DESIGN OF PLYWOOD WEBS IN BOX BEAMS

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FOREST SERVICE
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In Cooperation with the University of Wisconsin

DESIGN OF PLYWOOD WEBS IN BOX BEAMS[1,2]

Introduction

This progress report supplements the information contained in "ANC Handbook on Design of Wood Aircraft Structures," July 1942, Sec. 2.72, on the allowable shear in plywood webs. The data upon which this information is based were obtained from tests of 52 box beams (table 1). The beams were 10.5 feet long, either 4 or 5 inches wide and 12, 13.5, or 18 inches deep. They were loaded at the third points of a 10-foot span. The beam webs were made of three-ply 1:2:1 plywood with the grain of the adjacent plies at right angles and the grain of all plies inclined 45° to the axis of the beam. Plywood thicknesses varied from 1/16 to 1/4 inch. Stiffener spacing varied from 4 to 40 inches.

It is believed that the method of calculating the allowable (ultimate) shear strength of plywood webs proposed herein is safe for the range of variables covered thus far in this program. It is also believed that the curves obtained will apply reasonably well to other plywood constructions and angles of grain. It is suggested therefore that the proposed procedure be substituted for that given in the ANC Handbook.

Description of Beams

The box beams were made with yellow-poplar plywood webs glued to Sitka spruce flanges with Plaskon No. 250-2, a cold-setting urea-formaldehyde resin glue.

Webs consisted of three alternate plies of veneer, 1:2:1 thickness ratio, with the grain in contiguous plies at right angles and the grain in all plies inclined 45° to the beam axis. The grain of face plies in about half of the beams sloped upward from the reactions towards the load points (negative grain) and in the remainder of the beams the slope of the grain of the inner plies was in that direction (positive grain). The plywood was made from commercial veneer which was cut, taped, conditioned, and glued with Tego No. 2 film in a hot-press at the Laboratory.

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[1] The investigation here reported was planned and conducted by M. O. Withey, with the assistance of various other staff members of the Forest Products Laboratory, including W. S. Cottingham, E. R. Dawley, W. C. Lewis, P. G. Fluck, H. R. Puckett, and E. W. Kuenzi.

[2] This is one of a series of progress reports issued by the Forest Products Laboratory as background material for the design data presented in "ANC Handbook on Design of Wood in Aircraft Structures." Results here reported are preliminary and may be revised as additional data become available.

Flanges were cut from selected planks about 3 inches thick and 7 to 13 inches in width, which in turn had been sawed from logs at the Laboratory.

In beams 1A to 4B (table 1) solid filler blocks were placed at load and reaction points. The blocks in the "A" beams were of maple with the grain vertical, had rounded ends, and were free to rotate in the plane of the loads. The blocks in the "B" beams were of Sitka spruce with the grain horizontal. They had square ends and were glued to both flanges and webs. Ends and load blocks in other beams were built up as indicated in figure 1. These built-up blocks with birch sides and caps proved satisfactory and were much lighter than the solid Sitka spruce blocks.

Stiffeners of solid or built-up type, figure 1, were used in many of the beams. Of the various types tried, those made with four vertical side rails tied at the top, middle, and bottom with 1/8-inch transverse plywood webs (fig. 1, beam 38) were most effective. These were proportioned to provide sufficient end bearing area and column strength to hold the flanges apart, adequate glue area for fastening the webs, and enough rigidity to stiffen the webs against buckling. Stiffeners of this type made a much tougher web reinforcement than did the solid 1/4-inch Sitka spruce stiffeners which were of like weight, but lacked adequate edge glue areas.

Methods of Testing

Beams were loaded at the third points of a 120-inch span (figure 2) at A.S.T.M. standard rates of speed in predetermined increments. Head speed for the 18-inch beams was 0.096 inch per minute, for the shallower beams it was 0.138 inch per minute. During the initial stages of a test, loading was stopped while readings of deflections and strains were taken. When a beam began to show signs of distress, strain reading devices were removed and then the beam was continuously loaded to failure at the previously mentioned rate, taking center deflections and corresponding loads on "the run." Soon after failure moisture content determinations on specimens cut from the flanges and webs were made.

Minor specimens consisting of 1 by 1 by 16-inch prisms were taken from the flange materials and tested as beams over a 14-inch span. Compression tests were also run on 1 by 1 by 4-inch prisms cut from the ends of these small beams. From the plywood of the webs, or from corresponding material, small specimens with grain parallel to their long axes and others with the grain normal to their long axes were cut and tested in bending, tension, and compression. Moisture content determinations were also made on samples from the minor specimens when they were tested. The compression tests were made on 1 by $\underline{t}$ by 4-inch specimens which were prevented from bending laterally by flexible fins normal to and closely spaced along both 1 by 4-inch faces. Shear tests on small plywood panels are in progress.

Analysis of Results

The principal data from these tests pertaining to the allowable (ultimate) shear in the beams and the average results from bending, tension, and compression tests on plywood minor specimens are given in tables 1 and 2. A study of the data in table 1 plotted on a diagram similar to figure 2-19, p. 53, of the "ANC Handbook on Design of Wood Aircraft Structures" showed a widespread in the data points for panels differing materially in the ratio of the unsupported lengths of their sides.

