BUCKLING LOADS OF FLAT SANDWICH PANELS IN COMPRESSION

Buckling of Flat Sandwich Panels with Loaded Edges Clamped and the Remaining Edges Simply Supported

Original report dated September 1947

Information Reviewed and Reaffirmed August 1962

No. 1525-C

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

BUCKLING LOADS OF FLAT SANDWICH PANELS IN COMPRESSION[1]

Buckling of Flat Sandwich Panels with Loaded Edges Clamped and the Remaining Edges Simply Supported[2]

(Cores of End-grain Balsa or Cellular Cellulose Acetate and Facings of Aluminum or Glass Cloth Laminate)

By

K. H. BOLLER, Engineer

Forest Products Laboratory,[3] Forest Service
U.S. Department of Agriculture

Summary and Conclusions

This report presents the results of edgewise compression tests to determine the critical buckling loads of flat sandwich panels, having the loaded edges clamped and the remaining edges simply supported. This investigation of the instability of sandwich panels was conducted at the Forest Products Laboratory to confirm equations (14) and (15) of the theoretical analysis presented in Forest Products Laboratory Report No. 1525[4] and subsequent modifications that were introduced to take into account the effect of transverse shear and of stresses greater than the proportional limit.

[1] This report is one of a series of progress reports prepared by the Forest Products Laboratory relating to aircraft. Results here reported are preliminary and may be revised as additional data become available. Original report dated September 1947.

[2] This report is the fourth of a series of reports dealing with the buckling of flat sandwich panels in compression tested with various types of edge conditions.

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

[4] March, H. W., and Smith, C. B. Buckling Loads of Flat Sandwich Panels in Compression--Various Types of Edge Conditions. Forest Products Laboratory Report No. 1525. March 1945. Information reviewed and reaffirmed 1962.

The equations, as given in Report No. 1525, are applicable to sandwich panels that are clamped at the loaded edges and simply supported at the remaining edges. They were modified in this study to apply to panels that buckle at facing stresses above the proportional limit and also to take into account the effect of transverse shearing deformations in the core.

Tests were made on sandwich constructions that consisted of cores of either end-grain balsa or cellular cellulose acetate and facings of either aluminum or glass cloth laminate. The results of the tests show the experimental values of critical buckling loads to be approximately equal to the computed values as determined by the modified formulas.

Introduction

This report is one of a series concerning experimental confirmation of the mathematical analysis that was previously developed[4] at the Forest Products Laboratory for the critical buckling of flat panels supported by various types of edge conditions and modified to take into account the effect of transverse shear and of stresses greater than the proportional limit. It presents experimental data of edgewise compression tests on the buckling of flat sandwich panels clamped at the loaded edges and simply supported at the other edges. Information relative to materials, testing procedures, and results is arranged according to the outline used to present similar information in Report No. 1525-A.[5] Duplications of descriptions have been avoided by omitting them and referring to previous reports in this series, either Report No. 1525-A[5] or Report No. 1525-B.[6] Where variations from the previous reports were necessary, they are noted and fully described. The preparation and manufacture of specimens, the description of the test panels and coupons, and the procedure for determining the critical loads are identical to those described in Report No. 1525-B. The scope of the work covered by this report and that of the work covered by Report No. 1525-B differ only by the difference in the edge conditions of the panels.

---

[5]Boller, K. H. Buckling Loads of Flat Sandwich Panels in Compression--With Edges Simply Supported. Forest Products Laboratory Report No. 1525-A. February 1947. Information reviewed and reaffirmed 1960.

[6]Boller, K. H. Buckling Loads of Flat Sandwich Panels in Compression--With Loaded Edges Simply Supported and the Remaining Edges Clamped. Forest Products Laboratory Report No. 1525-B. September 1947. Information reviewed and reaffirmed 1962.

Methods of Test

A revision of the test apparatus used in the preceding studies was necessary to support the edges of the panels according to the requirements of this investigation. The loaded edges of the test panels were clamped and the remaining edges simply supported. The simple support was provided by vertical guide posts and rails, as shown in figure 13 of Report No. 1525-A. These fixtures and their function are described in that report.

The loaded edges were clamped by replacing the grooved end rods, rollers, and roller supports, shown in figure 24 of Report No. 1525-B, with the clamps shown in figure 33.[7] These clamps consisted of 3-inch angle irons, 3/8 inch thick, drawn together by bolts passing through the test panel. The angle irons were reinforced between the holes by triangular plates, and surfaced on their faces. They were made in several short lengths, and combinations of them were used to support panels from 5 to 45 inches in width. In fastening the clamps to the panel, the bolts were not drawn tight enough to damage the core material. (The holes in the test panels did not produce sufficient stress concentrations or reductions in cross-sectional area to cause failures within this clamped portion of the panel.) The clamps and the bearing edges of the test panel rested against 1/4-inch auxiliary loading plates, which were shimmed wherever necessary to provide uniform bearing.

Figure 34 shows a test panel supported in the apparatus. The vertical guide posts are those shown in figure 11 of Report No. 1525-A, and the loading beams are those shown in figure 26 of Report No. 1525-B.

The shear, flexure, and compression tests made on coupons for the determination of mechanical properties were conducted according to methods described in Report No. 1525-B.

Presentation of Data

Experimental data and results of computations are presented in tables 14 through 17 and figures 35 through 38. Most of the symbols used in this report are defined in the preceding reports in this series. Definitions of additional symbols are given in the appendix of this report. The tables are identical in form and have the same column headings as those of Report No. 1525-B. The descriptions of the columns are the same as presented in that report, except

---

[7] The figures and tables in this report are numbered consecutively with those of Report No. 1525, and its supplements A and B.

that some of the values were obtained by methods that were different from those previously used. The variations from the methods used in Report No. 1525-B are as follows:

Column 11.--Computed by the method employed in Report No. 1525-A.

Column 19.--The values in column 19 of this report were computed as follows:

(1) For panels having glass cloth facings (tables 16 and 17)

$$P_{cr\ comp} = \frac{4\pi^2}{a^2}\left[\frac{3}{16} D_1 \frac{b^2}{a^2} + D_2 \frac{a^2}{b^2} + \frac{1}{2} \left(\frac{E\sigma}{\lambda}\right)_{1,2} I + \mu_{1,2} I\right] \quad (1)$$

(2) For panels having aluminum facings (tables 14 and 15)

$$P_{cr\ comp} = \frac{4\pi^2}{a^2} \frac{(D_1 + D_2)}{2} \left(\frac{3b^2}{16a^2} + \frac{a^2}{b^2} + \frac{1}{2}\right) \quad (2)$$

Column 20.--This column presents the values of the shear reduction ratio, $\frac{1}{1 + \eta_3}$ in which

$$\eta_3{}^{8} = \frac{24\ fc\ P_{cr\ comp}}{(h^3 - c^3)\left[4(\mu_{yz})_c + 3(\mu_{xz})_c \left(\frac{b^2}{a^2}\right)\right]} \quad (3)$$

The values of $P_{cr\ comp}$ in this formula were computed according to either formula (1) or (2). The values of the shearing moduli that were substituted in this formula were 19,000 pounds per square inch for balsa and 3,500 pounds per square inch for cellular cellulose acetate.

Columns 21 and 22.--The values of M or N were obtained according to the definitions established in previous reports[5,6] except that $P_{cr\ comp}$ and the constant η_3, in the respective formulas were computed in accordance with formulas (1) or (2) and (3), respectively.

---

[8] This approximate formula was developed by H. W. March at the Forest Products Laboratory.

$$M = \frac{P_{cr\ comp}}{2f\ E_f} \tag{4}$$

$$N = \frac{\eta_3}{E_f} \tag{5}$$

Column 23.--This column presents the values for the critical loads obtained by the methods described in Report No. 1525-B but using values of η_3, M, and N as determined by formulas (3), (4), and (5) of the present report.

Figures 35 through 38.--Ratios of observed and computed values (cols. 24 through 26 of the tables) are presented graphically in figures 35 through 38. Figures 35 and 36 present the data obtained from panels having aluminum facings, and figures 37 and 38 present data obtained from panels having glass cloth facings. Figures 35 and 37 show the relationship of the observed values to the values computed by use of formulas (2) or (3) ($P_{cr\ comp}$), and figures 36 and 38 show this relationship when the proper modifications of those formulas are employed. The ordinates and abscissas are the same as those used in Report No. 1525-B.

