Supplement to

BUCKLING OF FLAT PLYWOOD PLATES IN COMPRESSION, SHEAR, OR COMBINED COMPRESSION AND SHEAR

Plates Having the Grain of the Face Plies Inclined to the Edges

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

Supplement to

BUCKLING OF FLAT PLYWOOD PLATES IN COMPRESSION, SHEAR, OR COMBINED COMPRESSION AND SHEAR

Plates Having the Grain of the Face Plies Inclined to the Edges[1]

By

Forest Products Laboratory,[2] Forest Service
U. S. Department of Agriculture

In Forest Products Laboratory Report No. 1316, "Buckling of Flat Plywood Plates in Compression, Shear, or Combined Compression and Shear," exact or approximate formulas were given for calculating the buckling stress of very long (infinite) flat plates under compression, shear, or combined compression and shear when the grain of the face plies is perpendicular or parallel to the edges or inclined to them at an angle of 45°. In certain cases formulas for the buckling of finite plates were given. In others it was pointed out that the buckling stress for a finite plate could be estimated with the aid of the curve given in figure 12 of Report No. 1316 from that of the corresponding infinite plate. The formulas for the critical compressive and shearing stresses were written in the forms:

$$p_{cr} = k_c E_L \frac{h^2}{a^2} \tag{1}$$

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[1] This progress report was originally issued by the Forest Products Laboratory in 1943.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

$$q_{cr} = k_s E_L \frac{h^2}{a^2} \tag{2}$$

respectively. Values of the constants k_c and k_s were given in tables and curves for several types of plywood in Report No. 1316. Similar values for further types of plywood are given in Supplement B to Report No. 1316.

In the present supplement approximate formulas are given for calculating the buckling stress of long plywood plates under the types of loading specified above when the grain of the face plies is inclined at any given angle to the edges. The results obtained by using the formulas for certain inclinations of the grain of the face plies and for certain types of plywood are shown in table 9 and in the curves of figures 43 to 70.[3] It is also pointed out that certain equations in Report No. 1316 can be written in simpler forms.

1. Notation

The notation of Report No. 1316 is used. In addition the following constants are defined in terms of constants previously defined:

$$K_1 = E_1 \cos^4 \theta + E_2 \sin^4 \theta + 2A \sin^2 \theta \cos^2 \theta$$

$$K_2 = E_1 \sin^4 \theta + E_2 \cos^4 \theta + 2A \sin^2 \theta \cos^2 \theta$$

$$K_5 = 4(E_1 - A) \sin^3 \theta \cos \theta - 4(E_2 - A) \sin \theta \cos^3 \theta$$

$$K_6 = 4(E_1 - A) \sin \theta \cos^3 \theta - 4(E_2 - A) \sin^3 \theta \cos \theta$$

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[3]The figures and tables in this supplement are numbered consecutively with those of Report No. 1316 and previous supplements.

$$R_1 = 6(E_1 + E_2) \sin^2 \theta \cos^2 \theta + 2A (\sin^4 \theta + \cos^4 \theta$$

$$- 4 \sin^2 \theta \cos^2 \theta)$$

The choice of axes and the angle θ are shown in figure 4 of Report No. 1316. It is to be observed that the angle θ is the angle made by the direction of the grain of the face plies with the axis OX which is perpendicular to the sides of the long plates under consideration.

2. Long Plates Under Uniform Compression

The energy method was used as explained on pages 4 and 5 of Report No. 1316. As before the form of the buckled surface was taken to be represented by the equation

$$w = H \sin \frac{\pi x}{a} \sin \frac{\pi}{b} (y - \gamma x) \tag{3}$$

By the processes previously described it was found that k_c of equation (1) is given by the formula

$$k_c = \frac{\pi^2}{12\lambda E_L} \left[2K_1 z^2 + 6K_1 \gamma^2 + R_1 - 3K_6 \gamma \right] \tag{4}$$

where z and γ satisfy the simultaneous equations

$$z^4 = \gamma^4 + \frac{K_2 + R_1 \gamma^2 - K_5 \gamma - K_6 \gamma^3}{K_1} \tag{5}$$

$$z^2 = \frac{3K_6 \gamma^2 + K_5 - 2R_1 \gamma - 4K_1 \gamma^3}{12K_1 \gamma - 3K_6} \tag{6}$$

3. Long Plates Under Uniform Shear

By using the energy method and equation (3) for the buckled surface it was found that k_s of equation (2) is given by the formula

$$k_s = \frac{\pi^2}{24\lambda\gamma E_L}\left[2K_1 z^2 + 6K_1 \gamma^2 + R_1 - 3K_6 \gamma\right] \tag{7}$$

where z and γ satisfy the simultaneous equations

$$z^4 = \gamma^4 + \frac{K_2 + R_1 \gamma^2 - K_5 \gamma - K_6 \gamma^3}{K_1} \tag{8}$$

$$z^2 = \frac{2K_2 - 2K_1 \gamma^4 - K_5 \gamma + K_6 \gamma^3}{6K_1 \gamma^2 - R_1} \tag{9}$$

4. Long Plates Under Uniform Compression (or Tension) and Shear

Let the shear stress be f times the compressive stress. Then by equations (1) and (2)

$$k_s = f\, k_c \tag{10}$$

By using the energy method and equation (3) for the buckled surface it was found that

$$k_c = \frac{\pi^2}{12\lambda\,(1 + 2\gamma f)\, E_L}\left[2K_1 z^2 + 6K_1 \gamma^2 + R_1 - 3K_6 \gamma\right] \tag{11}$$

where z and γ satisfy the simultaneous equations

$$z^4 = \gamma^4 + \frac{K_2 + R_1 \gamma^2 - K_5 \gamma - K_6 \gamma^3}{K_1} \tag{12}$$

$$z^2 = \frac{4K_2 f - 4K_1 (\gamma^3 + f\gamma^4) - 2R_1\gamma + K_5(1 - 2f\gamma) + K_6(3\gamma^2 + 2f\gamma^3)}{12K_1(\gamma + f\gamma^2) - 2R_1 f - 3K_6} \tag{13}$$

Values of k_c and k_s are given in table 9 and in figures 43 to 70 for various types of plywood and various inclinations of the grain of the face plies. The constants of Douglas-fir were used in the calculations. The construction and use of the figures are explained on page 14 of Report No. 1316. For types of plywood of symmetrical construction other than those given in table 9 and figures 43 to 70 the constants k_c and k_s can be found from the values given in these tables and figures by interpolation (or extrapolation) on the basis of the ratio $E_1/(E_1 + E_2)$ because, as explained in Report No. 1316-B, the constants plotted as functions of this ratio are found to lie on or very near to smooth curves.

From the values of the constants for very long plates as given in this report an estimate of their values for shorter plates can be made by using the curve of figure 12 of Report No. 1316.

The constants given in this Supplement were obtained by an approximate method. Compression tests over a considerable range of types of construction and angles of the face grain have yielded values of the constant k_c that appear to be in sufficiently good agreement with the approximate theoretical values, considering the nature of the test and the variability of the plywood. In buckling tests of panels the results are very sensitive to the effects of edge conditions and initial curvature. Definite conclusions will not be drawn until the test program has been completed.

