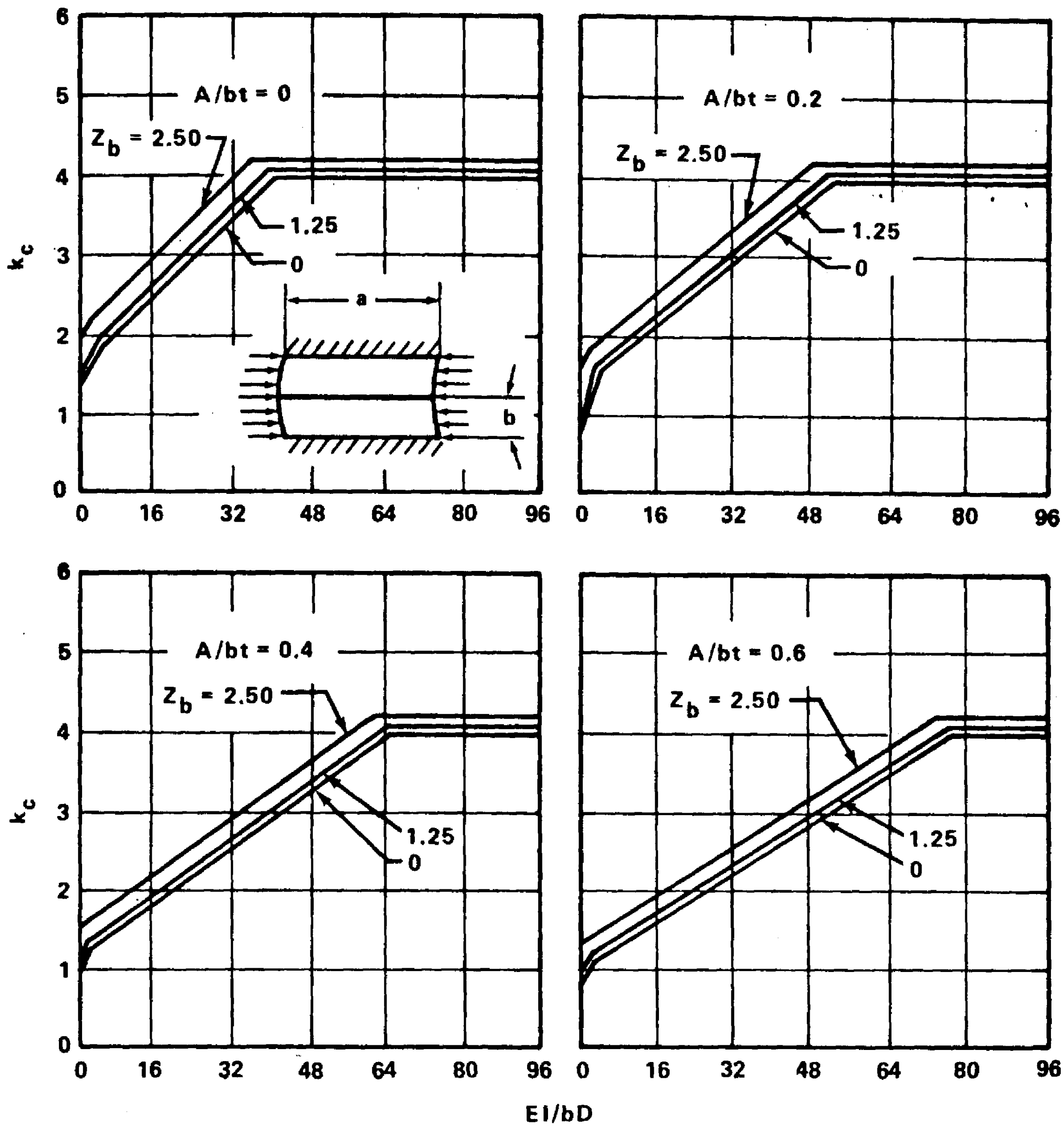
(b) a/b = 2

FIGURED C2-69. (Continued)



(c) a/b = 3

FIGURE C2-69. (Continued)



(d) a/b = 4

FIGURE C2-69. (Concluded)