Analysis of Results

The critical loads, $P_{cr\ comp}$, of the sandwich panels tested are given by equations (14) and (15) of Report No. 1525 under the assumption that the stresses in the facings are less than the proportional limit and that the effect of transverse shear can be neglected. In the present report these equations are modified to apply when these assumptions are not warranted. The application of these modifications results in computed values of critical loads that represent the observed values with reasonable accuracy.

From equations (14) and (15) of Report No. 1525 the value of the critical buckling load for stresses in the facings below the proportional limit when no allowance is made for shear deformations is given by equation (1) for panels having glass cloth facings and equation (2) for aluminum facings. These equations apply to panels whose dimensions are such that they will buckle in a single half wave in the direction of loading.

Values of the elastic properties obtained from tests of coupons of each plate were substituted in equations (1) or (2). The critical loads thus calculated are presented in column 19 of the tables. The relationship between these values and those observed in the tests is shown in figures 35 and 37. For the greater values of the coordinates the plotted points fall to the right of the 45-degree line indicating that the computed values are greater than the observed and that the modifications of formulas (1) and (2) subsequently described are necessary.

Modification for Shear

The factor employed to modify formulas (1) and (2) so as to take into account the effect of transverse shearing deformations in the core is $\frac{8}{} \frac{1}{1 + \eta_3}$, in which values of η_3 are obtained from equation (3), and $P_{cr\ comp}$ is obtained from equations (1) and (2).

The values of this factor for those panels that buckled at stresses below the proportional limit are given in column 20 of the tables. They range from 0.77 to 0.99 depending on the materials and dimensions of the panels. The lowest values are for the panels having cellular cellulose acetate cores, because of the low value of the shear modulus of this material. The effect of the use of this factor on the relation between the observed values and the computed values can be seen by comparing figure 37 with 38. In figure 37 many points fall to the right of the 45-degree line, while in figure 38 corresponding points fall approximately on that line.

Modification for Shear and for Stresses Above the Proportional Limit

Panels having aluminum facings that buckled at stresses above the proportional limit required a combination of two modifications: (1) to allow for the effect of shear, and (2) to allow for a decrease in the modulus of elasticity of the facings. Both of these modifications are taken into account simultaneously. The graphical method described in Report No. 1525-A is employed using values of M and N determined from equations (4) and (5) of the present report.

The effect of the application of these two modifications to the experimental data can be seen by comparing figure 35 with figure 36. The points in figure 36, corresponding to those in figure 35 that fall to the right of the 45-degree line, fall approximately on the line.

Appendix

Notation

The symbols used in this report are those of Report No. 1525 and supplements A and B, with the additional ones redefined for the purposes of the present report listed here.

$$M = \frac{P_{cr\ comp}}{2\ f\ E_f}$$

$$N = \frac{\eta_3}{E_f}$$

$$\eta_3 = \frac{24\ c\ f\ P_{cr\ comp}}{(h^3 - c^3)\left[4(\mu_{yz})_c + 3(\mu_{xz})_c \frac{b^2}{a^2}\right]}$$

$P_{cr\ comp}$ = critical buckling load as computed by the formula of Report No. 1525 applying to panels with loaded edges clamped and remaining edges simply supported (pounds per inch of panel width).

Table 14.--Comparison between experimental and theoretical values of compressive strength of flat sandwich panels of 0.012-inch aluminum sheet and 1/4-inch balsa (loaded edges clamped; remaining edges simply supported)

Panel No.	Dimensions: Thickness: Face f	Dimensions: Thickness: Core c	Dimensions: Thickness: Total h	Dimensions: Width: Free a	Dimensions: Width: Total a'	Dimensions: Height: Free b	Dimensions: Height: Total b'	Density Wt.	Observed data: Panel data: Critical load $P_{cr\ obs.}$	Observed data: Panel data: Maximum load P_m	Observed data: Panel data: Lateral deflection at maximum load e_0	Observed data: Panel data: Type of failure	Observed data: Coupon data: Stiffness factors: Bending D_m	Observed data: Coupon data: Stiffness factors: Bending D_1	Observed data: Coupon data: Stiffness factors: $\frac{(Ec)}{\lambda}_{12}$	Observed data: Coupon data: Stiffness factors: Shear μ_{12}	Observed data: Coupon data: Compression strength P_{2m}	Computed data: Critical load[1] $P_{cr\ comp.}$	Computed data: Shear reduction ratio $\frac{1}{1+\eta_1}$	Computed data: Constants K	Computed data: Constants k x 10^5	Computed data: Critical load reduced[2] $P_{cr\ re}$	Computed data: Comparative ratios $\frac{P_{cr\ obs.}}{P_{2m}}$	Computed data: Comparative ratios $\frac{P_{cr\ comp.}}{P_{2m}}$	Computed data: Comparative ratios $\frac{P_{cr\ re}}{P_{2m}}$	Computed data: Comparative ratios $\frac{P_m}{P_{2m}}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
	Inch	Inch	Inch	Inches	Inches	Inches	Inches	Lb. per cu. ft.	Lb. per in. width	Lb. per in. width	Inches						Lb. per in. width	Lb. per in. width				Lb. per in. width				
1-1	0.012	0.261	0.285	36.50	37.00	40.17	45.98	0.694	216	508	1.410	Buckle	4,775	5,331	....	....	900	232	0.978	....	....	227	0.240	0.258	0.252	0.564
2	.012	.256	.280	36.50	36.99	40.20	45.99	.628	227	493	1.580	..do..	4,617	5,585	....	....	1,475	235	.977	....	....	230	.154	.159	.156	.334
3	.012	.253	.277	36.50	37.00	40.22	45.97	.637	227	496	1.450	..do..	4,784	4,995	....	....	1,503	225	.978	....	....	220	.151	.150	.146	.330
4	.013	.256	.282	36.50	37.00	40.23	45.98	.623	195	510	1.380	..do..	4,796	5,266	....	....	1,310	231	.978	....	....	226	.149	.176	.173	.329
2-1	.012	.257	.281	31.50	31.96	36.20	41.95	.637	313	569	1.260	..do..	4,884	4,898	....	....	939	293	.973	....	....	285	.333	.312	.304	.606
2	.014	.252	.280	31.50	31.97	36.23	41.98	.649	295	519	1.090	..do..	4,555	5,186	....	....	1,263	291	.973	....	....	283	.236	.230	.224	.411
3	.014	.249	.277	31.50	32.01	36.20	41.95	.627	287	544	1.410	..do..	4,648	4,812	....	....	1,422	283	.974	....	....	276	.202	.199	.194	.363
4	.011	.262	.284	31.50	31.96	36.23	41.98	.633	313	569	1.380	..do..	4,800	5,551	....	....	1,080	310	.972	....	....	301	.290	.287	.279	.527
3-1	.012	.261	.285	25.50	26.01	28.21	33.96	.658	492	688	1.100	..do..	4,806	5,278	....	....	1,370	469	.957	....	....	449	.359	.342	.328	.502
2	.012	.268	.292	25.50	26.00	31.23	36.98	.667	431	603	.670	..do..	5,037	5,339	....	....	1,320	459	.963	....	....	442	.327	.348	.335	.457
3	.012	.261	.285	25.50	25.98	31.24	36.99	.648	477	675	1.040	..do..	5,654	5,129	....	....	1,472	430	.964	....	....	415	.324	.292	.282	.458
4	.014	.252	.280	25.50	26.00	31.25	37.00	.655	462	672	.930	..do..	4,789	5,217	....	....	1,607	439	.963	....	....	423	.287	.273	.263	.418
4-1	.015	.258	.288	21.50	22.02	25.25	31.00	.709	672	822	.830	..do..	4,934	5,347	....	....	1,714	651	......	0.00219	0.567	605	.392	.380	.353	.480
2	.016	.255	.287	21.50	21.99	25.23	30.98	.680	655	818	.950	..do..	4,782	5,424	....	....	1,811	647	......	.00204	.585	620	.362	.357	.362	.452
3	.014	.250	.278	21.50	22.00	25.25	31.00	.694	600	766	.860	..do..	4,808	4,906	....	....	1,677	590	.946	....	....	559	.356	.252	.333	.457
4	.014	.289	.317	21.50	21.98	25.25	31.00	.666	636	636	.020	Glue	....	5,552	....	....	1,320	703	......	.00254	.579	655	.482	.533	.496	.482
5-1	.012	.258	.282	18.50	19.00	22.26	28.01	.674	747	859	.920	Buckle	4,722	4,931	....	....	1,621	814	......	.00343	.734	710	.461	.502	.438	.530
2	.011	.260	.282	18.50	19.02	22.27	28.02	.673	736	855	.810	..do..	4,832	5,017	....	....	1,666	830	......	.00362	.717	692	.441	.498	.415	.512
3	.012	.249	.273	18.50	19.01	22.27	28.02	.671	664	764	.650	..do..	4,363	4,391	....	....	1,312	738	......	.00311	.687	674	.529	.562	.514	.505
4	.011	.256	.278	18.50	19.02	22.26	28.01	.667	715	863	.690	..do..	4,666	4,823	....	....	1,680	800	......	.00367	.730	675	.425	.476	.402	.514
6-1	.013	.251	.277	16.50	17.02	19.25	25.00	.645	752	802	.740	..do..	4,209	4,307	....	....	1,427	920	......	.00357	.871	783	.527	.648	.549	.562
2	.012	.262	.286	16.50	17.02	19.25	25.00	.636	787	867	.690	..do..	4,759	4,712	....	....	1,506	1,023	......	.00431	.940	769	.523	.479	.524	.576
3	.012	.256	.280	16.50	17.02	19.23	24.98	.635	519	519	.016	Glue	4,407	4,488	....	....	1,320	962	......	.00405	.903	709	.393	.729	.543	.393
4	.012	.258	.282	16.50	17.01	19.23	24.98	.646	776	849	.790	Buckle	4,332	4,580	....	....	1,414	963	......	.00405	.835	749	.549	.641	.544	.601
7-1	.011	.269	.291	15.50	16.00	18.27	24.02	.653	719	719	.000	Glue	4,403	4,609	....	....	1,190	1,096	......	.00403	.976	775	.604	.981	.651	.604
2	.012	.256	.280	15.50	16.00	18.28	24.01	.661	775	822	.710	Buckle	4,255	4,290	....	....	1,206	1,039	......	.00437	.961	797	.642	.860	.660	.650
3	.011	.269	.291	15.50	16.00	15.25	21.00	.666	812	868	.340	..do..	4,626	4,677	....	....	1,549	1,311	......	.00602	1.385	812	.524	.846	.524	.501
4	.011	.257	.279	15.50	16.00	18.27	24.02	.651	775	828	.650	..do..	4,393	4,288	....	....	1,616	1,053	......	.00484	.983	764	.547	.744	.540	.585

