Supplement to

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

Effective Width of Thin Plywood Plates at Maximum Load in Compression With the Face Grain at 0°, 15°, 30°, 45°, 60°, 75°, and 90° to Load

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EFFECTIVE WIDTH OF THIN PLYWOOD PLATES AT MAXIMUM LOAD IN COMPRESSION WITH THE FACE GRAIN AT 0°, 15°, 30°, 45°, 60°, 75°, and 90° TO LOAD[1]

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Summary

This report presents data on the effective width of plywood plates at maximum compressive load and curves for the determination of the effective width ratios of plywood plates under compressive stress at 0°, 15°, 30°, 45°, 60°, 75°, and 90° to the face grain direction. Values for other angles may be obtained by interpolation. An effective width ratio curve at the maximum stress is presented, which for the 0° and 90° directions supersedes that shown in figure 90 in Mimeograph 1316-E. The effective width ratio is here defined as the ratio of the maximum load sustained by a buckled plate to the maximum load it would have sustained had it been restrained from buckling.

Purpose

A theoretical analysis and formulas for the critical buckling stresses of flat plywood plates subjected to compression, shear, and combined compression and shear were presented in Forest Products Laboratory Mimeographs Nos. 1316 and 1316-C. Applicability of the formula, $p_{cr} = k_c E_L \frac{h^2}{a^2}$ for the critical buckling

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[1] This report is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available. Original report issued March 1945.

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

stress in compression at 0° or 90° to the face grain direction was verified by test (Mimeograph No. 1316-D). The same specimens were used also for the determination of maximum loads and effective width ratios (Mimeograph No. 1316-E). Buckling tests with compression at 15°, 30°, 45°, 60°, and 75° to the face grain demonstrated that modification of k_c was necessary to adapt the formula to such angles. Data and correction curves are given in Mimeograph No. 1316-G. The purpose of the present study was to determine an effective width curve, or family of curves, from a further analysis of the data reported in Mimeographs Nos. 1316-D, 1316-E, and 1316-G, together with the necessary additional data.

Material

A detailed description of the material used in this study is given in Mimeographs Nos. 1316-D and 1316-G.

Approximately half of the plates subjected to buckling tests were damaged to such an extent that it was impossible to obtain representative material from them for supplementary compression tests. It was possible to select coupons for the supplementary compression tests of the material from the plates that were damaged over a limited area only. Consequently, only the data from such plates are available for the present study of effective widths.

Because the plywood was thin, two or more pieces were taken from each acceptable plate and glued face to face with cold-setting urea-resin glue to make a specimen of such thickness that buckling was avoided during the compression test. In table 27 there are listed for each plate the number of pieces used to make compression test coupons.[3]

Coupons 6 inches wide and 2 inches or less in height for supplementary tests with compression at 0°, 15°, 30°, 45°, 60°, 75°, and 90° to the direction of face grain were stressed in the direction parallel to the height with the face grain at the same angle to the load as in the buckling test. The height of these coupons was made approximately six times the thickness to prevent buckling or column failure before failure occurred in compression. The width was made 6 inches in all specimens to facilitate testing. It would have been preferable to have coupons the same width as the plates tested in buckling, but this could not be done because the edges of the plates, which varied in width from 7-1/2 to 12 inches for 0° and 90°, and were all 9-1/2 inches wide for other angles, were damaged in the buckling test. The maximum compressive strength as found from coupons 6 inches wide should reasonably represent the maximum stresses that the plates would have sustained had they been restrained from buckling.

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[3] The figures and tables in this supplement are numbered consecutively with those of Mimeograph No. 1316 and its supplements, B, C, D, E, F, G, and H.

Methods of Tests

The data required for the determination of the effective width ratio for each plate included: (1) the maximum load and (2) the compressive strength of the material.

The first item was supplied by the tests for maximum load made previously on the plates used for study of the critical buckling load.

To determine the compressive strength, glued coupons, as described previously, were tested according to the procedure given in Mimeograph No. 1328-A. In the 0° and 90° angles, tests were also made on coupons of the same thickness as the plates but 1 inch wide and 4 inches high with support to prevent lateral buckling under load, as described in Mimeograph No. 1316-D. Both methods for determining the compressive strength were used because it was expected that the laterally supported column method might be made standard for 0° and 90°.

The maximum stresses obtained for 0° and 90° average some 15 percent higher by the method of Mimeograph No. 1328-A than by the laterally supported column procedure.

The discrepancy may be due to several factors. It has been observed in the laterally supported column compression test that material less than 1/8 inch in thickness generally fails in compression and bending between the end surface of the specimen and the lateral supports. This type of failure may be due to some unrecognized excentricity of loading, to a slight bending of the specimen, or to yielding of the spring steel lateral supports. Nevertheless, the maximum stresses averaged no less than the average maximum stresses obtained in tests of matched specimens by the same method but with ends widened to force failure in the central portion. Ends intentionally cut poorly, however, produced low values. Tests of short, wide plywood specimens in compression at 0° and 90° to the face grain were not extensively studied. It was noted that at failure such specimens bulged and occasionally delaminated. The factors causing the discrepancy between the two methods of test were not determined.

Explanations of Tables and Curves

The data from the buckling tests and compression tests pertaining to the effective width of flat plywood plates in compression at 15°, 30°, 45°, 60°, and 75° to the direction of the face grain, are presented in table 27, together with the computed values used as coordinates in figures 142, 143, and 144.

In this table, column 1 identifies each plate and indicates the direction of the face grain of the plate in relation to the loaded edges of the plate. Column 2 gives the effective width ratios, which are used for ordinates, and

column 3 gives the parameters of panel width ($\frac{a}{a_o}$) which are used for abscissas in plotting the data on figures 142, 143, and 144. In column 4 is given the computed maximum load for the plate if restrained from buckling. The observed maximum load and the critical buckling load determined in the buckling test of the plates are given in columns 5 and 6.

Results of the supplementary compression tests of coupons taken from the plates after the buckling tests were completed are tabulated in columns 7 through 12. The maximum stress, proportional limit stress, number of thicknesses used to fabricate the compression test specimen from the plate, specific gravity based on volume at test, moisture content based on ovendry weight, and the modulus of elasticity in compression are given respectively in columns 7, 8, 9, 10, 11, and 12. These compression test coupons were 6 inches wide and 2 inches, or less, high (short enough to eliminate buckling).

In table 28 are presented data from Forest Products Laboratory Mimeographs No. 1316-D, "Buckling of Flat Plywood Plates in Compression with Face Grain at 0° and 90° to Load," and No. 1316-E, "Effective Width of Thin Plywood Plates in Compression with the Face Grain at 0° and 90° to Load," and the parameter of panel width ($\frac{a}{a_o}$) computed from these data. The table is divided vertically to group the data for plates in compression parallel to face grain and perpendicular to face grain.

The material used for the tests is identified by the panel number tabulated in column 1 (refer to Mimeograph No. 1316-D). Effective width ratios from Mimeograph No. 1316-E were used as ordinates in figures 145 and 146 and are tabulated in columns 2 and 6. The computed parameters of panel width ($\frac{a}{a_o}$) were used as abscissas in figures 145 and 146 and are given in columns 3 and 7. Computations for these parameters were based on the observed critical buckling stresses from Mimeograph No. 1316-D tabulated in columns 4 and 8 and the average maximum stresses shown in columns 5 and 9 obtained by compression tests of coupons 1 inch wide by 4 inches long reported in Mimeograph No. 1316-D.