5. Simplified Forms of Certain Equations in Report No. 1316

Equations (17), (28), (32), (37), and (43) of Report No. 1316 can be simplified by collecting the terms in $1/z^2$ and using the expressions (11), (29), (33), (38), and (44), respectively. The simplified equations, numbered as before, are written below.

$$k_c = \frac{\pi^2}{12\lambda E_L}\left[2Gz^2 + 6G\gamma^2 + R - 3M\gamma\right] \tag{17}$$

$$k_s = \frac{\pi^2}{24\lambda\gamma E_L}\left[2Gz^2 + 6G\gamma^2 + R - 3M\gamma\right] \tag{28}$$

$$k_s = \frac{\pi^2}{24\lambda\gamma E_L}\left[2E_1z^2 + 6E_1\gamma^2 + 2A\right] \tag{32}$$

$$k_c = \frac{\pi^2}{12\lambda\,(1 + 2\gamma f)\,E_L}\left[2E_1z^2 + 6E_1\gamma^2 + 2A\right] \tag{37}$$

$$k_c = \frac{\pi^2}{12\lambda\,(1 + 2\gamma f)\,E_L}\left[2Gz^2 + 6G\gamma^2 + R - 3M\gamma\right] \tag{43}$$

Table 9.--Buckling of long plywood plates under combined compression or tension and shear. Edges simply supported. For compression $p_{cr} = k_c E_L h^2/a^2$. Negative k_c denotes tension. For shear $q_{cr} = k_s E_L h^2/a^2$. For combined stress the shear stress is equal to f times the compressive (or tensile) stress.

Loading	θ	f	k_c or k_s	2-ply 1:1	3-ply 1:1:1	3-ply 1:2:1	5-ply 1:1:1:1:1	5-ply 1:2:2:2:1	9-ply 1:1:1:1:1:1:1:1:1	Infinite-ply
	Deg.									
Compression	15	....	k_c	0.62	0.76	0.94	1.05	1.22	1.17	1.25
Shear	15	....	k_s	.85	1.17	1.37	1.49	1.60	1.58	1.59
Shear	15	....	k_s	-.98	-3.48	-3.30	-3.11	-2.57	-2.78	-2.29
Compression and shear	15	0.5	k_c	.55	.61	.76	.86	1.01	.97	1.05
			k_s	.27	.31	.38	.43	.50	.48	.52
"	15	1.0	k_c	.44	.50	.62	.70	.81	.78	.83
			k_s	.44	.50	.62	.70	.81	.78	.83
"	15	1.5	k_c	.36	.42	.51	.58	.66	.64	.67
			k_s	.54	.63	.77	.86	.99	.95	1.01
"	15	4.0	k_c	.18	.23	.27	.30	.33	.32	.33
			k_s	.71	.90	1.08	1.19	1.32	1.29	1.33
"	15	-.5	k_c	.58	.90	1.07	1.17	1.25	1.24	1.24
			k_s	-.29	-.45	-.54	-.59	-.63	-.62	-.62
"	15	-1.0	k_c	.48	.97	1.09	1.14	1.12	1.14	1.07
			k_s	-.48	-.97	-1.09	-1.14	-1.12	-1.14	-1.07
"	15	-1.5	k_c	.40	.95	1.01	1.03	.96	1.00	.90
			k_s	-.60	-1.43	-1.52	-1.54	-1.44	-1.50	-1.35
"	15	-4.0	k_c	.20	.63	.62	.59	.51	.55	.47
			k_s	-.81	-2.51	-2.46	-2.38	-2.06	-2.19	-1.86
Tension and shear	15	.5	k_c	-6.32	-28.35	-25.93	-23.64	-18.16	-20.14	-15.58
			k_s	-3.16	-14.18	-12.96	-11.82	-9.08	-10.07	-7.79
"	15	1.0	k_c	-1.94	-8.60	-7.88	-7.19	-5.55	-6.15	-4.78
			k_s	-1.94	-8.60	-7.88	-7.19	-5.55	-6.15	-4.78
"	15	1.5	k_c	-1.05	-4.53	-4.16	-3.81	-2.97	-3.27	-2.56
			k_s	-1.58	-6.80	-6.24	-5.71	-4.45	-4.90	-3.85
"	15	4.0	k_c	-.29	-1.16	-1.08	-1.00	-.80	-.87	-.70
			k_s	-1.18	-4.64	-4.32	-4.00	-3.20	-3.49	-2.81
"	15	-.5	k_c	-5.65	-18.45	-17.22	-16.05	-13.17	-14.22	-11.77
			k_s	2.83	9.23	8.61	8.02	6.58	7.11	5.88
"	15	-1.0	k_c	-1.68	-4.09	-4.04	-3.93	-3.54	-3.70	-3.30
			k_s	1.68	4.09	4.04	3.93	3.54	3.70	3.30
"	15	-1.5	k_c	-.90	-1.83	-1.90	-1.92	-1.83	-1.88	-1.74
			k_s	1.35	2.75	2.85	2.88	2.74	2.81	2.61
"	15	-4.0	k_c	-.25	-.40	-.45	-.47	-.49	-.49	-.48
			k_s	1.01	1.59	1.80	1.90	1.95	1.96	1.92

(continued)

Table 9.--Buckling of long plywood plates under combined compression or tension and shear. (continued)

Loading	θ	f	k_c or k_s	2-ply 1:1	3-ply 1:1:1	3-ply 1:2:1	5-ply 1:1:1:1:1	5-ply 1:2:2:2:1	9-ply 1:1:1:1:1:1:1:1:1	Infinite-ply
	Deg.									
Compression	30	....	k_c	0.68	0.82	1.06	1.23	1.51	1.43	1.57
Shear	30	....	k_s	.87	.79	1.04	1.23	1.58	1.47	1.71
Shear	30	....	k_s	-1.01	-4.21	-3.89	-3.58	-2.83	-3.11	-2.48
Compression and shear	30	0.5	k_c	.59	.56	.75	.90	1.17	1.09	1.28
			k_s	.30	.28	.38	.45	.59	.54	.64
"	30	1.0	k_c	.47	.42	.57	.68	.89	.82	.98
			k_s	.47	.42	.57	.68	.89	.82	.98
"	30	1.5	k_c	.38	.34	.45	.54	.71	.65	.78
			k_s	.57	.50	.67	.81	1.06	.98	1.16
"	30	4.0	k_c	.18	.16	.22	.26	.34	.31	.37
			k_s	.74	.65	.87	1.04	1.35	1.25	1.47
"	30	-.5	k_c	.63	1.22	1.42	1.53	1.57	1.58	1.52
			k_s	-.32	-.61	-.71	-.76	-.79	-.79	-.76
"	30	-1.0	k_c	.52	1.48	1.52	1.51	1.38	1.44	1.27
			k_s	-.52	-1.48	-1.52	-1.51	-1.38	-1.44	-1.27
"	30	-1.5	k_c	.42	1.44	1.40	1.35	1.16	1.23	1.05
			k_s	-.64	-2.15	-2.10	-2.02	-1.73	-1.85	-1.57
"	30	-4.0	k_c	.21	.84	.78	.73	.59	.64	.52
			k_s	-.84	-3.36	-3.14	-2.92	-2.36	-2.57	-2.08
Tension and shear	30	.5	k_c	-5.97	-23.70	-21.78	-19.97	-15.63	-17.20	-13.58
			k_s	-2.99	-11.85	-10.89	-9.98	-7.82	-8.60	-6.79
"	30	1.0	k_c	-1.89	-7.95	-7.29	-6.66	-5.18	-5.72	-4.47
			k_s	-1.89	-7.95	-7.29	-6.66	-5.18	-5.72	-4.47
"	30	1.5	k_c	-1.04	-4.45	-4.08	-3.73	-2.90	-3.20	-2.50
			k_s	-1.56	-6.67	-6.11	-5.59	-4.34	-4.80	-3.75
"	30	4.0	k_c	-.30	-1.28	-1.17	-1.08	-.84	-.93	-.73
			k_s	-1.19	-5.11	-4.70	-4.30	-3.37	-3.70	-2.92
"	30	-.5	k_c	-5.32	-10.09	-10.29	-10.36	-10.21	-10.31	-10.02
			k_s	2.66	5.05	5.14	5.18	5.11	5.15	5.01
"	30	-1.0	k_c	-1.63	-2.08	-2.43	-2.65	-2.99	-2.89	-3.08
			k_s	1.63	2.08	2.43	2.65	2.99	2.89	3.08
"	30	-1.5	k_c	-.89	-.98	-1.21	-1.36	-1.62	-1.54	-1.70
			k_s	1.34	1.46	1.81	2.04	2.43	2.31	2.55
"	30	-4.0	k_c	-.26	-.24	-.32	-.37	-.46	-.43	-.50
			k_s	1.03	.97	1.26	1.48	1.85	1.74	1.98