[1]Computed according to formulas in Forest Products Laboratory Report 1525.

[2]Computed by application of modifications to formulas in Forest Products Laboratory Report 1525.

Table 15.--Comparison between experimental and theoretical values of compressive strength of flat sandwich panels of 0.012-inch 24ST aluminum sheet and 1/4-inch cellular cellulose acetate (loaded along flanges, remaining edges simply supported)

Panel No.	Dimensions: Thickness: Face	Thickness: Core	Thickness: Total	Width: Free	Width: Total	Height: Free	Height: Total	Density	Observed data: Panel data: Critical load	Maximum load	Lateral deflection at maximum load	Type of failure	Coupon data: Stiffness factors: Bending			Shear	Compression strength	Computed data: Critical load[1]	Shear reduction ratio	Constants		Critical load reduced[2]	Comparative ratios			
	f	c	h	a	a'	b	b'	Wt.	$P_{cr\ obs.}$	P_m			D_2	D_1	$\frac{(E_f)}{\lambda}_{12}I$	μ_{12}	P_{2m}	$P_{cr\ comp.}$	$\frac{1}{1+r_1}$	K	$K \times 10^6$	$P_{cr\ rs}$	$\frac{P_{cr\ obs.}}{P_{2m}}$	$\frac{P_{cr\ comp.}}{P_{2m}}$	$\frac{P_{cr\ rs}}{P_{2m}}$	$\frac{P_m}{P_{2m}}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
	Inch	Inch	Inch	Inches	Inches	Inches	Inches	Lb. per sq. ft.	Lb. per in. width	Lb. per in. width	Inches						Lb. per in. width	Lb. per in. width				Lb. per in. width				
1-1	0.013	0.235	0.261	36.50	37.03	40.25	46.01	0.522	205	[illegible]	1.100	Buckle	4,399	4,286	....	....	620	199	0.898	....	....	179	0.331	0.321	0.289	0.651
2	.013	.257	.263	36.50	37.04	40.25	46.03	.515	182	350	.860	..do..	4,414	4,221	....	....	503	198	.899	....	....	178	.322	.394	.354	.695
3	.013	.235	.261	36.50	37.04	40.25	46.02	.513	151	355	.930	..do..	4,434	4,164	....	....	523	137	.899	....	....	177	.289	.377	.338	.679
4	.013	.240	.266	36.50	37.04	40.25	46.02	.519	194	375	.950	..do..	4,647	4,338	....	....	396	206	.897	....	....	185	.490	.520	.467	.948
2-1	.013	.241	.267	31.50	32.02	36.25	42.02	.517	250	292	.360	Glue	4,340	4,557	....	....	489	266	.875	....	....	233	.511	.544	.476	.597
2	.013	.240	.266	31.50	32.02	36.25	42.03	.515	237	317	.500	Buckle	4,430	4,620	....	....	310	271	.873	....	....	237	.765	.874	.765	1.023
3	.013	.240	.266	31.50	32.03	36.25	42.03	.517	225	350	.675	..do..	4,428	4,799	....	....	321	276	.871	....	....	240	.700	.860	.748	1.090
4	.013	.238	.264	31.50	32.02	36.25	42.05	.515	225	421	.810	..do..	4,405	4,300	....	....	338	261	.876	....	....	229	.666	.772	.678	1.247
3-1	.013	.242	.268	25.50	26.02	31.25	37.03	.523	336	381	.330	..do..	4,390	4,663	....	....	390	398	.834	....	....	332	.965	1.137	.949	1.086
2	.013	.242	.268	25.50	26.02	31.25	37.03	.526	338	400	.435	..do..	4,473	4,675	....	....	511	402	.833	....	....	335	.661	.787	.656	.782
3	.013	.241	.267	25.50	26.01	31.25	37.03	.531	354	501	.670	..do..	4,420	4,670	....	....	435	399	.833	....	....	332	.814	.917	.763	1.153
4	.013	.240	.266	25.50	26.02	31.25	37.03	.520	354	459	.430	..do..	4,361	4,567	....	....	586	392	.835	....	....	327	.604	.669	.558	.783
4-1	.013	.236	.262	21.50	21.99	25.25	31.02	.532	437	467	.320	..do..	4,035	4,551	....	....	715	544	.775	....	....	422	.609	.758	.588	.679
2	.014	.237	.265	21.50	22.00	25.25	31.03	.532	436	524	.310	..do..	4,253	4,742	....	....	699	570	.769	....	....	438	.624	.815	.627	.750
3	.012	.243	.267	21.50	21.99	25.25	31.02	.536	473	506	.160	..do..	4,304	4,702	....	....	895	571	.770	....	....	440	.528	.638	.492	.565
4	.013	.239	.265	21.50	21.99	25.25	31.00	.533	400	555	.525	..do..	4,111	4,705	....	....	813	558	.772	....	....	431	.492	.686	.530	.683
5-1	.014	.245	.273	18.50	19.00	22.25	28.02	.548	568	656	.380	..do..	4,566	4,931	....	....	868	801	....	0.00289	4.046	571	.655	.923	.658	.756
2	.013	.242	.268	18.50	19.00	22.25	28.03	.538	547	584	.230	..do..	4,501	4,662	....	....	930	773	....	.00300	3.975	562	.588	.831	.594	.628
3	.014	.240	.268	18.50	19.00	22.25	28.02	.549	397	397	.228	Glue	4,450	4,796	....	....	893	780	....	.00281	4.007	556	.445	.873	.623	.445
4	.013	.243	.269	18.50	19.00	22.25	28.05	.540	589	593	.100	Compression	4,442	4,844	....	....	804	783	....	.00304	4.013	552	.733	.974	.657	.738
6-1	.014	.244	.272	16.50	17.03	19.25	24.98	.558	611	627	.000	..do..	4,898	4,613	....	....	797	1,027	....	.00370	5.365	668	.767	1.289	.636	.787
2	.014	.244	.272	16.50	17.03	19.25	25.00	.571	617	617	.050	..do..	5,001	4,847	....	....	875	1,064	....	.00364	5.508	683	.705	1.216	.781	.705
3	.014	.244	.272	16.50	17.03	19.25	24.97	.552	613	613	.180	..do..	4,822	4,845	....	....	829	1,023	....	.00368	5.350	670	.740	1.234	.608	.740
4	.013	.244	.272	16.50	17.03	19.25	24.99	.554	634	659	.105	..do..	4,789	4,676	....	....	918	1,082	....	.00397	5.348	668	.690	1.113	.726	.718
7-1	....	....	.270	....	15.99	....	23.99	.545	....	....	....	Glue	4,018	....	....	....	833	....	....	....	....	....	....	....	....	....
2	.012	.244	.268	15.50	16.00	18.25	23.96	.499	419	419	.017	..do..	4,335	[illegible]	....	....	570	1,057	....	.00445	5.567	870	.856	[1]1.854	1.175	.736
3	.014	.247	.275	15.50	15.99	18.25	23.98	.571	258	258	.005	..do..	4,904	4,879	....	....	861	1,191	....	.00430	6.110	743	.303	1.400	.673	.303
4	.014	.245	.273	15.50	15.99	18.25	23.99	.569	687	687	.085	Compression	4,910	4,848	....	....	926	1,188	....	.00429	6.139	739	.741	1.280	.796	.741