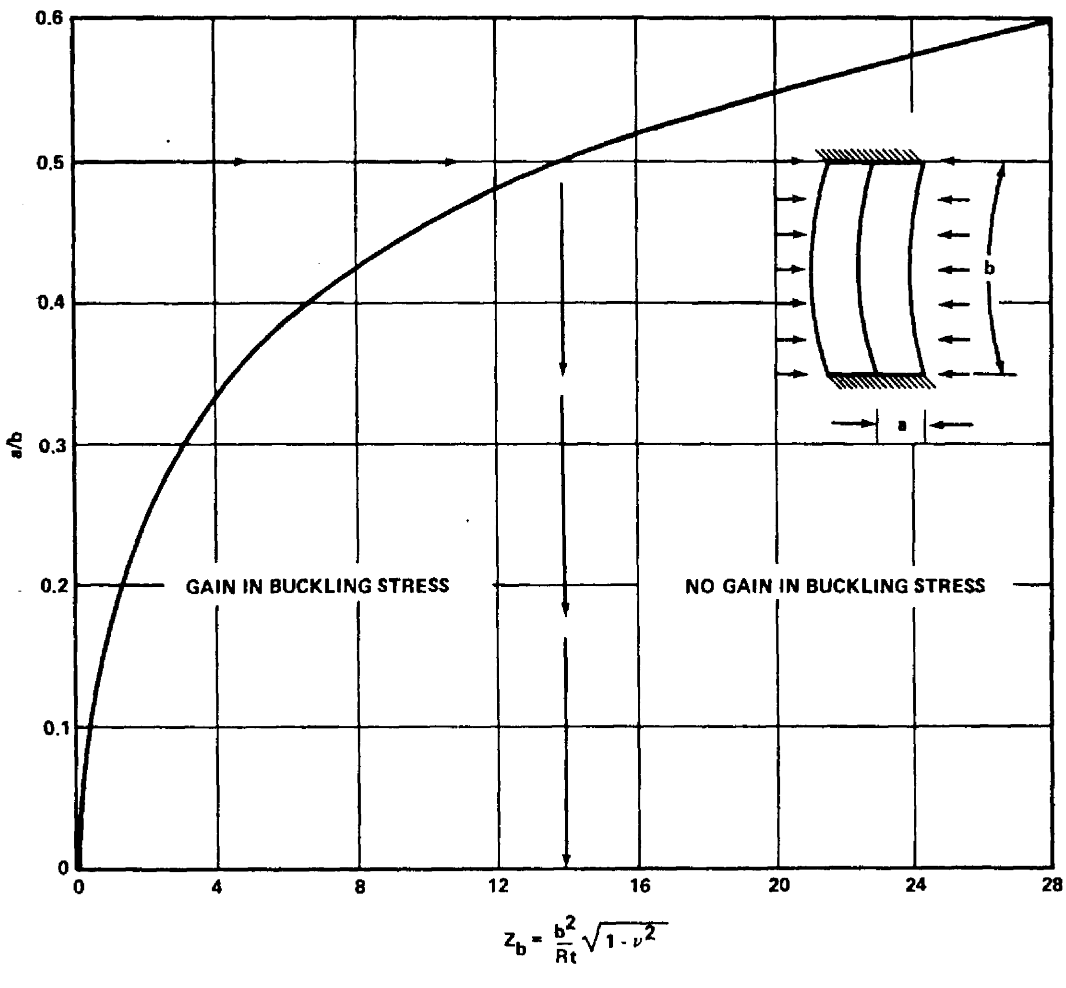


FIGURE C2-70. DEFINITION OF a/b VS Z_b RELATIONSHIP FOR GAIN IN BUCKLING STRESS OF AXIALLY COMPRESSED CURVED PLATES DUE TO ADDITION OF SINGLE CENTRAL CIRCUMFERENTIAL STIFFENER