(continued)

Table 9.--Buckling of long plywood plates under combined compression or tension and shear. (continued)

Loading	θ	f	k_c or k_s	2-ply 1:1	3-ply 1:1:1	3-ply 1:2:1	5-ply 1:1:1:1:1	5-ply 1:2:2:2:1	9-ply 1:1:1:1:1:1:1:1:1	Infinite-ply
	Deg.									
Compression	60	....	k_c	0.68	0.99	1.30	1.46	1.59	1.58	1.57
Shear	60	....	k_s	1.01	.58	.97	1.31	2.11	1.83	2.48
Shear	60	....	k_s	-.87	-2.03	-2.02	-1.98	-1.82	-1.88	-1.71
Compression and shear	60	0.5	k_c	.63	.57	.86	1.07	1.42	1.32	1.52
			k_s	.32	.29	.43	.54	.71	.66	.76
"	60	1.0	k_c	.52	.39	.61	.79	1.14	1.03	1.27
			k_s	.52	.39	.61	.79	1.14	1.03	1.27
"	60	1.5	k_c	.42	.29	.47	.62	.92	.82	1.05
			k_s	.64	.44	.70	.93	1.38	1.23	1.57
"	60	4.0	k_c	.21	.13	.21	.29	.45	.39	.52
			k_s	.84	.52	.85	1.15	1.80	1.57	2.08
"	60	-.5	k_c	.59	1.48	1.51	1.49	1.37	1.42	1.28
			k_s	-.30	-.74	-.75	-.74	-.68	-.71	-.64
"	60	-1.0	k_c	.47	1.26	1.23	1.19	1.06	1.11	.98
			k_s	-.47	-1.26	-1.23	-1.19	-1.06	-1.11	-.98
"	60	-1.5	k_c	.38	1.00	.97	.94	.83	.88	.78
			k_s	-.57	-1.50	-1.46	-1.41	-1.25	-1.31	-1.16
"	60	-4.0	k_c	.18	.46	.45	.44	.39	.41	.37
			k_s	-.74	-1.82	-1.79	-1.74	-1.58	-1.64	-1.47
Tension and shear	60	.5	k_c	-5.32	-7.93	-8.49	-8.94	-9.75	-9.50	-10.02
			k_s	-2.66	-3.96	-4.24	-4.47	-4.87	-4.75	-5.01
"	60	1.0	k_c	-1.63	-2.96	-3.06	-3.11	-3.13	-3.14	-3.08
			k_s	-1.63	-2.96	-3.06	-3.11	-3.13	-3.14	-3.08
"	60	1.5	k_c	-.89	-1.76	-1.79	-1.80	-1.75	-1.78	-1.70
			k_s	-1.34	-2.64	-2.69	-2.70	-2.63	-2.67	-2.55
"	60	4.0	k_c	-.26	-.56	-.56	-.56	-.52	-.54	-.50
			k_s	-1.03	-2.26	-2.26	-2.23	-2.09	-2.16	-1.98
"	60	-.5	k_c	-5.97	-3.21	-5.25	-7.12	-11.52	-9.94	-13.58
			k_s	2.99	1.60	2.63	3.56	5.76	4.97	6.79
"	60	-1.0	k_c	-1.89	-.96	-1.64	-2.27	-3.77	-3.23	-4.47
			k_s	1.89	.96	1.64	2.27	3.77	3.23	4.47
"	60	-1.5	k_c	-1.04	-.54	-.92	-1.27	-2.11	-1.81	-2.50
			k_s	1.56	.80	1.38	1.91	3.16	2.71	3.75
"	60	-4.0	k_c	-.30	-.16	-.28	-.38	-.62	-.53	-.73
			k_s	1.19	.65	1.10	1.51	2.47	2.13	2.92

(continued)

Table 9.--Buckling of long plywood plates under combined compression or tension and shear. (continued)

Loading	θ	f	k_c or k_s	2-ply 1:1	3-ply 1:1:1	3-ply 1:2:1	5-ply 1:1:1:1:1	5-ply 1:2:2:2:1	9-ply 1:1:1:1:1:1:1:1:1	Infinite-ply
	Deg.									
Compression	75	....	k_c	0.62	0.89	1.07	1.17	1.26	1.24	1.25
Shear	75	....	k_s	.98	.58	.96	1.29	1.99	1.75	2.29
Shear	75	....	k_s	-.85	-1.02	-1.22	-1.36	-1.55	-1.50	-1.59
Compression and shear	75	0.5	k_c	.58	.56	.81	.97	1.19	1.13	1.24
			k_s	.29	.28	.40	.48	.60	.56	.62
"	75	1.0	k_c	.48	.39	.59	.74	.99	.91	1.07
			k_s	.48	.39	.59	.74	.99	.91	1.07
"	75	1.5	k_c	.40	.29	.46	.59	.82	.74	.90
			k_s	.60	.44	.69	.88	1.23	1.12	1.35
"	75	4.0	k_c	.20	.13	.21	.28	.41	.37	.47
			k_s	.81	.52	.84	1.11	1.65	1.47	1.86
"	75	-.5	k_c	.55	.90	.99	1.03	1.06	1.06	1.05
			k_s	-.27	-.45	-.49	-.52	-.53	-.53	-.52
"	75	-1.0	k_c	.44	.67	.75	.80	.84	.83	.83
			k_s	-.44	-.67	-.75	-.80	-.84	-.83	-.83
"	75	-1.5	k_c	.36	.52	.59	.63	.67	.67	.67
			k_s	-.54	-.78	-.88	-.95	-1.01	-1.00	-1.01
"	75	-4.0	k_c	.18	.23	.27	.30	.33	.32	.33
			k_s	-.71	-.92	-1.08	-1.18	-1.31	-1.28	-1.33
Tension and shear	75	.5	k_c	-5.65	-4.10	-5.73	-7.15	-10.33	-9.21	-11.77
			k_s	-2.83	-2.05	-2.86	-3.58	-5.17	-4.61	-5.88
"	75	1.0	k_c	-1.68	-1.49	-1.95	-2.31	-3.02	-2.78	-3.30
			k_s	-1.68	-1.49	-1.95	-2.31	-3.02	-2.78	-3.30
"	75	1.5	k_c	-.90	-.88	-1.12	-1.30	-1.63	-1.52	-1.74
			k_s	-1.35	-1.33	-1.68	-1.95	-2.44	-2.28	-2.61
"	75	4.0	k_c	-.25	-.28	-.35	-.39	-.46	-.44	-.48
			k_s	-1.01	-1.13	-1.38	-1.56	-1.84	-1.76	-1.92
"	75	-.5	k_c	-6.32	-2.80	-5.23	-7.52	-12.99	-11.02	-15.58
			k_s	3.16	1.40	2.61	3.76	6.50	5.51	7.79
"	75	-1.0	k_c	-1.94	-.91	-1.66	-2.35	-4.00	-3.41	-4.78
			k_s	1.94	.91	1.66	2.35	4.00	3.41	4.78
"	75	-1.5	k_c	-1.05	-.52	-.93	-1.30	-2.16	-1.85	-2.56
			k_s	1.58	.78	1.39	1.94	3.24	2.78	3.85
"	75	-4.0	k_c	-.29	-.16	-.28	-.38	-.60	-.52	-.70
			k_s	1.18	.64	1.10	1.51	2.41	2.09	2.81