[1]Computed according to formulas in Forest Products Laboratory Report 1525.
[2]Computed by application of modifications to formulas in Forest Products Laboratory Report 1525.
[3]Value not plotted.

Report No. 1525-C

Table 18.—Comparison between experimental and theoretical values of compressive strength of flat sandwich panels of six-ply glass cloth laminate and 1/4-inch balsa (loaded edges clamped, remaining edges simply supported)

Panel No.	Dimensions: Thickness: Face f	Thickness: Core c	Thickness: Total h	Width: Free a	Width: Total a'	Height: Free b	Height: Total b'	Density: Wt.	Observed data: Panel data: Critical load $P_{cr\ obs.}$	Maximum load P_m	Lateral deflection at maximum load d_m	Type of failure	Unpanel data: Stiffness factors: Bending D_2	Bending D_1	$(\frac{E}{\lambda})I$	Shear $\mu_{12}I$	Compression strength F_{px}	Critical load[1] $P_{cr\ comp.}$	Computed data: Shear reduction ratio $\frac{1}{1+r_3}$	Constants: K	B x 10^6	Critical load reduced[2] $P_{cr\ rs}$	Comparative ratios: $\frac{P_{cr\ obs.}}{P_{2m}}$	$\frac{P_{cr\ comp.}}{P_{2m}}$	$\frac{P_{cr\ rs}}{P_{2m}}$	$\frac{P_m}{P_{2m}}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
	Inch	Inch	Inch	Inches	Inches	Inches	Inches	Lb. per sq. ft.	Lb. per in. width	Lb. per in. width	Inches						Lb. per sq. inch	Lb. per in. width				Lb. per in. width				
1-1	0.016	0.250	0.282	33.50	33.98	38.24	43.99	.465	68	223	1.410	Buckle	1,587	1,648	249	329	768	73	0.993	....	....	72	0.089	0.096	0.094	0.290
2	.020	.241	.281	33.50	33.99	38.25	44.00	.455	71	228	1.480	...do..	1,616	1,660	300	420	686	78	.993	....	....	77	.107	.117	.116	.342
3	.022	.240	.284	33.50	33.96	37.97	43.72	.404	77	270	1.640	...do..	1,602	1,644	333	356	609	76	.993	....	....	75	.126	.125	.123	.444
4	.022	.242	.286	33.50	33.98	38.23	43.98	.422	71	249	1.570	...do..	1,575	1,634	338	317	618	74	.993	....	....	73	.115	.120	.118	.403
2-1	.018	.244	.280	26.50	26.95	14.22	18.97	.445	289	318	.350	...do..	1,640	1,670	272	332	635	352	.949	....	....	334	.455	.554	.526	.501
2	.020	.242	.282	26.50	26.94	31.23	36.98	.475	126	325	1.360	...do..	1,733	1,741	303	328	831	123	.989	....	....	122	.152	.148	.147	.391
3	.019	.244	.282	26.50	26.94	31.25	37.00	.432	111	258	1.120	...do..	1,651	1,656	290	303	642	116	.990	....	....	115	.173	.181	.179	.402
4	.019	.247	.285	26.50	26.97	31.22	36.97	.417	104	227	1.050	...do..	1,665	1,600	296	307	573	116	.990	....	....	115	.181	.202	.201	.396
3-1	.021	.243	.285	21.50	22.03	25.27	31.02	.432	168	300	1.060	...do..	1,464	1,508	323	301	487	163	.985	....	....	161	.345	.335	.331	.617
2	.021	.245	.287	21.50	22.02	25.27	31.02	.431	173	282	.825	...do..	1,550	1,529	328	271	534	167	.983	....	....	164	.324	.313	.307	.528
3	.021	.243	.285	21.50	22.02	25.27	31.02	.442	163	354	1.060	...do..	1,542	1,556	323	257	514	165	.985	....	....	163	.317	.321	.317	.689
4	.020	.243	.283	21.50	22.00	25.25	31.00	.434	173	311	1.050	...do..	1,418	1,468	305	242	572	154	.987	....	....	152	.302	.269	.266	.543
4-1	.019	.248	.286	17.50	18.05	21.26	27.01	.446	233	370	.735	...do..	1,523	1,566	298	245	634	240	.980	....	....	235	.367	.379	.371	.583
2	.022	.243	.287	17.50	18.05	21.27	27.02	.416	227	387	.770	...do..	1,492	1,566	341	294	567	246	.979	....	....	241	.400	.434	.425	.682
3	.020	.249	.286	17.50	18.05	21.23	26.98	.415	244	361	.760	...do..	1,514	1,674	312	262	576	246	.979	....	....	241	.424	.427	.416	.627
4	.019	.247	.285	17.50	18.04	21.26	27.01	.412	238	350	.750	...do..	1,574	1,677	296	266	571	251	.979	....	....	246	.417	.440	.431	.613
5-1	.020	.245	.285	15.50	15.97	18.22	23.97	.460	319	389	.430	...do..	1,624	1,617	310	249	731	328	.971	....	....	318	.436	.449	.435	.532
2	.020	.242	.282	15.50	15.97	18.23	23.98	.485	319	446	.690	...do..	1,519	1,615	303	222	773	311	.973	....	....	303	.413	.402	.392	.577
3	.018	.246	.282	15.50	15.98	18.25	24.00	.464	313	478	.780	...do..	1,536	1,602	276	281	789	320	.972	....	....	311	.397	.406	.394	.606
4	.019	.243	.261	15.50	15.98	18.27	24.02	.422	307	401	.600	...do..	1,498	1,592	287	275	682	314	.977	....	....	305	.450	.460	.447	.588
6-1	.020	.243	.283	13.50	13.96	16.22	21.97	.446	394	460	.405	...do..	1,488	1,604	306	254	670	405	.965	....	....	391	.588	.604	.584	.687
2	.019	.248	.286	13.50	13.97	16.26	22.01	.436	415	432	.210	Compression	1,551	1,598	298	304	534	424	.964	....	....	409	.749	.765	.753	.780
3	.019	.248	.286	13.50	13.98	16.28	22.03	.501	406	458	.340	Buckle	1,515	1,738	298	278	684	421	.964	....	....	406	.594	.615	.594	.677
4	.018	.250	.286	13.50	13.97	16.22	21.97	.478	435	543	.610	...do..	1,598	1,726	285	272	858	430	.961	....	....	413	.507	.501	.481	.633
7-1	.020	.246	.286	12.50	12.99	15.25	21.00	.520	493	562	.397	...do..	1,453	1,752	312	282	965	481	.960	....	....	462	.511	.498	.479	.582
2	.021	.246	.288	12.50	12.97	15.28	21.00	.526	509	651	.560	...do..	1,501	1,799	330	301	900	499	.959	....	....	479	.546	.537	.515	.700
3	.020	.245	.285	12.50	13.00	15.23	20.98	.553	508	615	.510	...do..	1,563	1,734	310	294	1,017	501	.958	....	....	480	.499	.493	.472	.605
4	.020	.244	.284	12.50	13.00	15.26	21.01	.520	462	526	.330	...do..	1,478	1,734	307	287	949	484	.960	....	....	465	.487	.510	.490	.554

[1]Computed according to formulas in Forest Products Laboratory Report 1525.