In table 29 is given a comparison of the maximum stresses in compression at 0° and 90° to the face grain obtained by a short column test method described in Mimeograph No. 1328-A and the maximum stresses obtained by the laterally supported column test and reported in Mimeograph No. 1316-D. The first column gives the panel number that identifies the material. The thickness of the specimens is tabulated in columns 2 and 5. Maximum stresses are given in column 3, 4, 6, and 7. The ratio of the stresses obtained by the short column method to the stresses obtained by the laterally supported column method are listed in column 8 for compression parallel to the face grain and in column 9 for compression perpendicular to the face grain.

A family of curves for the effective width ratio of flat plywood plates in compression at 0°, 15°, 30°, 45°, 60°, 75°, and 90° to the direction of face grain are presented in figure 141. These curves are based on buckling tests

of flat plates and compression tests of material matched to the plates. The supplementary compression tests with the stress at 0° and 90° to the face grain were made on 1- by 4-inch coupons laterally supported against buckling. Compression tests with the stress at the intermediate angles were made on 6- by 2-inch (or less) coupons that were short enough to eliminate buckling before failure in compression. The dashed curves are based on a small amount of data that do not definitely locate the curves.

Figures 142, 143, and 144 show, respectively, the appropriate curve from figure 141 compared with the test results for the angles 75° and 15°, 60° and 30°, and 45°.

Figure 145 shows the curve from figure 141 and the test data for compression at 0° and 90° to the direction of the face grain.

Figure 146 shows the curve from figure 141 for compression at 0° and 90° to the direction of the face grain and the effect of changing the basis for computations from the maximum stresses obtained by the laterally supported column compression test to the maximum stresses obtained by the short column test (table 29).

Analysis of Results

The effective width ratio is defined as the ratio of the maximum load sustained by a buckled plate to the maximum load it would have sustained had it been restrained from buckling. It is computed from the maximum load observed in the buckling test and the ultimate stress obtained in the compression test of the material.

The maximum loads obtained in the buckling tests of plates apply only for the precise edge and end conditions existing during the test. These conditions, which approximated hinged edges, are shown in detail in figures 74 and 75 of Mimeograph No. 1316-D. Variation in these conditions between one test and another may cause variation in values of the effective width ratios obtained.

The ultimate stresses obtained in the compression tests on coupons of the material of the plates were used to compute the maximum load that the plate would have sustained had it been restrained from buckling.

The effective width ratios used as ordinates of the curves were based on the buckling tests of plates and laterally supported column compression tests of matched coupons stressed at 0° or 90° to the direction of the face grain and compression tests at acute angles to the face grain of 6- by 2-inch (or less) coupons of the material from the plates.

The abscissa of the curves is a nondimensional parameter of panel width determined as follows:

The critical buckling stress in compression may be computed by the formula:

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

The width of a plate in compression theoretically may be adjusted so that the buckling stress and the ultimate stress are the same. The symbol a_o is used for this width and the formula becomes:

$$F_{cu} = k_c E_L \frac{h^2}{a_o^2} \tag{2}$$

Dividing equation (2) by equation (1) and taking the square root, the following is obtained:

$$\frac{a}{a_o} = \sqrt{\frac{F_{cu}}{q_{cr}}} \tag{3}$$

The constant k_c is used in both (2) and (3) to allow for the specific edge and end conditons that occur, as well as the properties and dimensions of the plate, but cancels out of formula (3). Abscissas of the points plotted were based on the maximum stresses from compression tests of the material and the critical buckling stresses observed in the buckling tests. The ratio $(\frac{a}{a_o})$ is therefore a parameter of panel width that does not depend on the edge or end conditions of the plate, except as these conditions enter the experimentally determined critical stress q_{cr}.

Sufficient data were obtained to locate the curves for compression at 0°, 45°, and 90° to the direction of face grain. If the material were such that the proportional limit in compression conincided with the ultimate stress and if it were perfectly uniform in strength properties and perfectly flat at the start of test, the curves would go through the point 1, 1. Experimental curves, however, will not pass through this point.

Data obtained for compression at 15°, 30°, 60°, and 75° to the direction of face grain indicate the approximate location of these curves but are insufficient to define them. It was assumed that the relative location of these curves between the curves for compression at 0° and 90° and at 45° does not change throughout their length. Because there is insufficient data to substantiate the entire curves for compression at 15°, 30°, 60°, and 75° to the face grain, they are shown with a broken line in figure 141.

The curve for effective width at 0° and 90° and the effect of the compression test data on several of the points used to draw this effective-width curve are shown in figure 146. Each point based on 1- by 4-inch coupons is shown connected with the corresponding point based on 6- by 2-inch coupons. Because the maximum compressive stress (F_{cu}) determined by test of coupons appears in the

ordinate, $\frac{F_{c\ eff.}}{F_{cu}}$, and in the abscissa, $\sqrt{\frac{F_{cu}}{p_{cr}}}$, changing the maximum stress moves the points along the hyperbola ($y = ax^{-2}$) where (a) is a factor depending on the critical buckling stress and the maximum stress observed in the buckling test for each point in question.

The effective width curve is not a hyperbola, but it is sufficiently similar to one in the range where data were obtained so that small changes in the value of the maximum stress would not appreciably alter the effective width curve given.

Conclusions

The curves presented in figure 141 may be used to determine the effective width at maximum stress in compression at 0°, 15°, 30°, 45°, 60°, 75°, and 90° to the face grain of a plywood plate with its edges and ends approximately freely supported in a plane, providing the critical buckling stress of the plate is computed in accordance with the formula $p_{cr} = k_c\ E_L\ \frac{h^2}{a^2}$ as presented in Mimeograph Nos. 1316 and 1316-G, and providing the maximum stress is determined for the material considered. This curve is probably sufficiently accurate for edge conditions other than freely supported if these edge conditions are taken into account in computing the critical stress and therefore the values of $\frac{a}{a_o}$.

The common compression formulas are applicable for computing loads, stresses, or strains before buckling occurs. After buckling occurs a portion of the plate may be considered to carry the load. It is evident that this portion is a maximum when buckling starts and decreases as buckling progresses. The portion, effective width ratio, at ultimate stress is therefore conservative for lower stresses.

Further study is necessary to establish accurately the effective width ratios at the proportional limit stress and at other stresses between the critical buckling stress and maximum stress. Such determinations are not simple because of the complicated stress distribution in a plate of orthotropic material after buckling has occurred in compression at an angle other than 0° or 90° to the principal axes. Further study would involve mathematical analyses and the development of new and more complicated testing techniques.

Table 27.--Observed and computed values obtained from the buckling test of flat plywood plates and the test of 6- by 2-inch coupons in compression at 15°, 30°, 45°, 60° and 75° to the direction of face grain