(concluded)

EXPLANATION OF FIGURES 43 TO 70

The following figures show associated values of k_c and k_s, the constants in equations (36) and (40) of Report No. 1316, for the buckling of long rectangular plates of plywood under combined uniform compression (or tension) and shear. The edges were taken to be simply supported. The constants for rotary-cut Douglas-fir plywood were used in the calculations of the coordinates of the points on these curves. Curves showing the ratio of the half wave length b to the width a and the slope γ of the wrinkles as functions of k_s are plotted to the left in each figure.

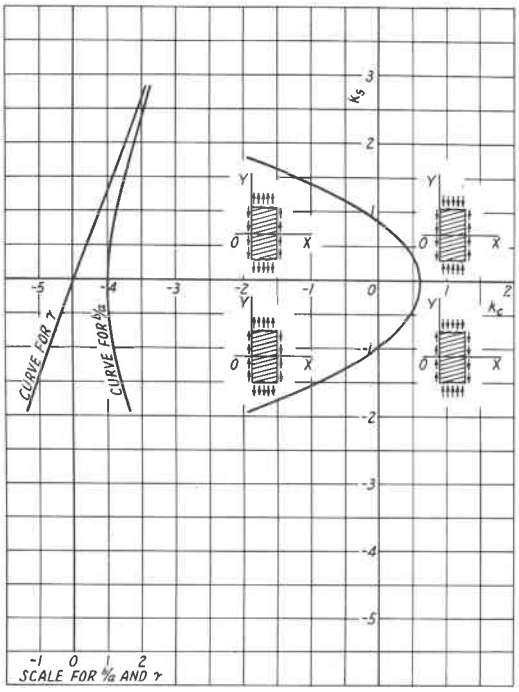

FIG. 43
2-PLY (1:1) θ = 15°

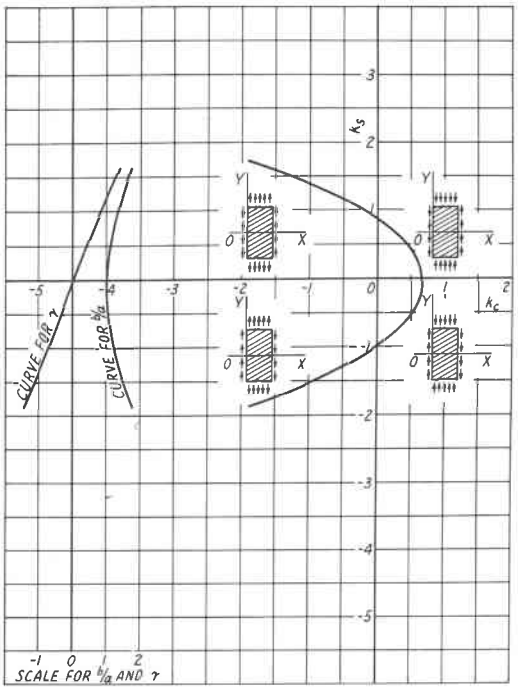

FIG. 44
2-PLY (1:1) θ = 30°

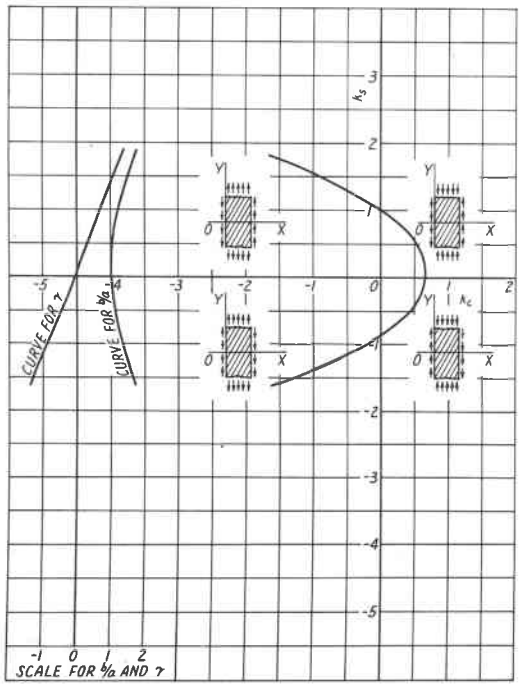

FIG. 45
2-PLY (1:1) θ = 60°

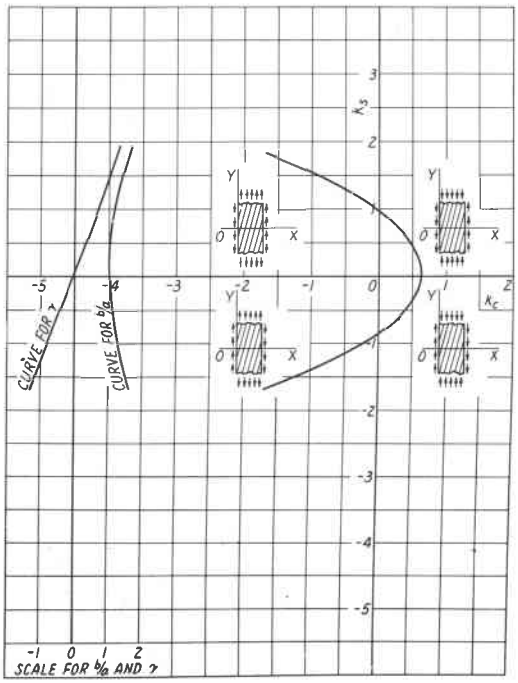

FIG. 46
2-PLY (1:1) θ = 75°

Z M 44375 F

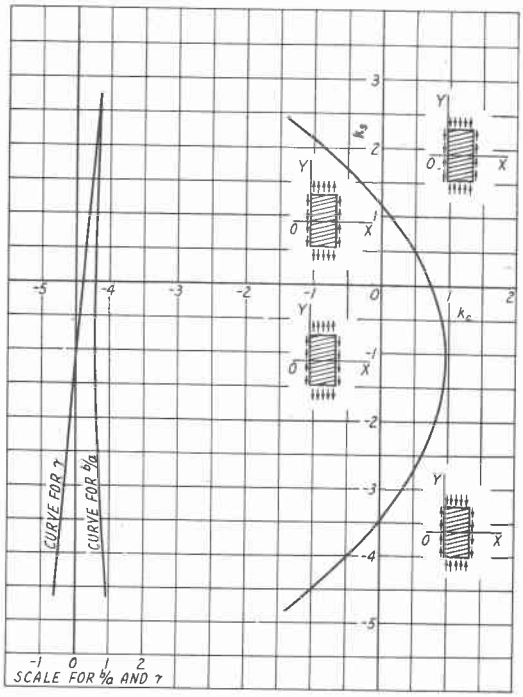

FIG. 47
3-PLY (1:1:1) θ = 15°

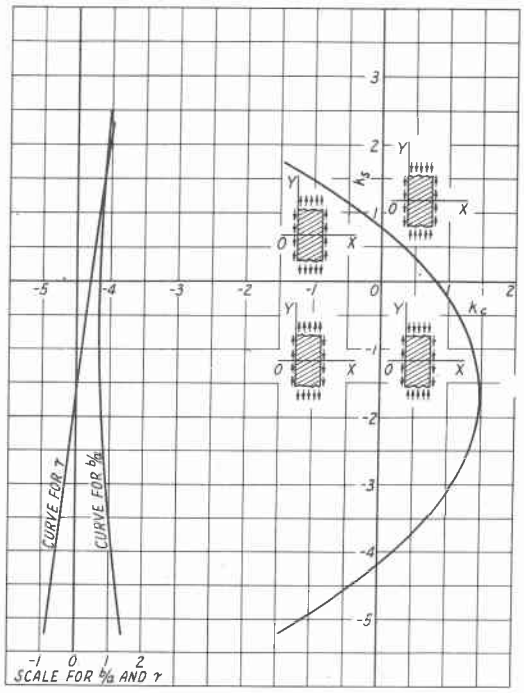

FIG. 48
3-PLY (1:1:1) θ = 30°

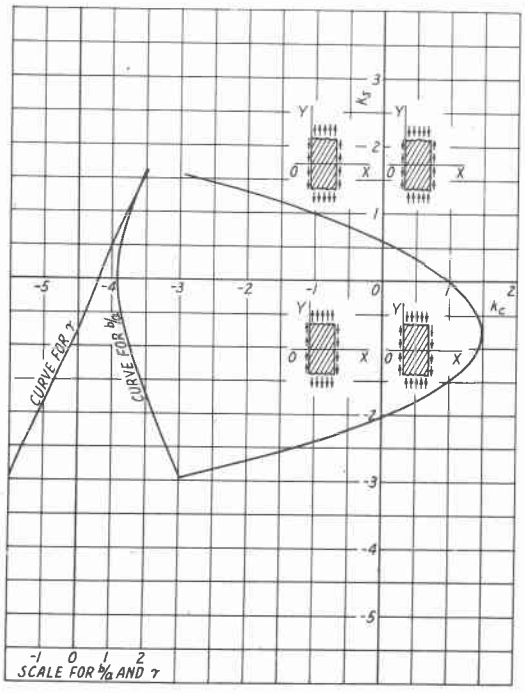

FIG. 49
3-PLY (1:1:1) θ = 60°

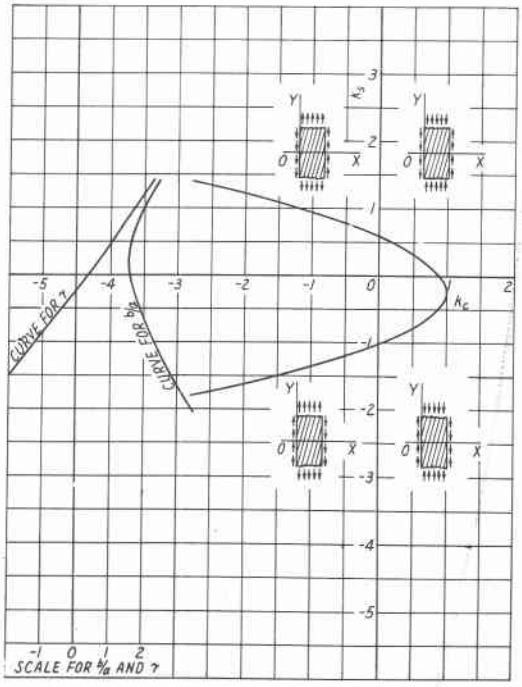