[2]Computed by application of modification to formulas in Forest Products Laboratory Report 1525.

Table 17.—Comparison between experimental and theoretical values of compressive strength of flat sandwich panels of [illegible]-ply glass cloth laminate and 1/4-inch cellular cellulose acetate core [illegible] loaded edges clamped; remaining edges simply supported

Panel No.	Dimensions: Thickness: Face f	Thickness: Core c	Thickness: Total h	Width: Free a	Width: Total a'	Height: Free b	Height: Total b'	Density: Wt.	Observed data: Panel data: Critical load $P_{cr\,obs.}$	Maximum load P_m	Lateral deflection at maximum load w_o	Type of failure
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Inch	Inch	Inch	Inches	Inches	Inches	Inches	Lb. per sq. ft.	Lb. per in. width	Lb. per in. width	Inches	
1-1	0.022	0.227	0.271	33.50	34.00	40.37	46.07	0.480	71	178	1.330	Buckle
2	.022	.231	.275	33.50	33.98	40.33	46.03	.437	65	190	1.450	..do..
3	.023	.228	.274	33.50	34.00	40.34	46.04	.455	71	225	1.610	..do..
4	.023	.228	.274	33.50	34.00	40.35	46.05	.463	71	198	1.400	..do..
2-1	.023	.230	.276	21.50	22.00	25.34	31.04	.511	164	296	.960	..do..
2	.022	.233	.277	21.50	22.04	25.34	31.04	.510	163	303	.980	..do..
3	.021	.234	.276	21.50	22.03	25.35	31.05	.490	145	290	.960	..do..
4	.022	.232	.276	21.50	22.02	25.34	31.04	.453	145	251	.840	..do..
3-1	.022	.231	.275	15.50	16.02	18.32	24.02	.489	272	346	.565	..do..
2	.021	.233	.275	15.50	16.03	18.32	24.02	.495	281	368	.595	..do..
3	.024	.226	.274	15.50	16.01	18.33	24.03	.492	281	368	.600	..do..
4	.022	.226	.270	15.50	16.02	18.31	24.01	.489	290	375	.590	..do..
4-1	.022	.230	.274	12.50	13.02	15.32	21.02	.464	380	403	.250	..do..
2	.021	.229	.271	12.50	13.02	15.33	21.03	.458	357	390	.300	..do..
3	.022	.229	.273	12.50	13.03	15.34	21.04	.463	391	406	.090	Compression
4	.022	.227	.271	12.50	13.02	15.33	21.03	.452	380	410	.330	Buckle

Panel No.	Observed data: Coupon data: Stiffness factors: Bending D_2	Bending D_1	$\frac{E_2 I}{\lambda}$ 12[1]	Shear -12^1	Compression strength P_{2m}	Computed data: Critical load[1] $P_{cr\,comp.}$	Shear reduction ratio $\frac{1}{1+r_y}$	Constants: M	Constants: N x 10^6	Critical load reduced[2] $P_{cr\,re}$	Comparative ratios: $P_{cr\,obs.}/P_{2m}$	$P_{cr\,comp.}/P_{2m}$	$P_{cr\,re}/P_{2m}$	P_m/P_{2m}
(1)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
					Lb. per in. width	Lb. per in. width				Lb. per in. width				
1-1	1,442	1,649	301	289	596	66	0.968	.....	.....	64	0.119	0.111	0.107	0.299
2	1,477	1,620	311	277	409	67	.968	.....	.....	65	.159	.164	.159	.465
3	1,455	1,718	320	262	556	69	.967	.....	.....	67	.128	.124	.121	.405
4	1,629	1,736	320	274	517	71	.966	.....	.....	69	.137	.137	.133	.383
2-1	1,540	1,646	325	281	647	169	.922	.....	.....	156	.253	.261	.241	.457
2	1,577	1,736	316	285	595	173	.920	.....	.....	159	.274	.291	.267	.509
3	1,555	1,606	301	277	592	168	.922	.....	.....	155	.245	.284	.262	.490
4	1,533	1,575	313	275	553	166	.923	.....	.....	153	.262	.300	.277	.454
3-1	1,470	1,492	311	281	540	309	.866	.....	.....	268	.504	.572	.496	.641
2	1,493	1,526	299	285	649	313	.864	.....	.....	270	.433	.482	.416	.567
3	1,564	1,570	331	283	650	325	.860	.....	.....	280	.432	.500	.431	.566
4	1,503	1,616	298	283	602	317	.860	.....	.....	273	.482	.527	.453	.623
4-1	1,581	1,548	308	380	617	511	.801	.....	.....	409	.616	.828	.663	.653
2	1,560	1,514	289	379	611	502	.802	.....	.....	403	.584	.822	.660	.638
3	1,588	1,570	306	452	598	531	.795	.....	.....	422	.654	.888	.706	.679
4	1,402	1,560	301	428	483	493	.605	.....	.....	397	.787	1.021	.822	[illegible]

[1]Computed according to formulas in Forest Products Laboratory Report 1525.

[2]Computed by application of modifications to formulas in Forest Products Laboratory Report 1525.

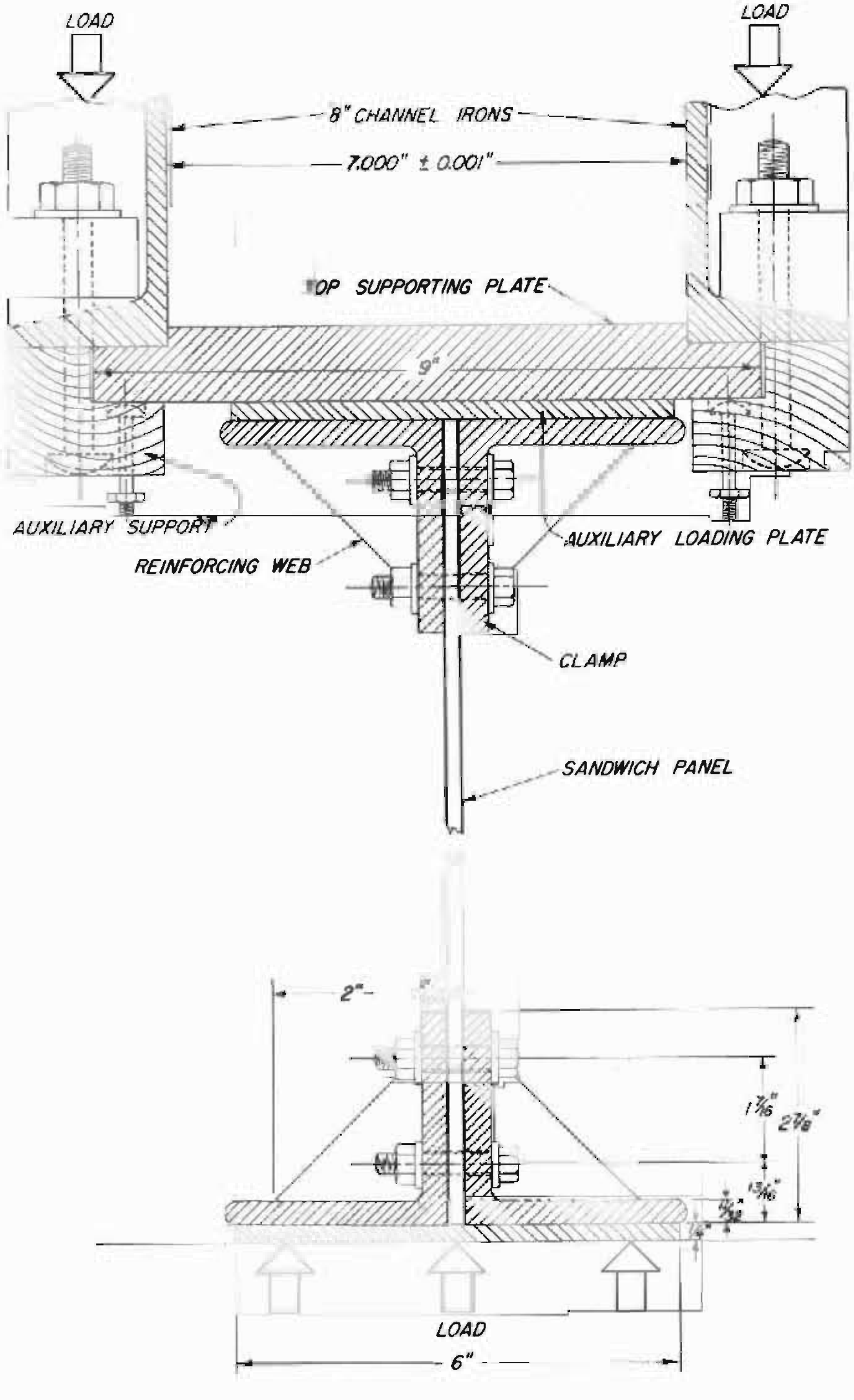

Figure 33.--Sketch showing the clamping fixtures at the loaded edges of the panel.