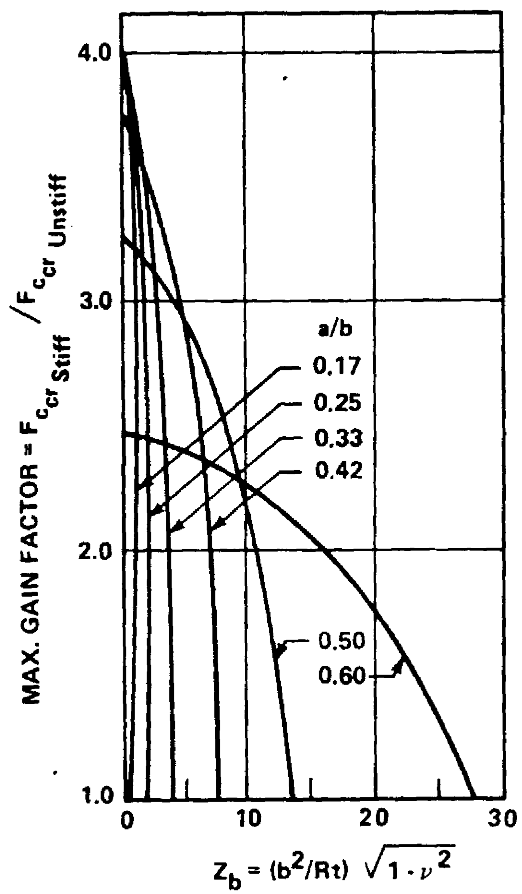


FIGURE C2-71. MAXIMUM GAIN FACTORS FOR SIMPLY SUPPORTED CURVED PLATES WITH A SINGLE, CENTRAL, CIRCUMFERENTIAL STIFFENER

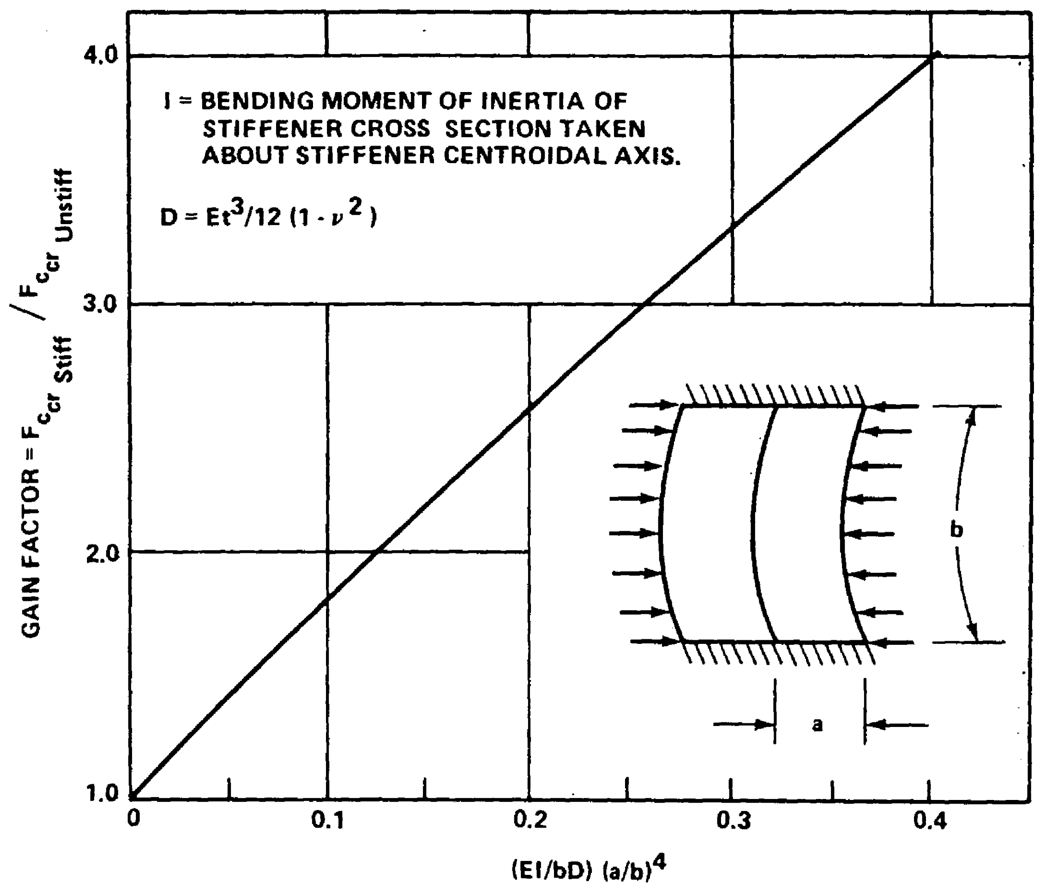


FIGURE C2-72. STIFFNESS REQUIREMENTS AS A FUNCTION OF GAIN FACTOR FOR SIMPLY SUPPORTED CURVED PLATES WITH A SINGLE CENTRAL CIRCUMFERENTIAL STIFFENER