FIG. 50
3-PLY (1:1:1) θ = 75°

Z M 44376 F

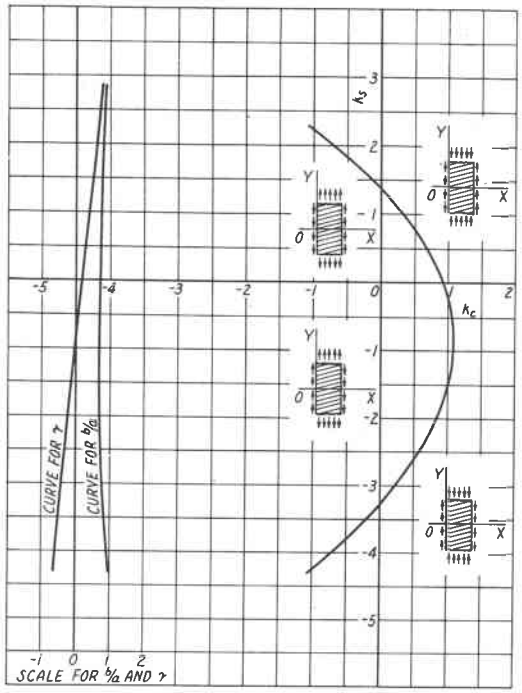

FIG. 51
3-PLY (1:2:1) $\theta = 15°$

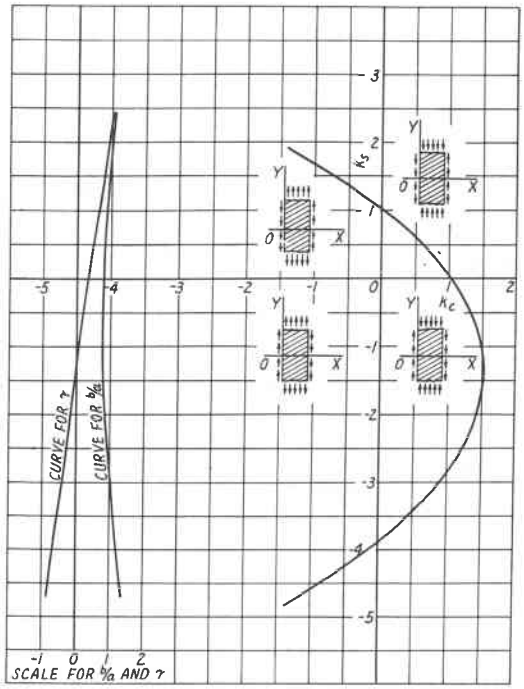

FIG. 52
3-PLY (1:2:1) $\theta = 30°$

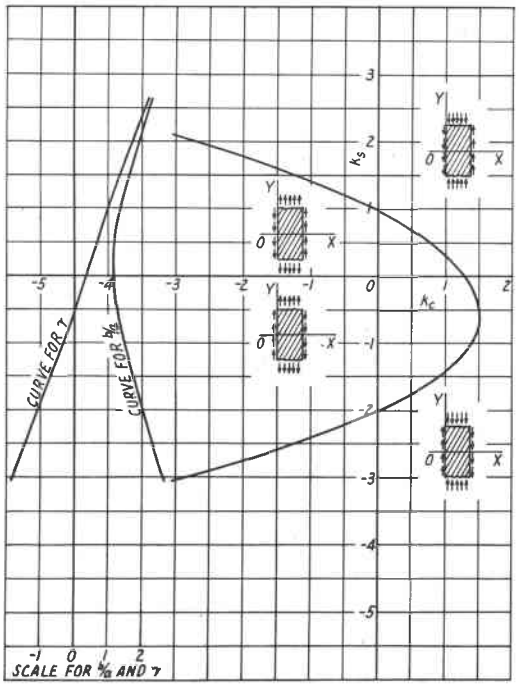

FIG. 53
3-PLY (1:2:1) $\theta = 60°$

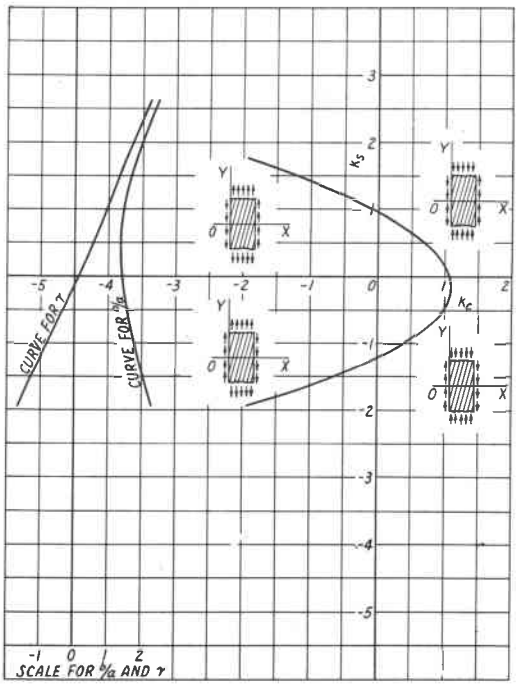

FIG. 54
3-PLY (1:2:1) $\theta = 75°$

Z M 44377 F

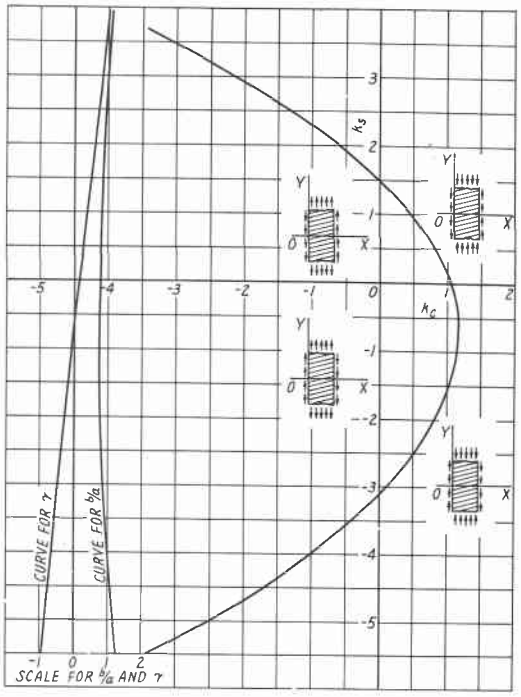

FIG. 55
5-PLY (1:1:1:1:1) $\theta = 15°$

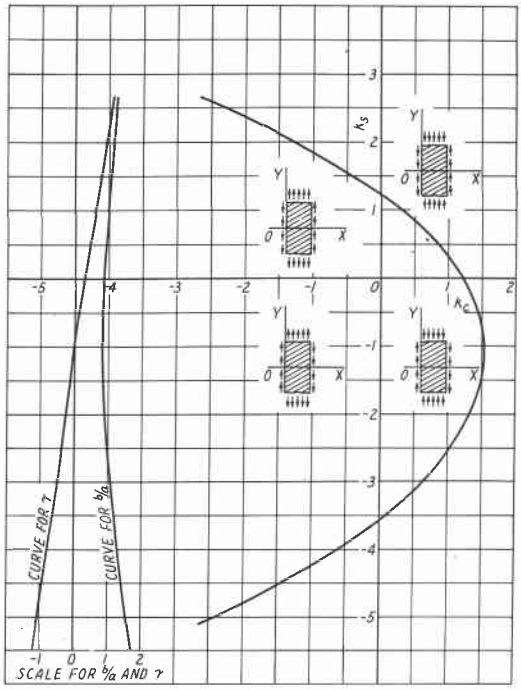

FIG. 56
5-PLY (1:1:1:1:1) $\theta = 30°$

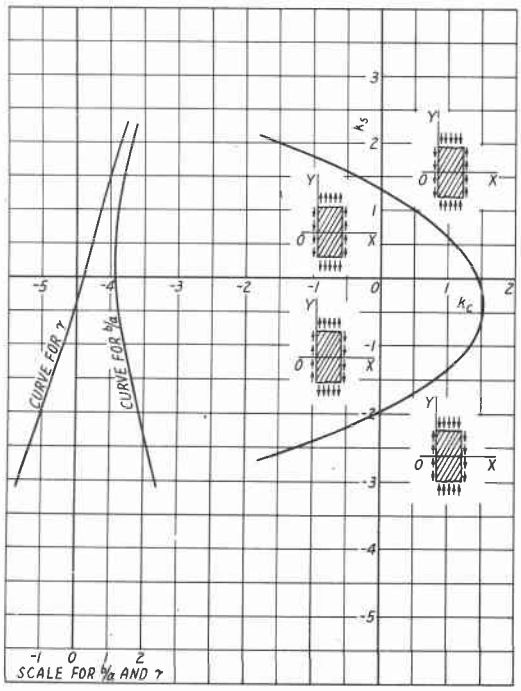