ZM 74247 F

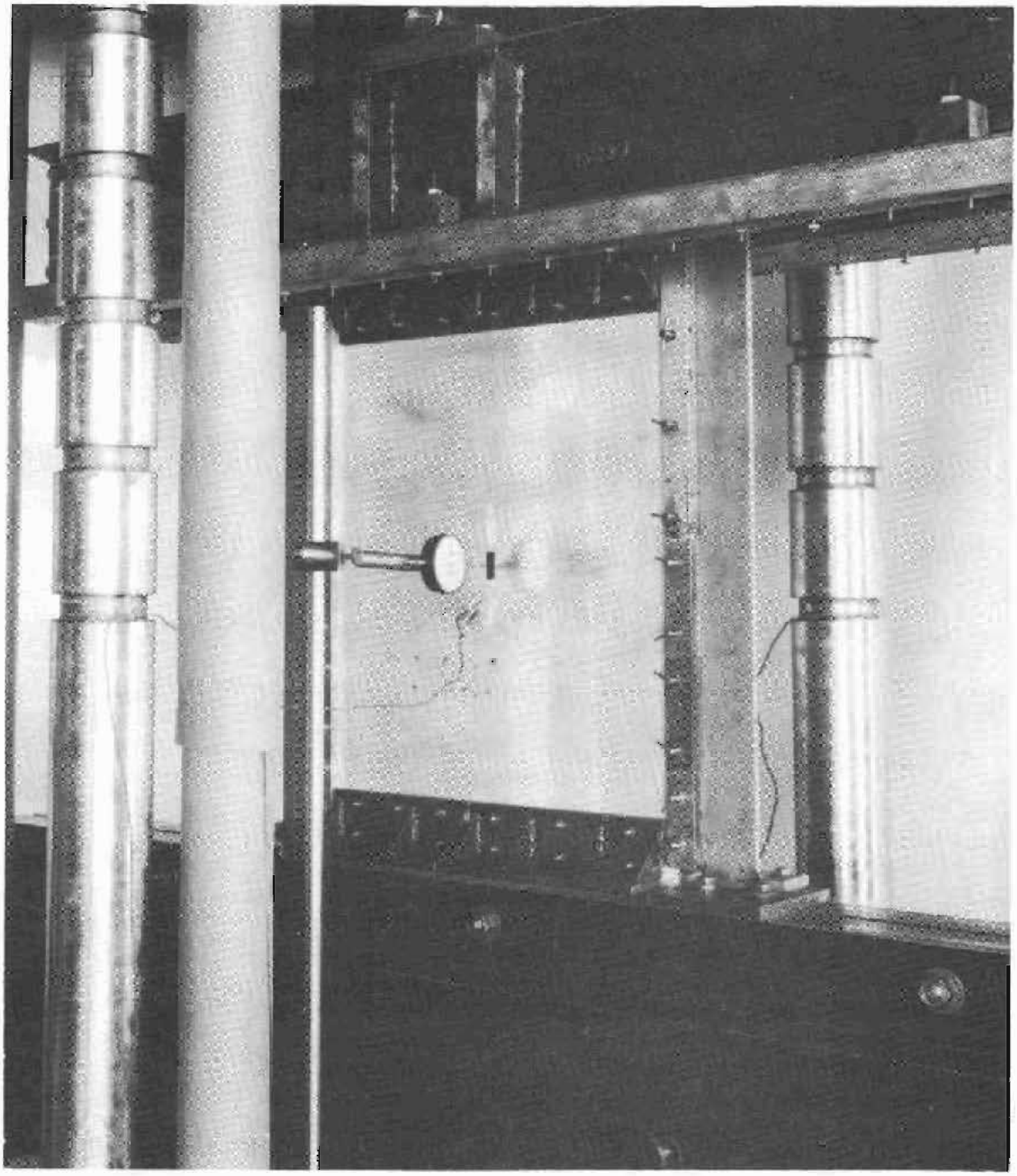

Figure 34.--Apparatus for testing sandwich panels having loaded edges clamped and other edges simply supported.

ZM 74715 F

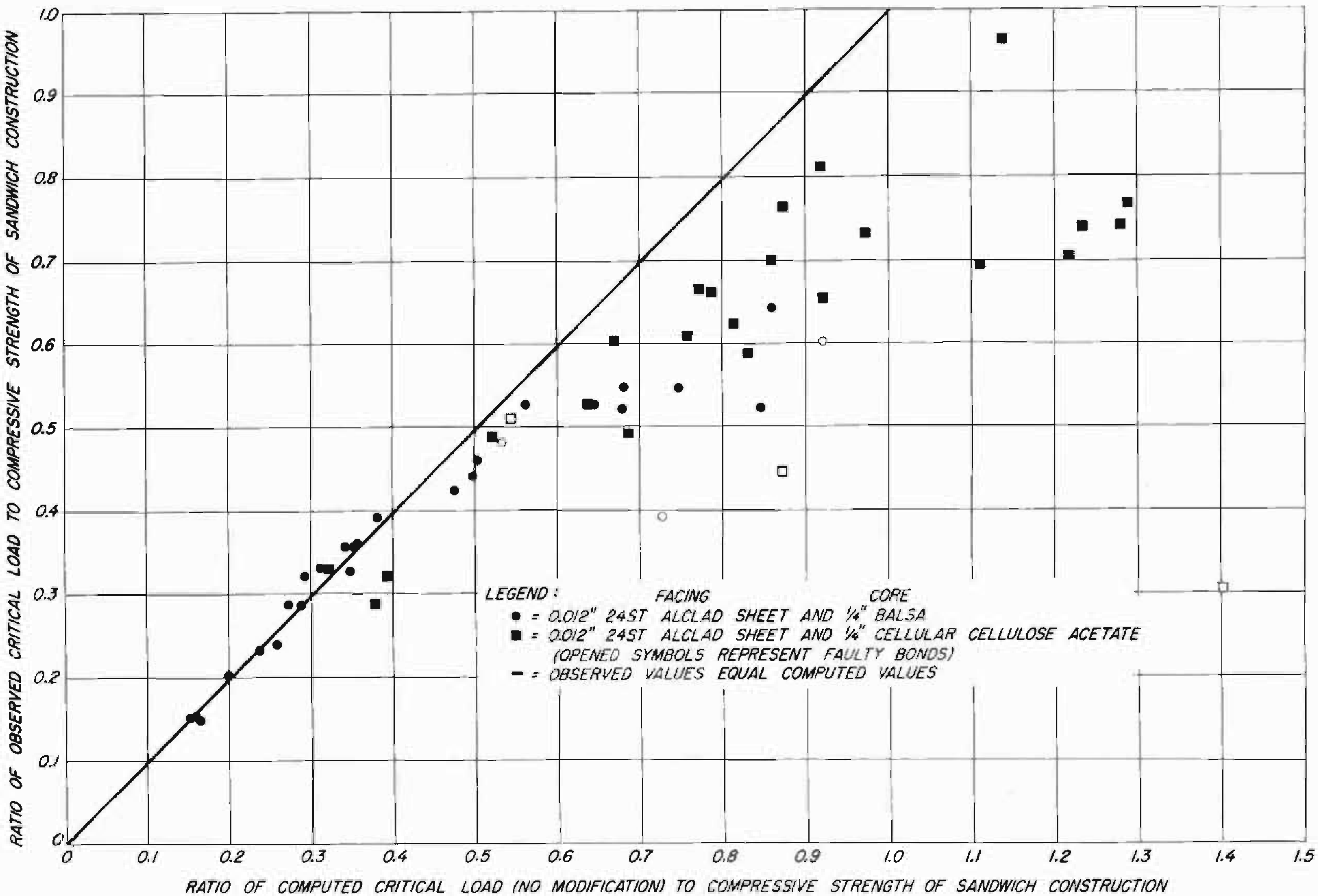

Figure 35.--Observed critical load plotted against the computed critical load (no modifications); both expressed as ratios of the compressive strength of the sandwich construction. Critical buckling of panels faced with aluminum, clamped on the loaded edges and simply supported on the remaining edges.