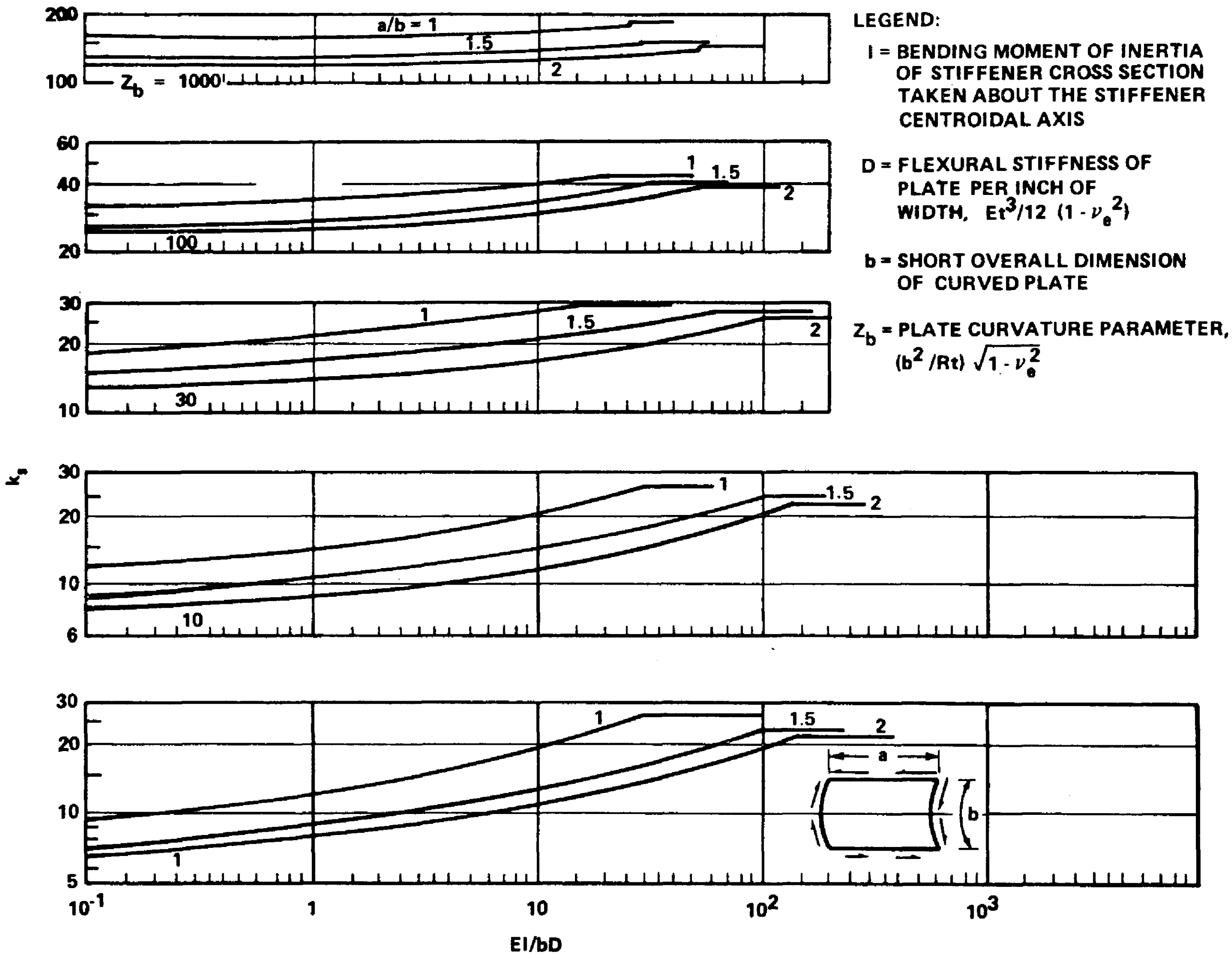