Plate No.	Effective width ratio $\frac{F_{c\,eff}}{F_{cu}}$	Parameter of panel width $\frac{a}{a_o}$	Computed maximum load for plate	Observed results of buckling tests: Maximum load	Observed results of buckling tests: Critical buckling load	Compression test results: Maximum stress	Compression test results: Proportional limit stress	Compression test results: Number of plate thicknesses	Compression test results: Specific gravity	Compression test results: Moisture content	Compression test results: Modulus of elasticity
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
			Pounds	Pounds	Pounds	Psi	Psi			Percent	1,000 psi
Specimens tested with face grain direction at 15° to loaded edge (75° to compressive stress)											
3q - 15°	0.333	2.65	6,321	2,108	900	3,980	1,420	2	0.654	9.1	616
6q - 15°	.402	2.38	4,527	1,820	800	2,830	1,580	2	.440	9.6	435
8q - 15°	.451	2.44	3,578	1,614	600	2,580	1,360	3	.430	9.2	585
12q - 15°	.394	2.43	5,894	2,320	1,000	3,390	1,830	2	.560	8.9	562
14q - 15°	.477	1.83	9,922	4,728	2,950	4,430	1,920	2	.596	8.8	882
15q - 15°	.453	1.60	13,751	6,230	5,400	4,820	2,580	2	.624	8.6	766
17q - 15°	.484	1.69	7,173	3,470	2,500	3,120	1,290	2	.436	8.2	526
20q - 15°	.406	1.91	10,261	4,170	2,800	4,400	2,140	2	.499	7.6	830
21q - 15°	.518	1.41	11,778	6,100	5,900	4,030	2,260	2	.476	7.6	691
23q - 15°	.525	1.53	7,694	4,040	3,300	3,450	2,110	2	.516	9.2	676
24q - 15°	.548	1.47	9,050	4,960	4,200	3,120	2,040	2	.500	9.4	385
Specimens tested with face grain direction at 30° to loaded edge (60° to compressive stress)											
3p - 30°	.319	2.44	8,009	2,555	1,350	4,840	2,180	2	0.640	9.4	703
3m - 30°	.330	2.31	7,996	2,635	1,500	4,620	2,350	2	.620	9.6	648
6p - 30°	.356	2.06	4,884	1,740	1,150	2,850	1,100	2	.438	9.7	504
6m - 30°	.341	2.15	5,541	1,890	1,200	3,170	1,640	2	.481	9.3	500
12p - 30°	.360	2.00	6,201	2,230	1,550	3,540	1,720	2	.554	9.4	543
15p - 30°	.444	1.66	14,080	6,249	5,100	4,930	2,200	2	.613	8.6	638
21p - 30°	.569	1.44	10,107	5,750	4,900	3,410	1,520	2	.485	7.4	510
24p - 30°	.365	1.65	9,302	3,390	3,400	3,200	1,440	2	.482	8.8	461
Specimens tested with face grain direction at 45° to loaded edge											
1r - 45°	.130	6.50	3,161	410	75	5,260	2,340	4	0.566	10.3	764
2e - 45°	.210	3.05	6,300	1,320	675	4,610	2,290	3	.599	9.5	612
3e - 45°	.274	2.33	8,405	2,304	1,550	4,840	2,030	2	.628	9.2	772
3f - 45°	.254	2.50	8,991	2,288	1,440	5,200	2,190	2	.630	9.5	797
3r - 45°	.276	2.60	8,368	2,310	1,240	5,140	2,110	2	.658	9.2	614
4r - 45°	.130	5.21	2,308	300	85	3,670	1,680	4	.445	10.3	610
4rs- 45°	.133	4.41	2,436	325	125	3,990	1,460	4	.459	10.4	514
6r - 45°	.331	2.32	5,127	1,695	950	2,940	1,710	2	.468	9.6	330
10r - 45°	.165	4.32	3,025	500	125	5,040	2,420	4	.560	10.1	721
11r - 45°	.269	2.95	6,449	1,736	740	4,630	2,500	3	.592	9.5	618
12r - 45°	.377	2.24	6,506	2,450	1,300	3,690	1,340	2	.536	9.8	548
13d - 45°	.234	3.80	6,117	1,430	425	5,860	3,110	4	.578	9.5	690
13e - 45°	.232	3.34	5,375	1,364	525	5,680	2,760	4	.562	9.2	700
14d - 45°	.427	1.59	11,648	4,970	4,630	4,890	3,040	2	.586	8.8	602
14e - 45°	.488	1.52	10,606	5,180	4,600	4,520	2,520	2	.564	8.8	657
14f - 45°	.452	1.48	9,901	4,475	4,500	4,140	1,890	2	.556	9.3	600
15r - 45°	.544	1.53	14,116	7,675	6,000	4,910	2,490	2	.623	9.2	594
16r - 45°	.252	3.54	3,940	992	315	3,950	1,680	4	.434	9.7	566
17d - 45°	.479	1.57	7,152	3,425	2,900	3,140	960	2	.402	8.8	412
18r - 45°	.577	1.45	8,846	5,100	4,200	3,080	1,020	2	.452	9.0	688
20d - 45°	.462	1.54	8,824	4,075	3,700	3,940	2,480	2	.448	8.3	554
23d - 45°	.424	1.53	8,428	3,575	3,600	3,670	1,370	2	.494	9.0	536
23e - 45°	.482	1.52	8,577	4,130	3,700	3,750	2,140	2	.534	9.5	421
23r - 45°	.476	1.52	9,253	4,405	4,000	4,000	2,300	2	.532	9.5	512
24r - 45°	.537	1.55	9,865	5,300	4,100	3,390	2,060	2	.494	9.2	385
25e - 45°	.247	3.27	5,788	1,428	540	5,440	2,390	4	.568	9.1	790
25f - 45°	.230	3.25	5,801	1,333	550	5,540	2,570	4	.586	9.5	685
27d - 45°	.457	1.48	12,994	5,940	5,900	4,480	2,590	2	.586	8.8	538
29f - 45°	.479	1.51	7,166	3,430	3,150	3,210	2,020	2	.504	8.7	376
32e - 45°	.530	1.40	7,815	4,140	4,000	3,410	1,720	2	.442	7.9	538
35d - 45°	.470	1.46	8,101	3,808	3,800	3,520	1,580	2	.510	8.7	404
35e - 45°	.476	1.65	9,241	4,400	3,400	4,070	1,820	2	.506	8.3	553
35f - 45°	.455	1.51	8,397	3,820	3,700	3,660	2,080	2	.507	8.9	489
Specimens tested with face grain direction at 60° to loaded edge (30° to compressive stress)											
3m - 60°	.351	2.18	8,796	3,090	1,850	4,930	2,170	2	.617	9.3	566
5p - 60°	.264	2.85	4,784	1,263	590	3,480	1,690	3	.470	8.5	430
6p - 60°	.351	2.07	6,400	2,243	1,500	3,730	1,680	2	.484	8.9	457
6m - 60°	.362	2.17	6,116	2,215	1,300	3,480	1,730	2	.474	8.8	458

(Continued)

Table 27.--Observed and computed values obtained from the buckling test of flat plywood plates and the test of 6- by 2-inch coupons in compression at 15°, 30°, 45°, 60° and 75° to the direction of face grain (Continued)