ZM 74249 F

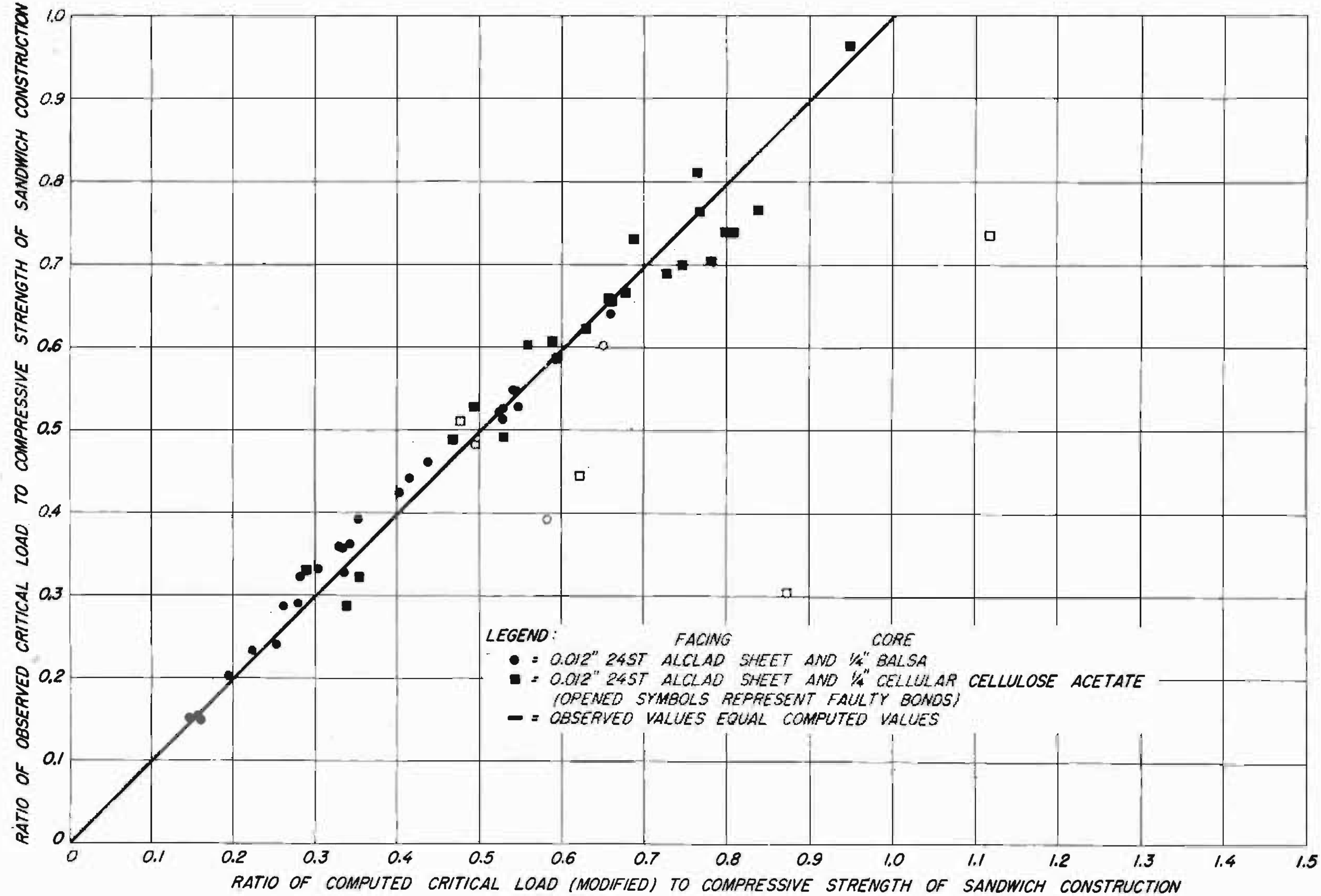

Figure 36.--Observed critical load plotted against the computed critical load (modified for reduced modulus and shear); both expressed as ratios of the compressive strength of the sandwich construction. Critical buckling of panels faced with aluminum, clamped on the loaded edges and simply supported on the remaining edges.

ZM 74248 F

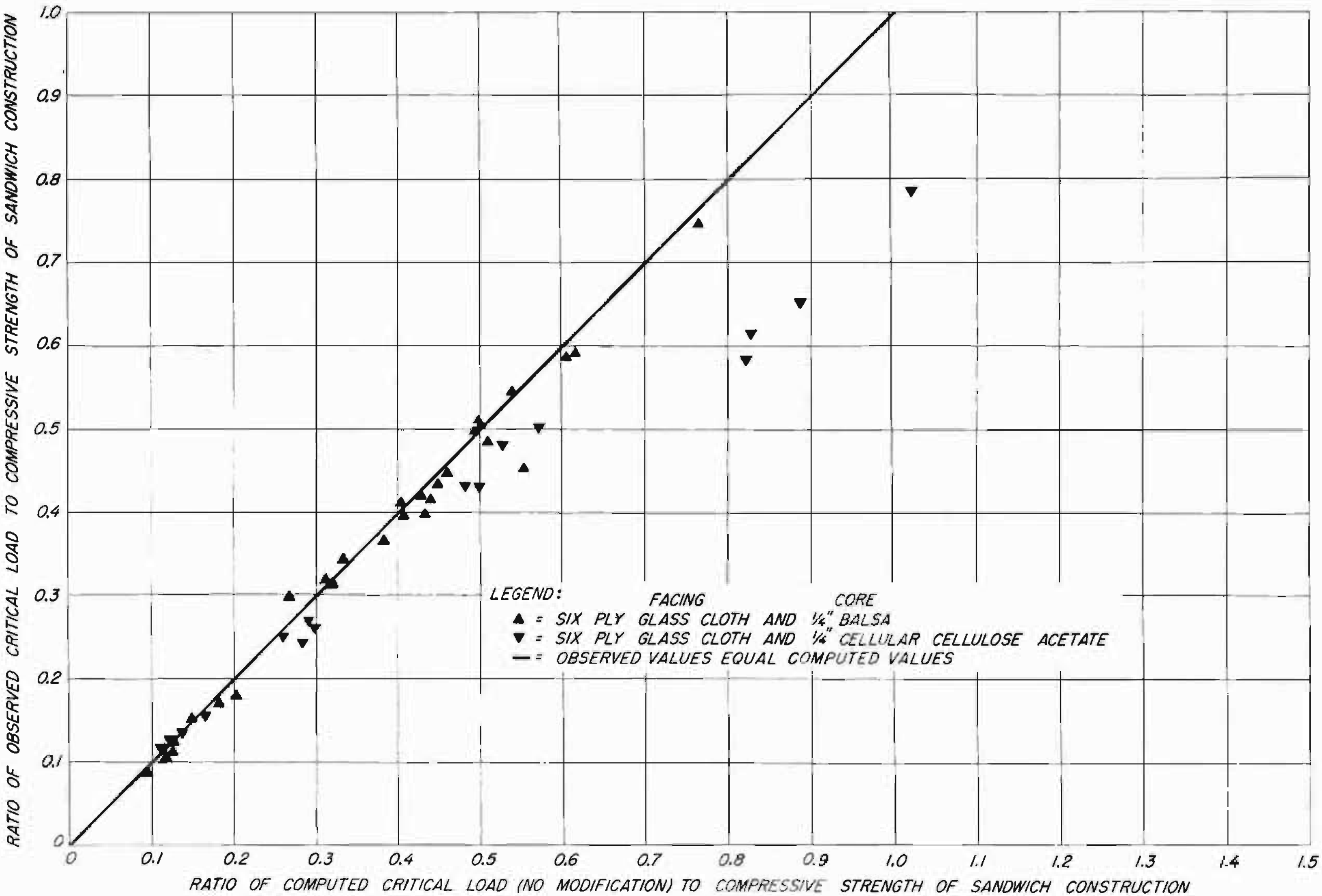

Figure 37.--Observed critical load plotted against the computed critical load (no modification); both expressed as ratios of the compressive strength of the sandwich construction. Critical buckling of panels faced with glass cloth laminate, clamped on the loaded edges and simply supported on the remaining edges.