FIG. 57
5-PLY (1:1:1:1:1) $\theta = 60°$

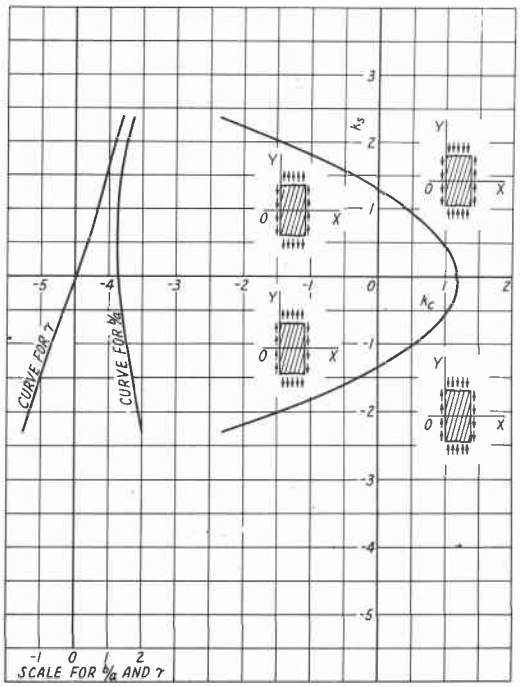

FIG. 58
5-PLY (1:1:1:1:1) $\theta = 75°$

Z M 44378 F

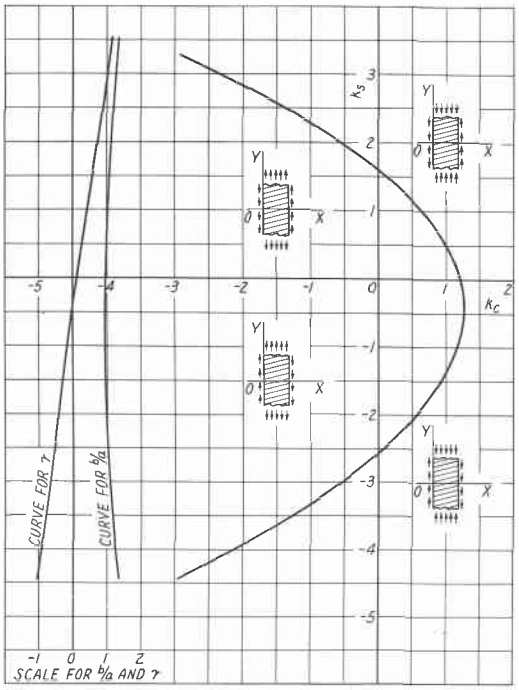

FIG. 59
5-PLY (1:2:2:2:1) $\theta = 15°$

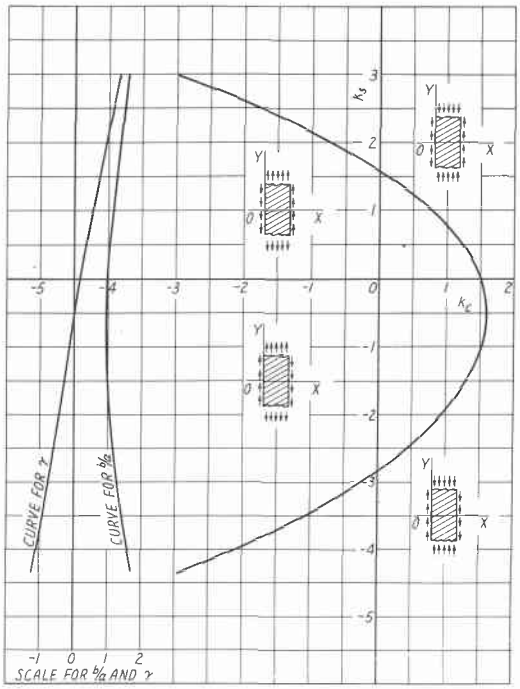

FIG. 60
5-PLY (1:2:2:2:1) $\theta = 30°$

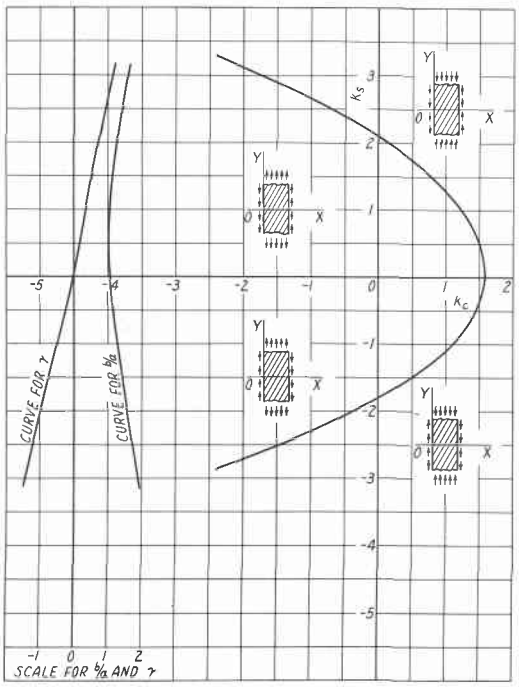

FIG. 61
5-PLY (1:2:2:2:1) $\theta = 60°$

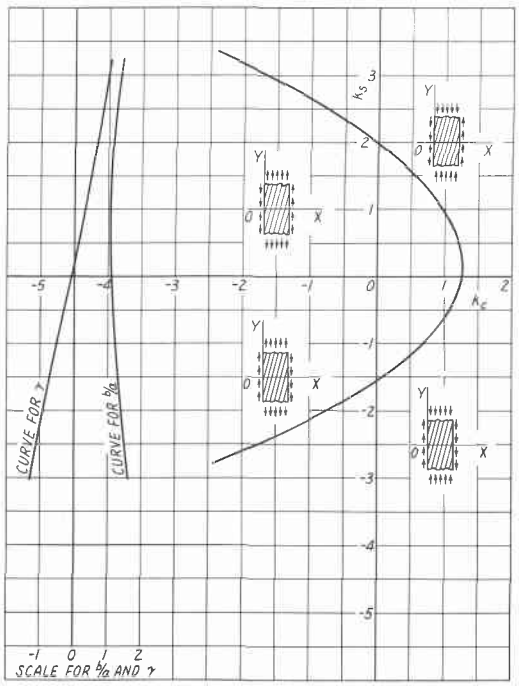

FIG. 62
5-PLY (1:2:2:2:1) $\theta = 75°$

Z M 44379 F

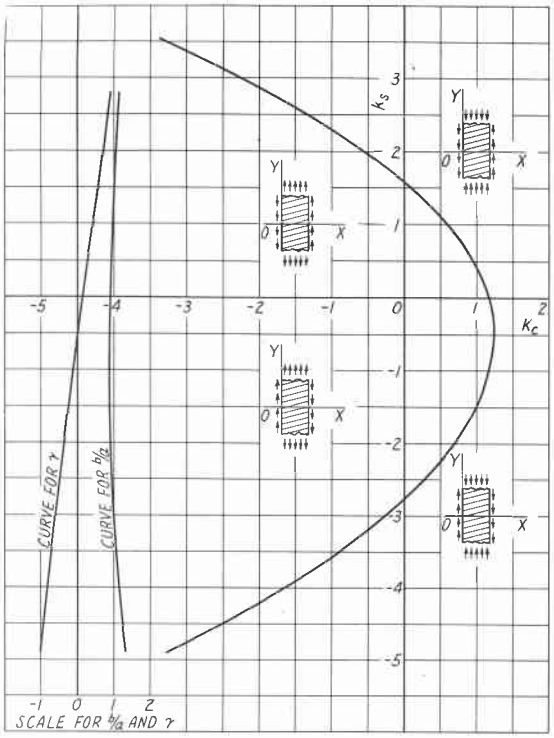

FIG. 63
9-PLY (1:1:1:1:1:1:1:1:1) θ = 15°