Plate No.	Effective width ratio $\frac{F_{c\,eff}}{F_{cu}}$	Parameter of panel width $\frac{a}{a_0}$	Computed maximum load for plate	Observed results of buckling tests: Maximum load	Observed results of buckling tests: Critical buckling load	Compression test results: Maximum stress	Compression test results: Proportional limit stress	Compression test results: Number of plate thicknesses	Compression test results: Specific gravity	Compression test results: Moisture content	Compression test results: Modulus of elasticity
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
			Pounds	Pounds	Pounds	Psi	Psi			Percent	1,000 psi
Specimens tested with face grain direction at 60° to loaded edge (30° to compressive stress) (continued)											
7p - 60°	0.140	4.59	2,943	412	140	4,850	2,860	4	0.489	10.4	680
9p - 60°	.453	2.06	6,398	2,900	1,500	3,590	2,070	2	.499	8.0	670
9m - 60°	.400	2.06	6,505	2,600	1,530	3,650	2,050	2	.514	8.2	708
12p - 60°	.313	2.55	8,486	2,660	1,300	4,860	2,100	2	.582	9.4	768
12m - 60°	.340	2.22	6,877	2,340	1,400	3,900	1,980	2	.552	9.4	771
13p - 60°	.197	4.11	6,748	1,332	400	7,040	3,680	4	.646	9.8	1,037
14m - 60°	.469	1.80	11,725	5,500	3,600	5,100	1,940	2	.608	8.9	616
15p - 60°	.438	1.64	16,605	7,280	6,200	5,800	2,330	2	.608	8.7	896
17m - 60°	.480	1.83	8,010	3,840	2,400	3,400	1,500	2	.440	8.9	504
18p - 60°	.611	1.54	9,446	5,770	4,000	3,260	1,320	2	.453	9.0	518
19p - 60°	.231	3.54	5,002	1,155	400	4,880	1,920	4	.470	9.2	802
20m - 60°	.520	1.61	9,087	4,725	3,500	3,920	1,800	2	.496	7.9	668
22p - 60°	.238	3.85	5,321	1,266	360	5,340	2,260	4	.506	9.4	888
22m - 60°	.233	3.60	5,186	1,210	400	5,300	2,330	4	.514	7.1	723
Specimens tested with face grain direction at 75° to loaded edge (15° to compressive stress)											
3n - 75°	.259	2.82	12,687	3,285	1,600	7,180	3,020	2	.610	9.5	1,077
5n - 75°	.259	3.41	6,384	1,653	550	4,480	2,800	3	.430	8.2	576
6q - 75°	.313	2.84	7,252	2,268	900	4,180	1,860	2	.444	9.1	636
6n - 75°	.266	2.77	8,464	2,250	1,100	4,790	2,370	2	.490	9.1	1,205
11n - 75°	.239	3.21	8,764	2,092	850	6,220	2,560	3	.594	8.4	870
12q - 75°	.288	3.02	10,507	3,030	1,150	6,090	2,530	2	.554	8.2	802
14n - 75°	.406	2.00	15,173	6,155	3,800	6,600	2,960	2	.622	9.2	1,154
15q - 75°	.436	1.81	18,346	8,010	5,600	6,560	2,950	2	.635	8.9	1,281
16q - 75°	.207	3.97	4,894	1,014	310	4,770	2,170	4	.434	9.9	921
17q - 75°	.396	1.90	10,103	4,000	2,800	4,350	2,690	2	.434	8.4	952
17n - 75°	.452	1.84	9,465	4,285	2,800	4,050	1,870	2	.442	8.6	780
19q - 75°	.223	4.40	5,811	1,294	300	5,670	3,290	4	.482	9.1	1,470
20n - 75°	.435	1.89	11,459	4,985	3,200	4,830	2,940	2	.487	7.6	842
22q - 75°	.239	3.98	5,552	1,327	350	5,680	2,700	4	.500	9.4	1,384
23n - 75°	.469	1.71	11,639	5,460	4,000	4,940	2,200	2	.518	9.5	934

Table 28.--Computed values and data from Forest Products Laboratory Mimeos. No. 1315-D and No. 1315-E pertinent to the effective width of plywood plates in compression at 0° and 90° to direction of face grain

Panel No.	Compression parallel to face grain: Effective width ratio $\frac{F_{c\ eff}}{(F_{cu})_a}$	Parameter of panel width $\frac{a}{a_o}$	Observed critical stress	Average maximum stress (1" x 4" coupons)	Compression perpendicular to face grain: Effective width ratio $\frac{F_{c\ eff}}{(F_{cu})_b}$	Parameter of panel width $\frac{a}{a_o}$	Observed critical stress	Average maximum stress (1" x 4" coupons)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			Psi.	Psi.			Psi.	Psi.
1a	0.289	4.44	230	4,540	.....	.....	.....	.....
1b	.286	5.27	185	5,140	.....	.....	.....	.....
1c	.309	5.13	181	4,760	.....	.....	.....	.....
2a	.340	3.39	497	5,710	0.351	3.29	273	2,960
2b	.384	3.11	596	5,780	.348	4.02	204	3,300
2c	.400	3.43	473	5,580	.305	3.99	230	3,670
3a	.406	2.52	791	5,030	.339	2.99	360	3,220
3b	.472	2.27	1,012	5,230	.291	3.02	394	3,580
3c	.422	2.50	800	5,000	.361	2.86	357	2,910
4a	.271	6.52	104	4,420	.....	.....	.....	.....
4b	.279	5.69	143	4,620	.....	.....	.....	.....
4c	.246	6.28	123	4,840	.....	.....	.....	.....
5a	.320	3.43	451	5,320	.....	.....	.....	.....
5b	.342	2.88	682	5,680	.338	3.38	243	2,780
5c	.400	2.77	665	5,100	.319	4.06	159	2,620
6a	.382	3.11	500	4,820	.326	3.06	299	2,800
6b	.440	2.69	539	3,910	.....	.....	.....	.....
6c	.394	3.12	428	4,160	.....	.....	.....	.....
7a	.343	4.92	145	3,500	.....	.....	.....	.....
7b	.230	5.42	161	4,740	.....	.....	.....	.....
7c	.259	5.58	139	4,330	.....	.....	.....	.....
8a	.370	2.98	604	5,350	.274	3.73	226	3,140
8b	.386	3.13	527	5,150	.284	3.84	214	3,160
8c	.373	3.40	442	5,120	.279	3.54	242	3,040
9a	.382	2.35	641	3,560	.329	3.35	187	2,100
9b	.362	2.45	634	3,810	.320	3.34	177	1,970
9c	.418	2.40	635	3,660	.359	2.94	257	2,220
10a	.258	5.30	182	5,120	.....	.....	.....	.....
10c	.240	5.95	166	5,880	.....	.....	.....	.....
11a	.337	3.29	584	6,320	.331	3.54	243	3,050
11b	.327	3.32	588	6,480	.303	3.64	247	3,270
11c	.345	3.34	543	6,050	.340	3.49	242	2,940
12a	.385	2.42	872	5,090	.326	3.15	318	3,160
12b	.410	2.35	944	5,200	.350	2.87	363	3,000
12c	.419	2.49	839	5,200	.310	3.15	316	3,130
13a	.400	2.90	579	4,880	.269	4.94	174	4,240
13b	.376	3.11	548	5,230	.244	4.35	227	4,300
13c	.412	3.04	578	5,340	.226	4.16	262	4,520
14a	.616	1.45	2,520	5,310	.469	2.09	923	4,010
14b	.583	1.52	2,518	5,830	.450	2.01	1,042	4,220
14c	.596	1.43	2,690	5,500	.467	2.00	923	3,680
15a	.625	1.33	2,920	5,140	.439	1.98	1,127	4,440
15b	.627	1.42	2,638	5,310	.447	1.82	1,257	4,180
15c	.641	1.44	2,322	4,790	.441	1.82	1,261	4,170
16a	.335	3.45	404	4,800	.247	4.68	136	2,980
16b	.337	3.38	456	5,200	.246	4.70	136	3,000
16c	.372	3.39	424	4,870	.261	5.13	109	2,870
17a	.597	1.50	1,636	3,570	.478	2.21	570	2,780
17b	.573	1.55	1,609	3,860	.397	2.39	527	3,020
17c	.645	1.44	1,678	3,460	.409	2.33	556	3,030
18a	.529	1.53	1,765	4,120	.464	1.92	742	2,740
18b	.574	1.44	1,979	4,080	.440	1.81	1,038	3,410
18c	.650	1.38	2,059	3,940	.472	1.85	932	3,200

(Continued)

Table 28.--Computed values and data from Forest Products Laboratory Mimeos. No. 1316-D and No. 1316-E pertinent to the effective width of plywood plates in compression at 0° and 90° to direction of face grain (Continued)