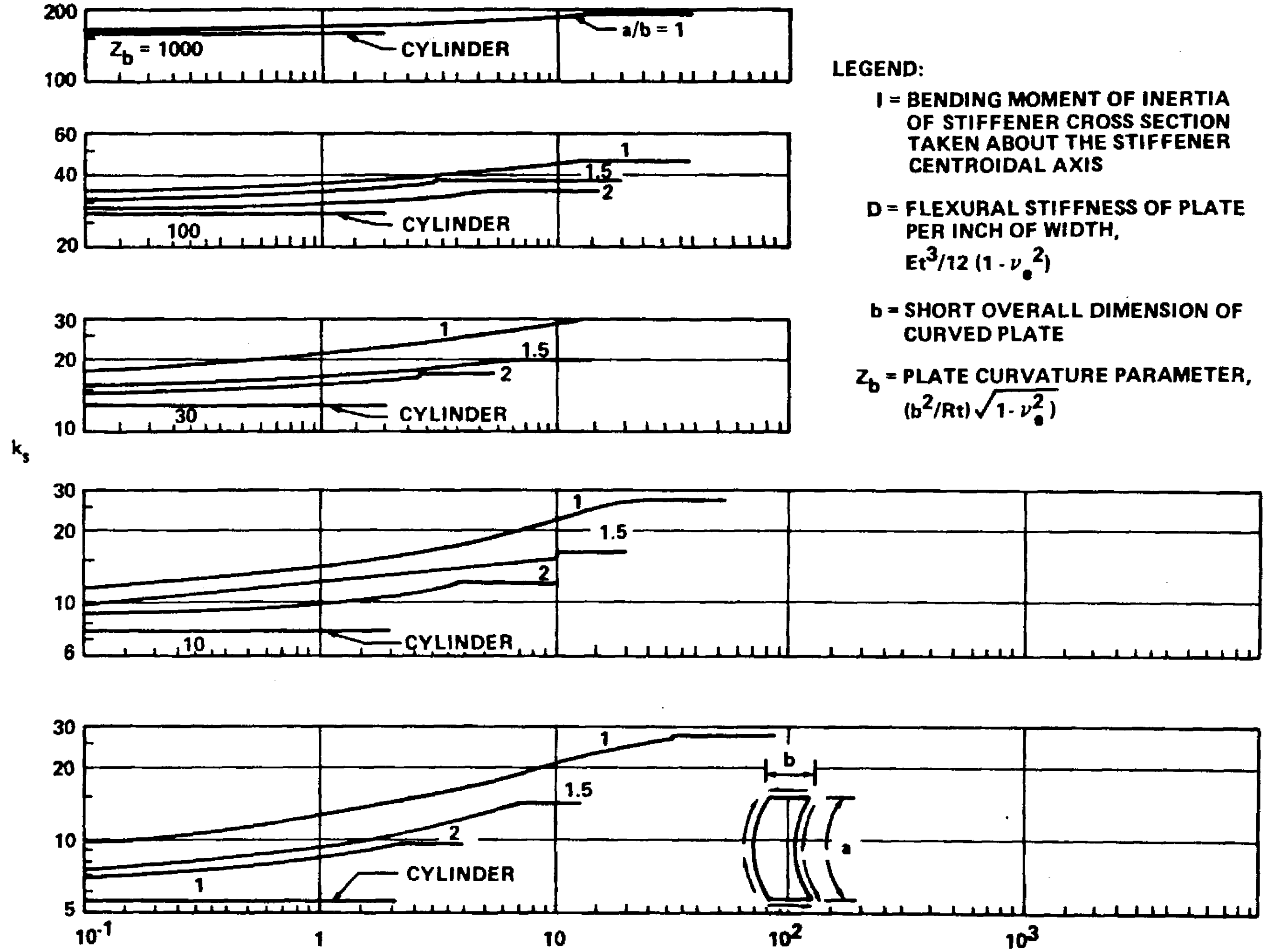