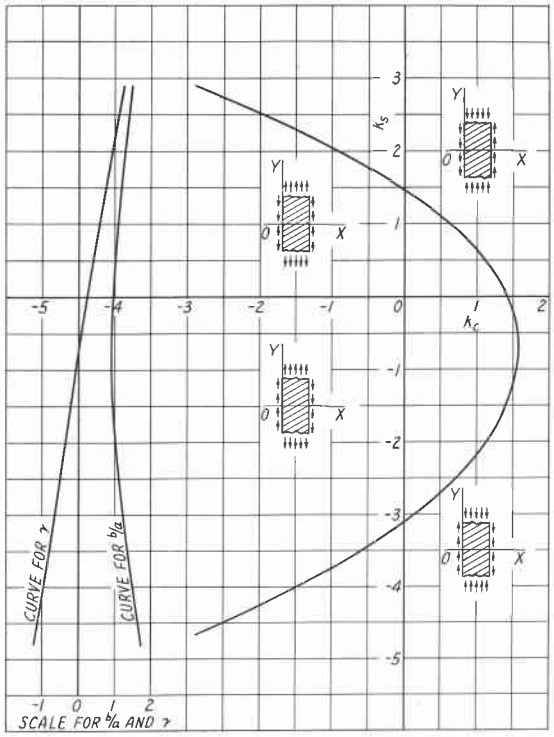

FIG. 64
9-PLY (1:1:1:1:1:1:1:1:1) θ = 30°

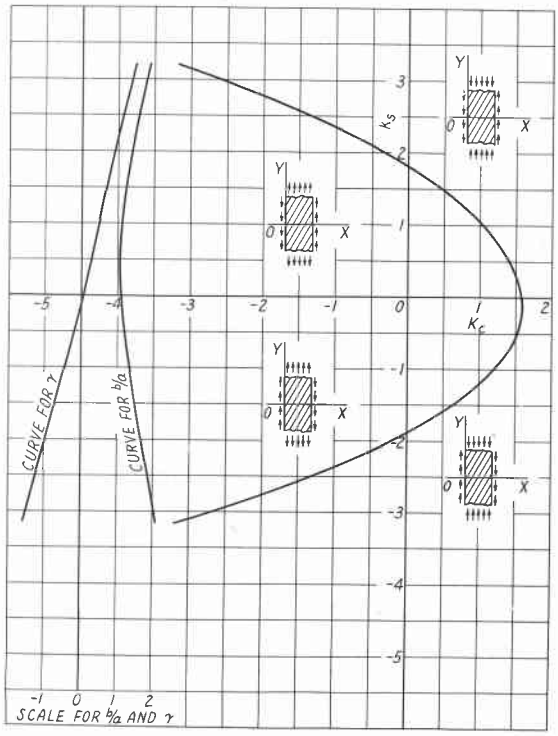

FIG. 65
9-PLY (1:1:1:1:1:1:1:1:1) θ = 60°

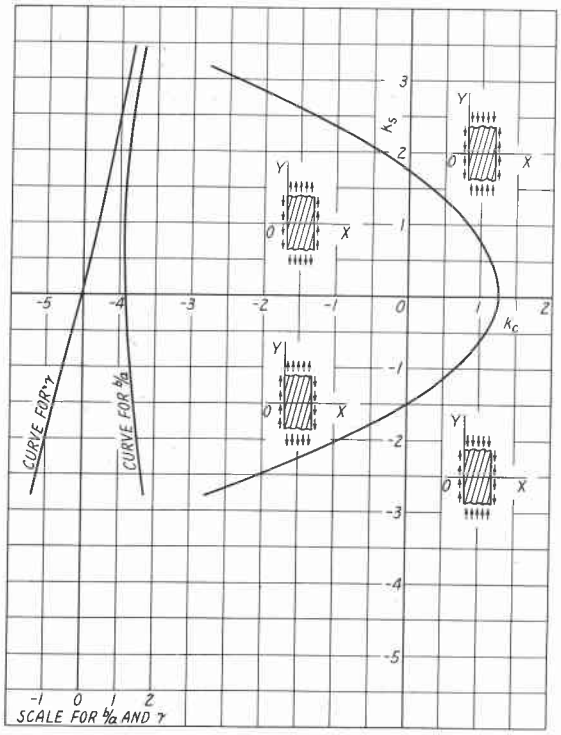

FIG. 66
9-PLY (1:1:1:1:1:1:1:1:1) θ = 75°

Z M 44443 F

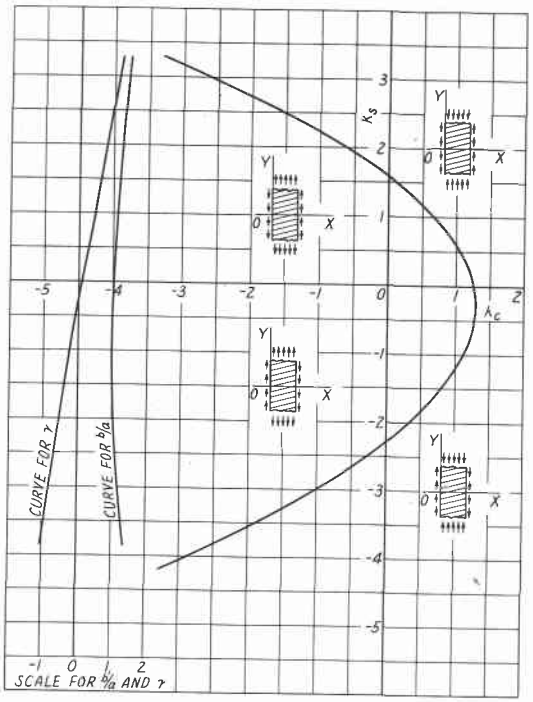

FIG. 67
∞-PLY $\theta = 15°$

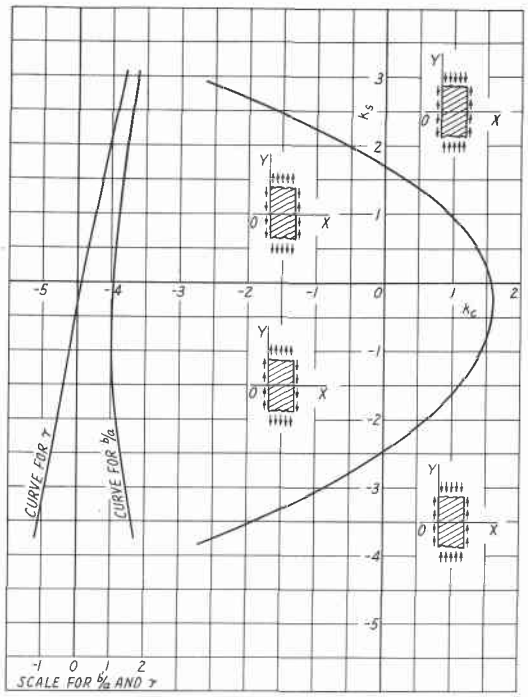

FIG. 68
∞-PLY $\theta = 30°$

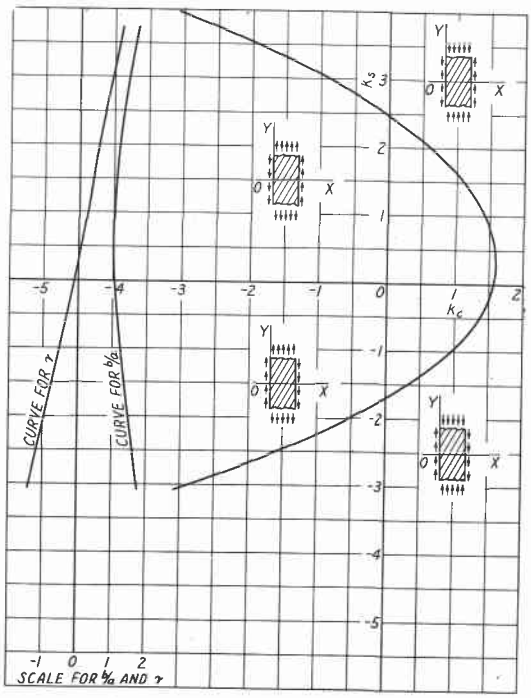

FIG. 69
∞-PLY $\theta = 60°$

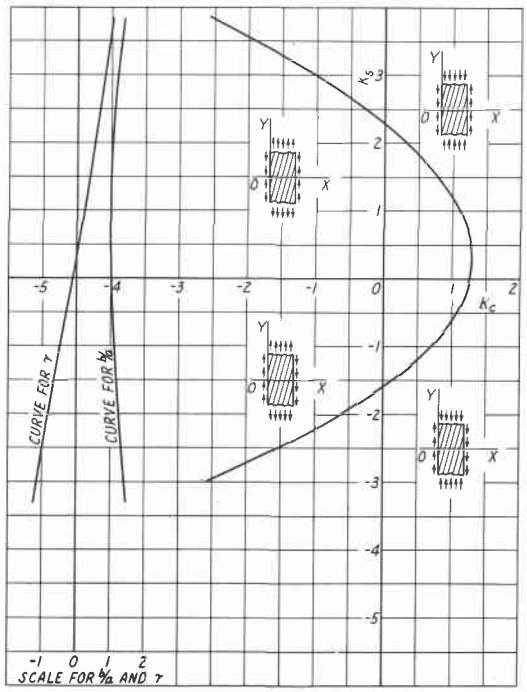

FIG. 70
∞-PLY $\theta = 75°$

Z M 44495 F