Panel No.	Compression parallel to face grain: Effective width ratio $\frac{F_{c\ eff}}{(F_{cu})_a}$	Compression parallel to face grain: Parameter of panel width $\frac{a}{a_o}$	Compression parallel to face grain: Observed critical stress	Compression parallel to face grain: Average maximum stress (1" x 4" coupons)	Compression perpendicular to face grain: Effective width ratio $\frac{F_{c\ eff}}{(F_{cu})_b}$	Compression perpendicular to face grain: Parameter of panel width $\frac{a}{a_o}$	Compression perpendicular to face grain: Observed critical stress	Compression perpendicular to face grain: Average maximum stress (1" x 4" coupons)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			Psi.	Psi.			Psi.	Psi.
19a	.428	2.85	479	3,880	.266	4.43	164	3,210
19b	.376	2.98	479	4,250	.246	4.75	142	3,200
19c	.416	2.60	5[illegible]4	3,800	.238	4.76	149	3,380
20a	.507	1.61	2,145	5,580	.395	2.21	801	3,920
20b	.533	1.53	2,334	5,460	.427	2.21	763	3,720
20c	.536	1.53	2,246	5,280	.429	2.10	795	3,520
21a	.610	1.30	2,215	3,740	.434	1.71	856	2,490
21b	.598	1.32	2,027	3,510	.447	1.71	882	2,570
21c	.600	1.32	1,965	3,400	.442	1.77	828	2,580
22a	.330	3.18	483	4,880	.....	.....	.....	.....
22b	.280	3.71	439	6,040	.293	3.83	193	2,830
22c	.321	3.19	496	5,040	.298	3.97	176	2,770
23a	.547	1.67	1,695	4,720	.445	1.90	959	3,460
23b	.545	1.65	1,855	5,030	.389	2.08	856	3,700
23c	.534	1.55	1,964	4,700	.459	1.99	857	3,400
24a	.602	1.48	2,107	4,620	.459	1.73	1,109	3,310
24b	.651	1.33	2,699	4,780	.509	1.54	986	2,330
24c	.653	1.43	2,080	4,240	.531	1.48	1,127	2,450
25a	.439	2.59	609	4,080	.175	5.22	231	6,300
25b	.405	2.68	616	4,420	.199	5.49	202	6,080
25c	.401	2.69	610	4,410	.183	5.12	232	6,080
26a	.563	1.52	2,135	4,900	.312	2.53	890	5,710
26b	.552	1.43	2,420	4,980	.365	2.57	830	5,500
26c	.619	1.33	2,605	4,640	.354	2.72	760	5,600
27a	.714	1.24	2,634	4,060	.396	2.02	1,296	5,300
27b	.614	1.38	2,405	4,590	.389	2.10	1,337	5,910
27c	.797	1.13	3,163	4,030	.365	1.96	1,404	5,420
28a	.403	2.86	388	3,180	.169	5.74	128	4,220
28b	.358	2.97	453	4,000	.199	5.42	135	3,960
28c	.367	2.56	587	3,840	.187	4.93	173	4,210
29a	.589	1.40	1,903	3,720	.369	2.54	690	4,450
29b	.630	1.33	2,088	3,700	.366	2.63	624	4,320
29c	.668	1.31	2,109	3,640	.361	2.69	593	4,290
30a	.659	1.26	1,860	2,960	.425	1.95	958	3,650
30b	.679	1.24	2,000	3,050	.372	2.00	862	3,440
30c	.697	1.22	2,023	3,000	.411	1.87	949	3,330
31a	.527	2.49	417	2,580	.231	5.32	149	4,210
31b	.556	2.42	428	2,500	.182	5.61	151	4,760
31c	.533	2.43	416	2,460	.186	5.71	135	4,400
32a	.684	1.18	2,264	3,160	.362	2.54	753	4,860
32b	.652	1.28	2,063	3,360	.322	2.68	728	5,220
32c	.636	1.29	2,174	3,600	.322	2.74	684	5,130
33a	.733	1.17	1,735	2,360	.417	1.95	934	3,550
33b	.951	1.03	1,942	2,060	.368	1.92	907	3,340
33c	.723	1.18	1,590	2,200	.387	1.92	936	3,440
34a	.381	3.09	410	3,910	.235	4.76	172	3,920
34b	.348	3.51	380	4,680	.230	4.55	210	4,340
34c	.404	3.07	444	4,180	.236	4.94	163	3,970
35a	.548	1.37	2,208	4,140	.367	2.27	889	4,580
35b	.580	1.38	2,167	4,140	.452	2.08	994	4,290
35c	.545	1.33	2,310	4,000	.379	2.27	897	4,620
36a	.638	1.25	2,504	3,920	.517	1.73	1,164	3,480
36b	.594	1.37	2,102	3,940	.501	1.78	1,137	3,590
36c	.650	1.26	2,463	3,910	.449	1.76	1,267	3,940

Table 29.--Comparison of maximum stresses in compression at 0° and 90° to face grain obtained by the short column pack test (6" x 1-1/2" coupons) with the maximum stresses obtained by the laterally supported column test (1" x 4" coupons)

Panel No.	Laterally supported column method of determining maximum stress in compression			Short column method of determining maximum stress in compression 1/			Ratio of short column method to laterally supported column method	
	Specimen thickness	Maximum stress		Specimen thickness	Maximum stress			
		Parallel	Perpendicular		Parallel	Perpendicular	Parallel	Perpendicular
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Inch	Psi.	Psi.	Inch	Psi.	Psi.		
13a	0.110	4,880	.....	0.322	6,240	.....	1.28	.....
13b	.110	5,290	4,300	.330	6,300	5,300	1.19	1.23
16a	.105	4,800	.....	.316	5,520	.....	1.15	.....
16b	.103	5,200	3,000	.312	5,840	3,300	1.12	1.10
16c	.104	4,870	2,870	.304	5,130	3,330	1.05	1.16
19a	.114	3,880	.....	.339	4,750	.....	1.22	.....
19b	.112	.....	3,200	.329	.....	3,540	.....	1.11
19c	.114	3,800	.....	.335	4,630	.....	1.22	.....
25a	.108	4,080	.....	.329	4,780	.....	1.17	.....
25b	.108	4,420	6,080	.330	4,750	6,620	1.07	1.09
25c	.110	4,410	.....	.330	5,050	.....	1.15	.....
28a	.102	3,180	.....	.307	4,080	.....	1.28	.....
28b	.104	4,000	3,960	.312	4,260	4,250	1.06	1.07
28c	.103	3,840	.....	.303	4,020	.....	1.05	.....
31a	.112	2,580	4,210	.324	3,330	4,800	1.29	1.14
31c	.112	2,460	.....	.327	3,410	.....	1.39	.....
34a	.108	.....	3,920	.325	.....	4,150	.....	1.06
34b	.106	.....	4,340	.318	.....	4,320	.....	1.00
34c	.106	.....	3,970	.319	.....	4,410	.....	1.11

1/ The short column test method is described in Forest Products Laboratory Mimeo. No. 1328-A.