FIGURE C2-73a. SHEAR BUCKLING COEFFICIENTS FOR SIMPLY SUPPORTED CURVED PLATES WITH CENTER AXIAL STIFFENER, AXIAL LENGTH GREATER THAN CIRCUMFERENTIAL WIDTH



LEGEND:

I = BENDING MOMENT OF INERTIA OF STIFFENER CROSS SECTION TAKEN ABOUT THE STIFFENER CENTROIDAL AXIS

D = FLEXURAL STIFFNESS OF PLATE PER INCH OF WIDTH, $Et^3/12\,(1 - \nu_e^2)$

b = SHORT OVERALL DIMENSION OF CURVED PLATE

Z_b = PLATE CURVATURE PARAMETER, $(b^2/Rt)\sqrt{1 - \nu_e^2}$

FIGURE C2-73b. SHEAR BUCKLING COEFFICIENTS FOR SIMPLY SUPPORTED CURVED PLATES WITH CENTER AXIAL STIFFENER, AXIAL LENGTH LESS THAN CIRCUMFERENTIAL WIDTH

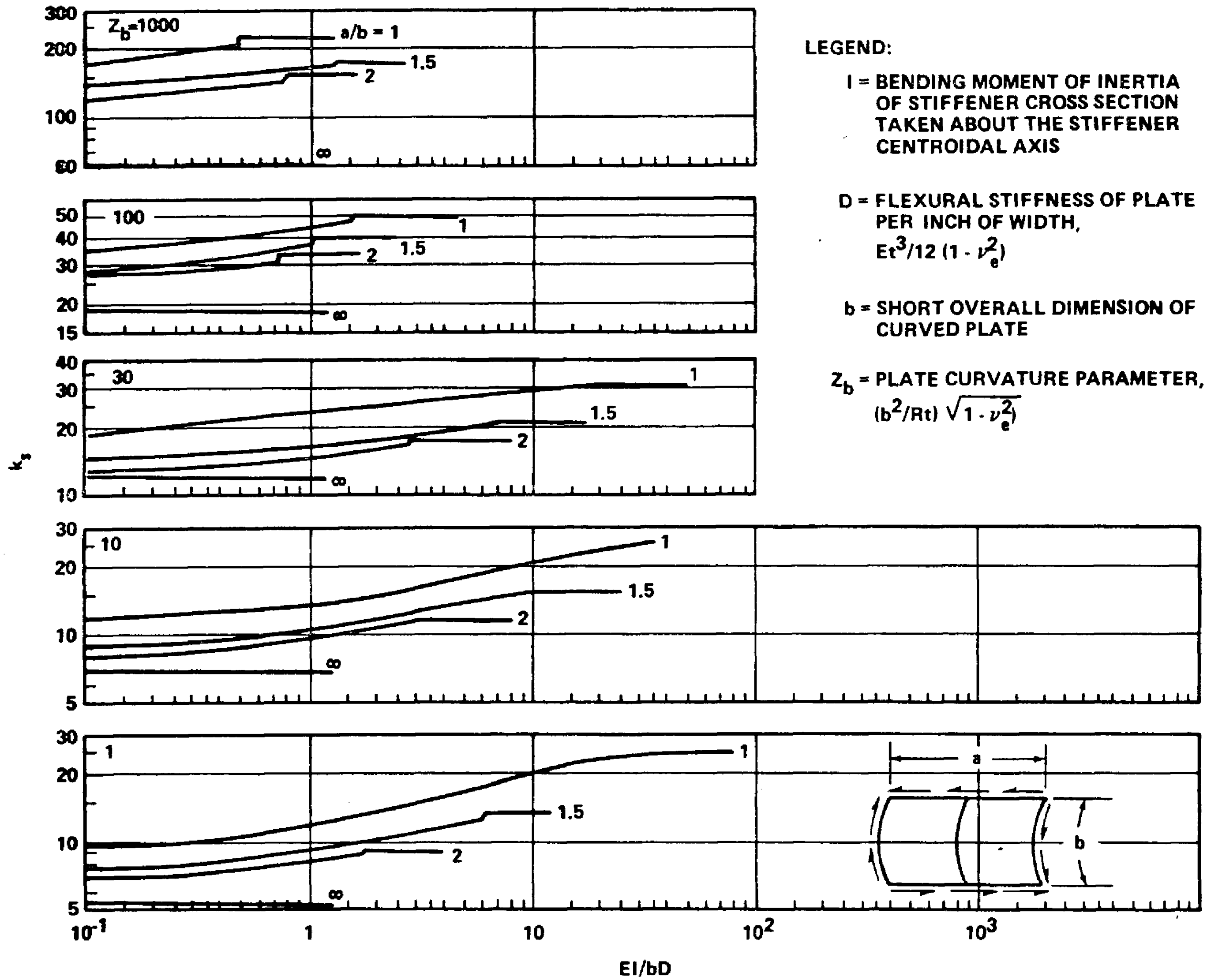


FIGURE C2-74a. SHEAR BUCKLING COEFFICIENTS FOR SIMPLY SUPPORTED CURVED PLATES WITH CENTER CIRCUMFERENTIAL STIFFENER, AXIAL LENGTH GREATER THAN CIRCUMFERENTIAL WIDTH