ZM 74250 F

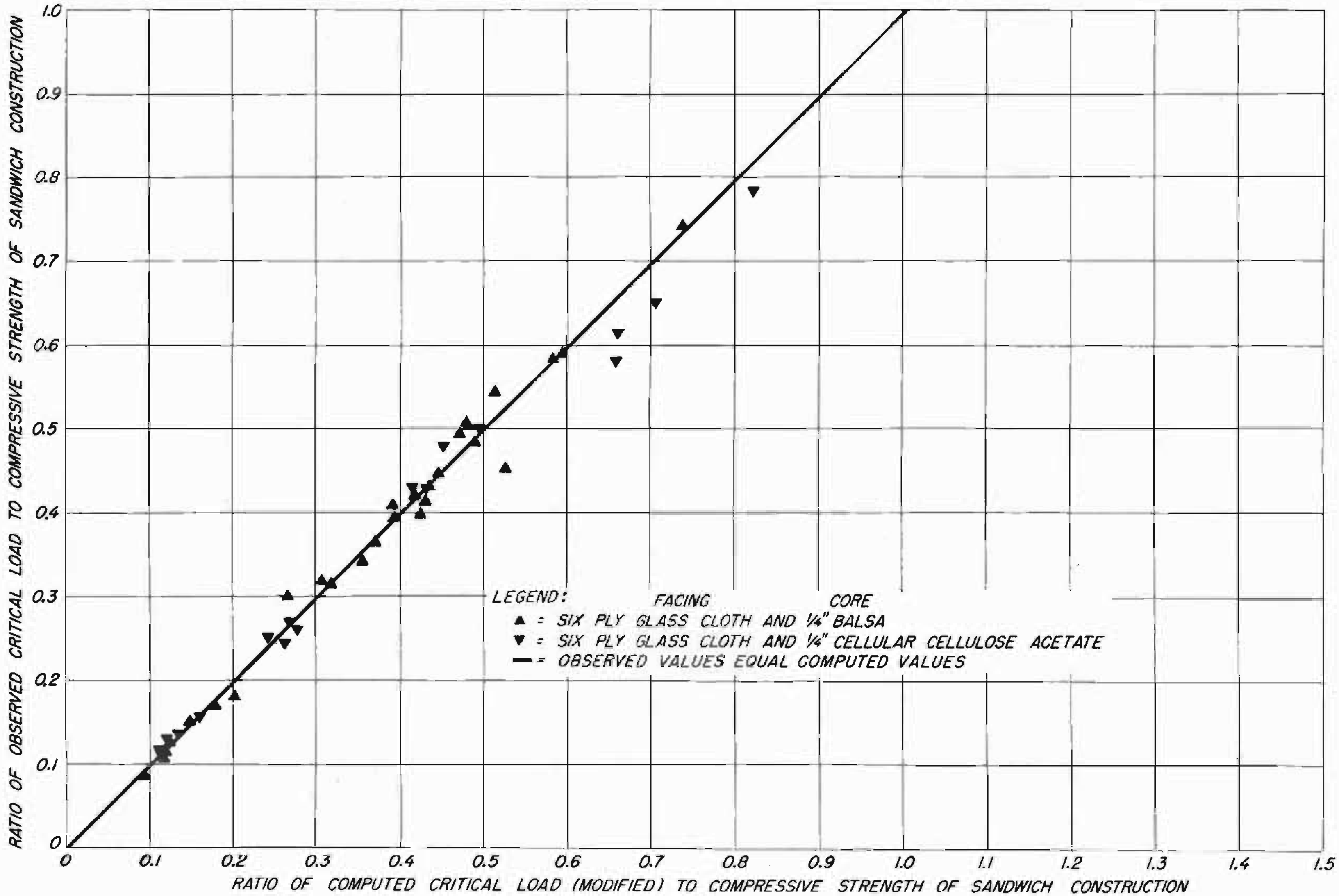

Figure 38.--Observed critical load plotted against the computed critical load (modified for shear); both expressed as ratios of the compressive strength of the sandwich construction. Critical buckling of panels faced with glass cloth laminate, clamped on the loaded edges and simply supported on the remaining edges.

ZM 74251 F

SUBJECT LISTS OF PUBLICATIONS ISSUED BY THE FOREST PRODUCTS LABORATORY

The following are obtainable free on request from the Director, Forest Products Laboratory, Madison 5, Wisconsin.

List of publications on
Box and Crate Construction and Packaging Data

List of publications on
Chemistry of Wood and Derived Products

List of publications on
Fungus Defects in Forest Products and Decay in Trees

List of publications on
Glue, Glued Products, and Veneer

List of publications on
Growth, Structure, and Identification of Wood

List of publications on
Mechanical Properties and Structural Uses of Wood and Wood Products

Partial list of publications for
Architects, Builders, Engineers, and Retail Lumbermen

List of publications on
Fire Protection

List of publications on
Logging, Milling, and Utilization of Timber Products

List of publications on
Pulp and Paper

List of publications on
Seasoning of Wood

List of publications on
Structural Sandwich, Plastic Laminates, and Wood-Base Aircraft Components

List of publications on
Wood Finishing

List of publications on
Wood Preservation

Partial list of publications for
Furniture Manufacturers, Woodworkers and Teachers of Woodshop Practice

Note: Since Forest Products Laboratory publications are so varied in subject, no single list is issued. Instead a list is made up for each Laboratory division. Twice a year, December 31 and June 30, a list is made up showing new reports for the previous 6 months. This is the only item sent regularly to the Laboratory's mailing list. Anyone who has asked for and received the proper subject lists and who has had his name placed on the mailing list can keep up to date on Forest Products Laboratory publications. Each subject list carries descriptions of all other subject lists.

FPL FILING SYSTEM DESIGNATION--S-5-4

Boller, Kenneth Harold
Buckling loads of flat sandwich panels in compression. Buckling of flat sandwich panels with loaded edges clamped and the remaining edges simply supported. (Cores of end-grain balsa or cellular cellulose acetate and faces of aluminum or glass cloth laminate) 2 ed. Madison, Wis., U.S. Forest Products Laboratory, 1962.
7 p., illus. (F.P.L. rpt. no. 1525-C)

Report presents experimental verification of theories presented in FPL Report No. 1525.

Boller, Kenneth Harold
Buckling loads of flat sandwich panels in compression. Buckling of flat sandwich panels with loaded edges clamped and the remaining edges simply supported. (Cores of end-grain balsa or cellular cellulose acetate and faces of aluminum or glass cloth laminate) 2 ed. Madison, Wis., U.S. Forest Products Laboratory, 1962.
7 p., illus. (F.P.L. rpt. no. 1525-C)

Report presents experimental verification of theories presented in FPL Report No. 1525.

Boller, Kenneth Harold
Buckling loads of flat sandwich panels in compression. Buckling of flat sandwich panels with loaded edges clamped and the remaining edges simply supported. (Cores of end-grain balsa or cellular cellulose acetate and faces of aluminum or glass cloth laminate) 2 ed. Madison, Wis., U.S. Forest Products Laboratory, 1962.
7 p., illus. (F.P.L. rpt. no. 1525-C)

Report presents experimental verification of theories presented in FPL Report No. 1525.

Boller, Kenneth Harold
Buckling loads of flat sandwich panels in compression. Buckling of flat sandwich panels with loaded edges clamped and the remaining edges simply supported. (Cores of end-grain balsa or cellular cellulose acetate and faces of aluminum or glass cloth laminate) 2 ed. Madison, Wis., U.S. Forest Products Laboratory, 1962.
7 p., illus. (F.P.L. rpt. no. 1525-C)

Report presents experimental verification of theories presented in FPL Report No. 1525.