Z M 59519 F

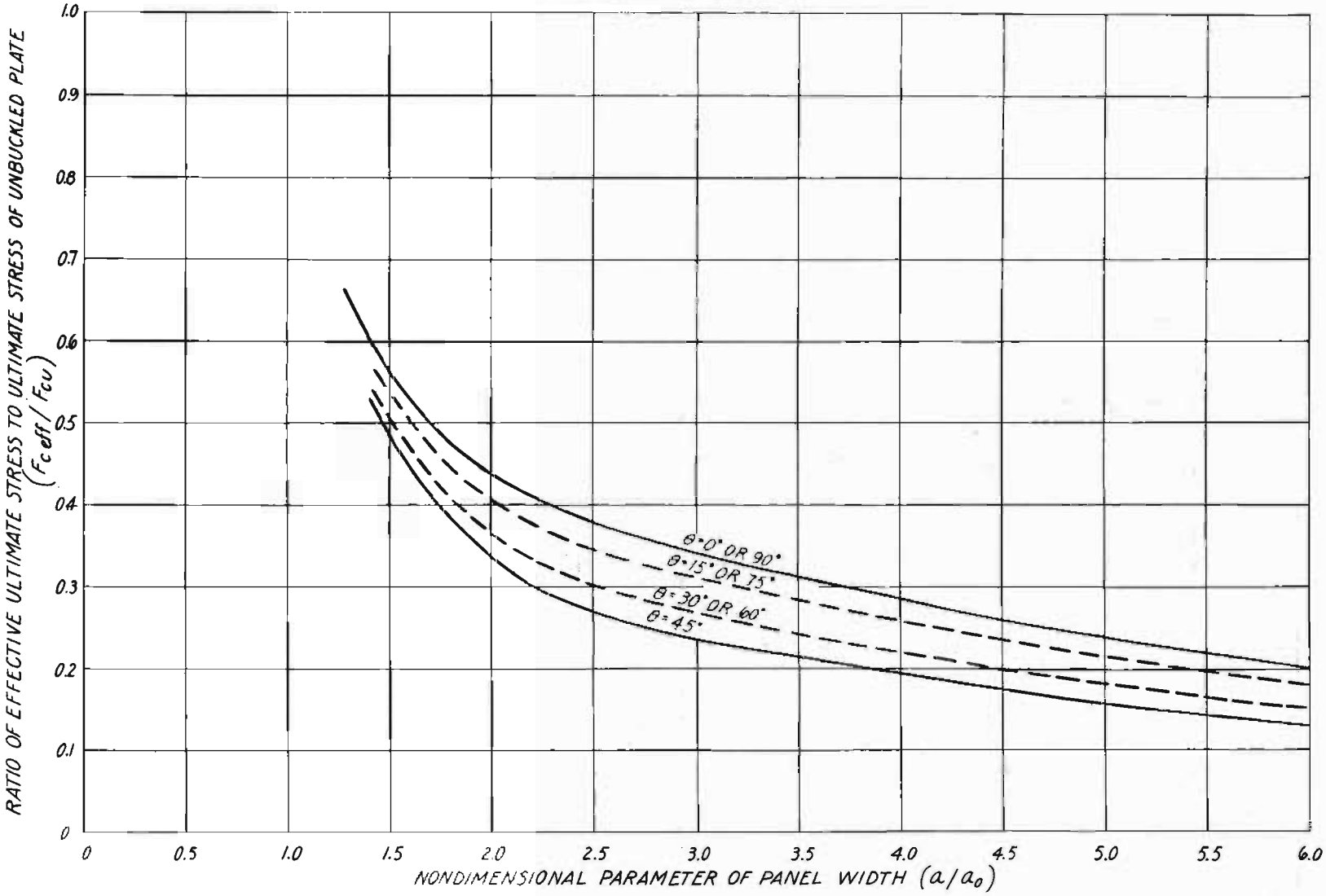

Figure 141.--Effective width of flat plywood plates in compression at 0°, 15°, 30°, 45°, 60°, 75°, or 90° to direction of face grain. (Curves based on buckling tests of plates and compression tests of coupons 1 inch wide by 4 inches long for 0° or 90° and 6 inches wide by 2 inches or less long for 15°, 30°, 45°, 60°, or 75°.)

Z M 59520 F

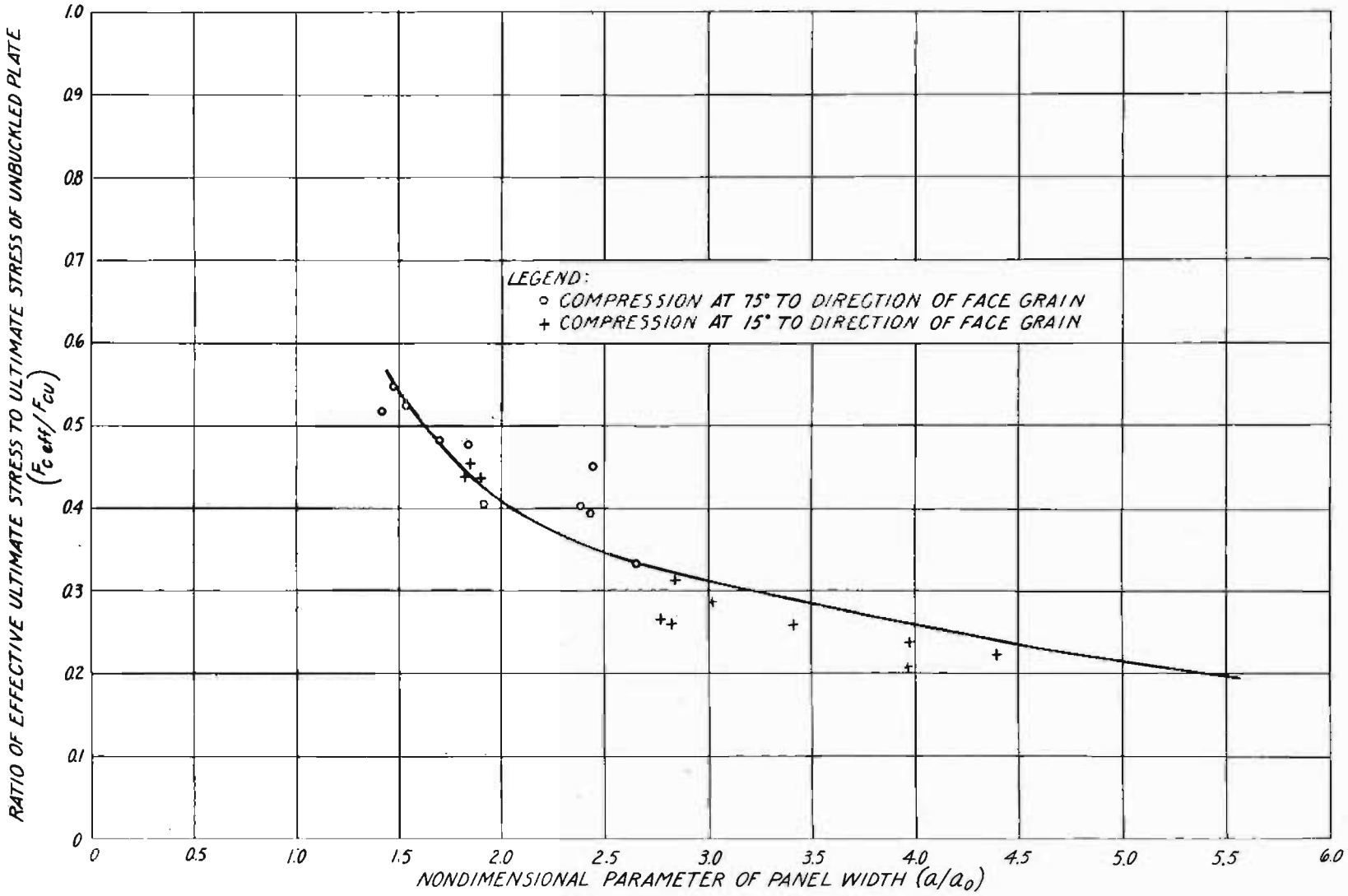

Figure 142.--Test data compared with curve for effective width of flat plywood plates in compression at 15° and 75° to direction of face grain (θ = 75° and 15°). (Curve based on tests of plates and 6- by 2-inch coupons.)