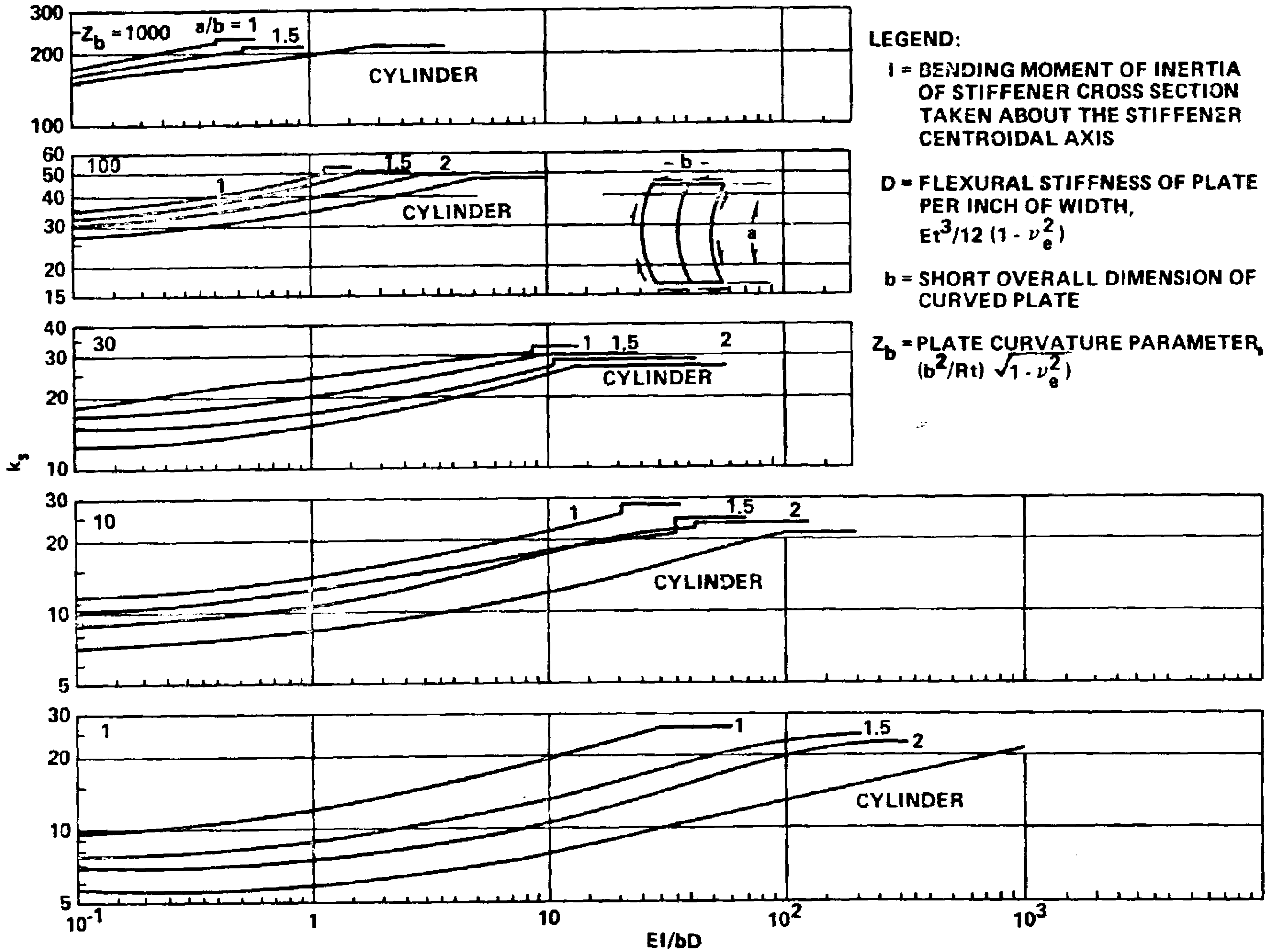


FIGURE C2-74b. SHEAR BUCKLING COEFFICIENTS FOR SIMPLY SUPPORTED CURVED PLATES WITH CENTER CIRCUMFERENTIAL STIFFENER, AXIAL LENGTH LESS THAN CIRCUMFERENTIAL WIDTH

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