Z M 59521 F

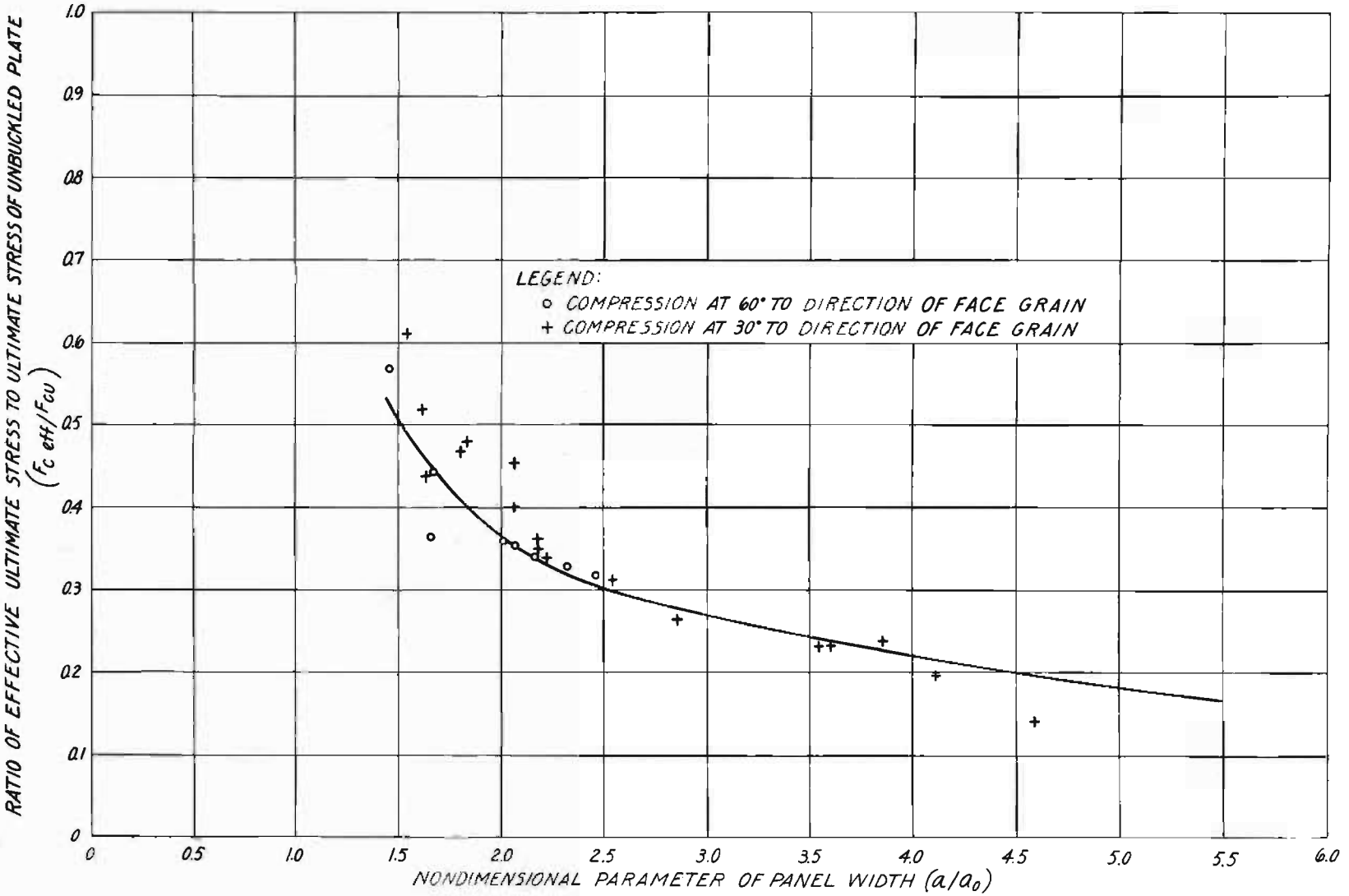

Figure 143.--Test data compared with curve for effective width of flat plywood plates in compression at 30° and 60° to direction of face grain (θ = 60° and 30°). (Curve based on tests of plates and 6- by 2-inch coupons.)

Z M 59522 F

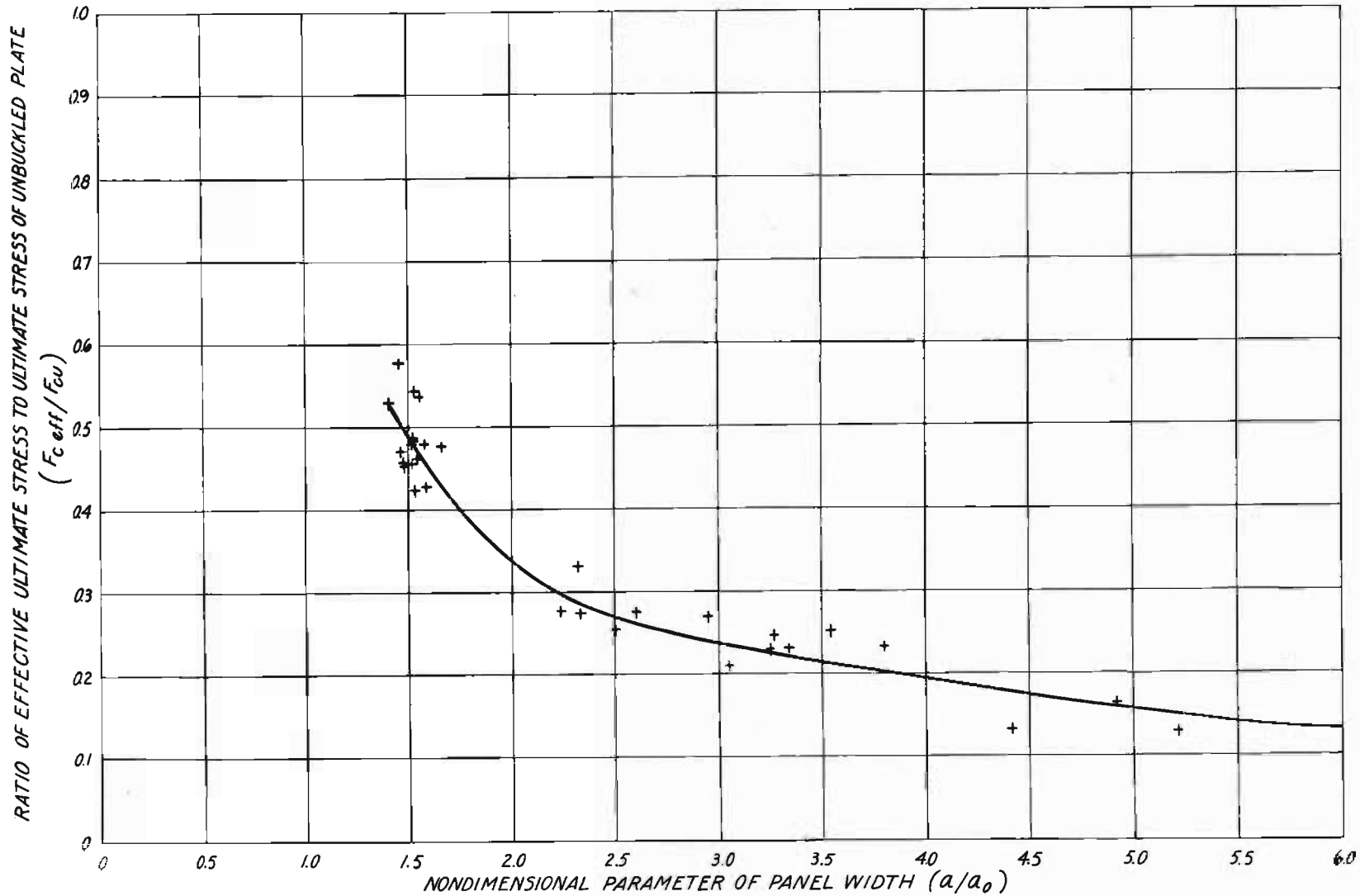

Figure 144.--Test data compared with curve for effective width of flat plywood plates in compression at 45° to direction of face grain (θ = 45°). (Curve based on tests of plates and 6- by 2-inch coupons.)

Z M 59523 F

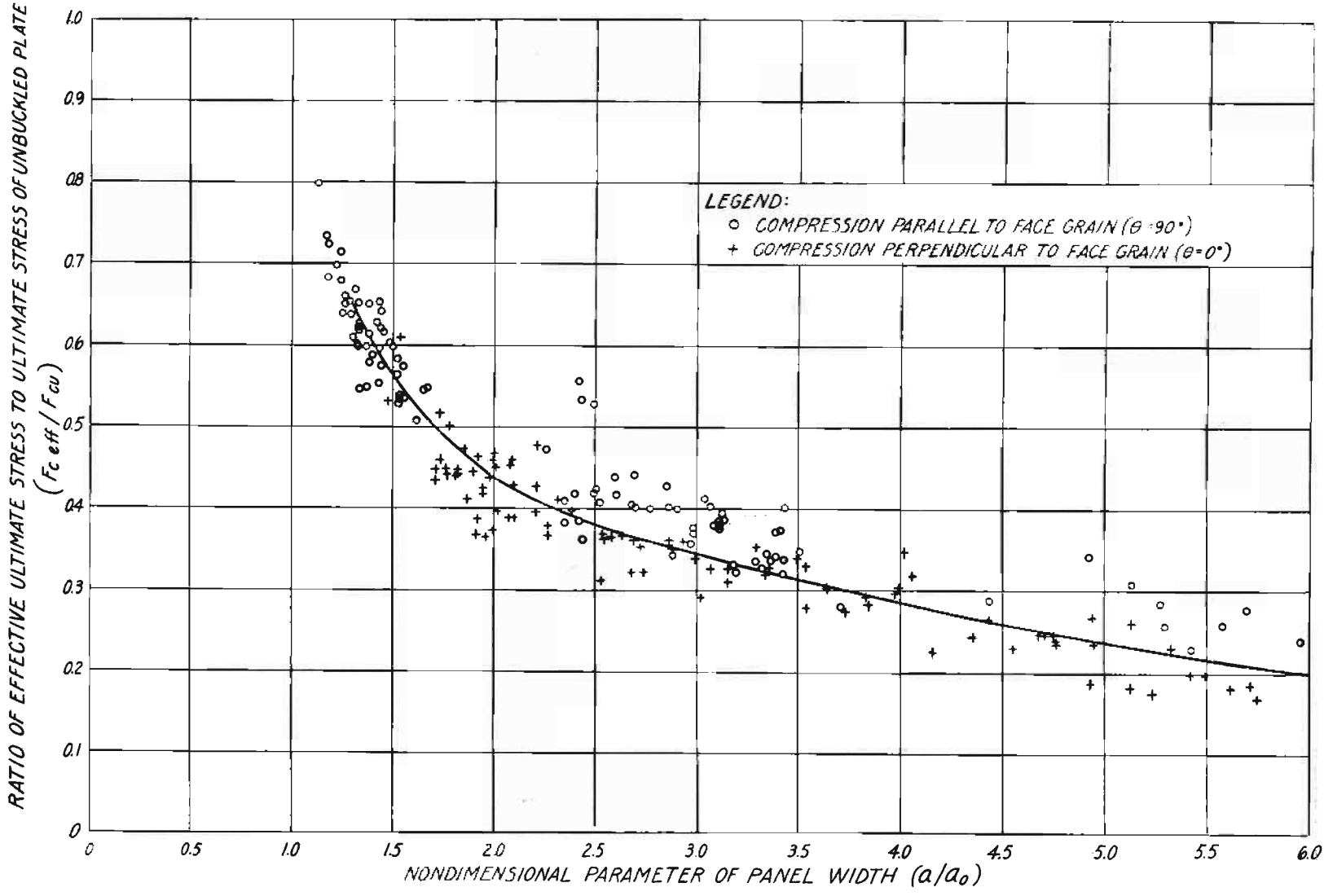

Figure 145.--Test data compared with curve for effective width of flat plywood plates in compression at 0° or at 90° to direction of face grain (curve based on tests of plates and 1- by 4-inch coupons).

Z M 59524 F

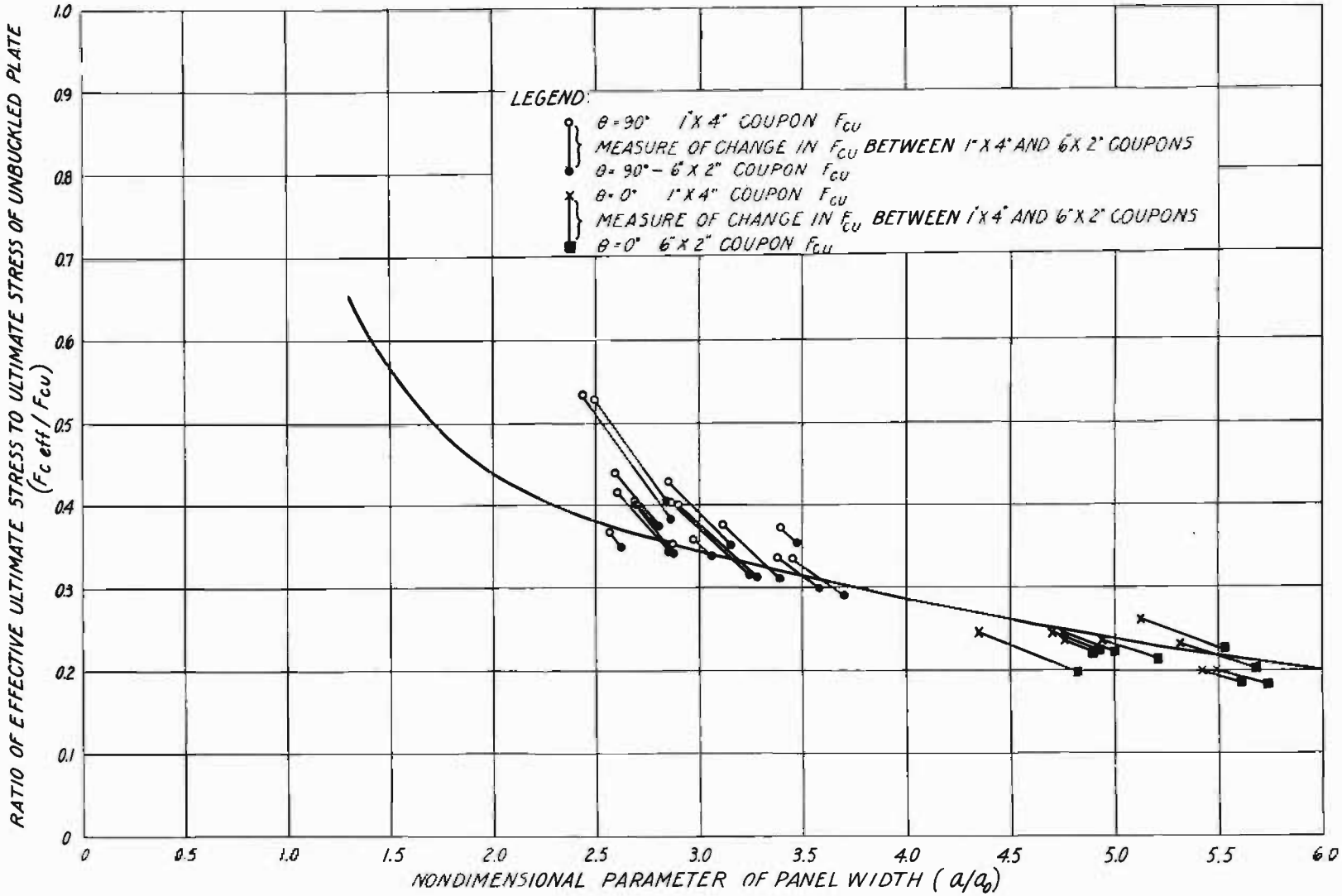

Figure 146.--Effect of compression tests of coupons on data, also curve for effective width of flat plywood plates in compression at 0° or at 90° to direction of face grain. (Curve based on tests of plates and 1- by 4-inch coupons.)

Z M 59525 F