The foregoing study led to the plot of figure 3. This figure shows the influence of the ratio of the unsupported length of the short side (a) to the unsupported length of the long side (b) on the $\frac{f_{su}}{F_{s45}}$ vs. $\frac{a}{a_o}$ relationship for the webs of these box beams. In preparing figure 3, values of f_{su} were calculated from the ultimate loads for the beams; values of F_{s45} were computed from the tensile and compressive strength tests made on plywood minors; a and a_o were determined by the procedure in Sec. 2.721 of the Handbook using plywood minor test data wherever needed. The ratio of the short to the long dimension of the rectangular panel in shear is a/b. The lower set of curves represents the influence of the $\frac{a}{b}$ ratio on shear strength, when the short dimension (a) was vertical (parallel to the transverse load on the beam), the upper set of curves shows the effect when the short dimension was horizontal.

In the plotting of figure 3, points for beams which failed due to weakness of flanges, obvious defects in plywood, or defects in construction were omitted. Points for beams 12, 13, 14, 15, and 17 having $\frac{a}{a_o}$ ratios greater than 4, shown at the right in figure 3, are in good agreement with the extended $\frac{a}{b}$ lines. Essential details involved in making computations for figure 3 are presented in the sample computations appended.

Conclusions

Figure 4, which shows only the empirical curves of figure 3, can be used to compute the allowable (ultimate) shear stress in plywood webs of 1:2:1 construction with the grain of adjacent plies at right angles and the grain of all plies at 45° to the beam axis.

For thin beam webs constructed and stiffened similarly to those tested, the data show the significant increases in web shear resistance that can be secured by reducing the spacing of stiffeners or diaphragms. Such web reinforcement serves the important dual purposes of holding the flanges apart and stiffening the web. Therefore, the minimum stiffener spacing compatible with economy should be used.

For web panels of a given $\frac{a}{b}$ ratio those made with negative grain possess greater shear strength than similar panels with positive grain.

The data for beams 1A to 4B (table 1) indicate that fixing the end-blocks and load-blocks had relatively little influence on the shear strength of beams of the types tested.

APPENDIX

Sample Calculations

The following procedure was used in determining the position of the points in figure 3. After studying the minor test data, it was decided that the average minor test values for a given thickness of plywood from a given source of veneer represented more truly the webs of the various beams made with that plywood than did the average values from individual beams (see columns 33, 35, 37, 39 of table 1). Hence the averages given in table 2 were used in calculating E_L and $F_{s\theta}$ ($=F_{s45}$ herein)[3]. Values of E_1 and E_2 were averaged before computing E_L (table 1, column 44). The effects of corrections for differences in moisture content of beam webs and minors were studied and, after due consideration, omitted in determining F_{s45} and E_L. The average of the moisture contents of the beam webs was 7.4 percent, of the minors 6.6 percent.

Sample Computations

Symbols (ANC where possible)

a = the length of the short side of the panel (the distance between flanges or stiffeners whichever is smaller) in inches.

a_o = the width of a hypothetical panel of length b which will buckle at a shearing stress of $F_{s\theta}$, in inches.

b = the length of long side of the panel, in inches.

b' = 1/2 the distance between buckle ridges in an infinitely long panel, measured parallel to the b side, in inches.

[3] In this connection it is of interest to note that the average ultimate compressive strength of yellow-poplar parallel to the grain (U.S.D.A. Tech. Bul. 479) at 12 percent moisture is 5290 pounds per square inch. For 7.4 percent moisture the corresponding value is 7150 pounds per square inch. The proportional limit in compression perpendicular at 7.4 percent moisture would be about 725 pounds per square inch. Hence 1:2:1 plywood of this material would be expected to have F_{cu} of half the sum of these values or 3940 pounds per square inch. The average of all the compression minors was 3880 pounds per square inch.

E_L = modulus of elasticity of wood in the direction parallel to the grain, in pounds per square inch.

E_T = modulus of elasticity of wood in the direction tangential to the annual growth rings, in pounds per square inch.

E_1 = effective bending modulus of elasticity of the plywood when the grain of the face plies is parallel to the span, in pounds per square inch.

E_2 = effective bending modulus of elasticity of the plywood when the grain of the face plies is perpendicular to the span in pounds per square inch.

$(F_{cu})_a$ = ultimate compressive strength of plywood with grain of face plies parallel to the stress, in pounds per square inch.

$(F_{cu})_b$ = ultimate compressive strength of plywood with grain of face plies perpendicular to the stress, in pounds per square inch.

$(F_{tu})_a$ = ultimate tensile strength of plywood with grain of face plies parallel to the stress, in pounds per square inch.

$(F_{tu})_b$ = ultimate tensile strength of plywood with grain of face plies perpendicular to the stress, in pounds per square inch.

$F_{s\theta}$ = allowable (ultimate) stress for plywood in shear, in pounds per square inch, where θ is the angle of the face plies from the horizontal.

f_c = calculated maximum stress in compression flange = $M_{max}\ C_c/I.$, in pounds per square inch.

f_t = calculated maximum stress in tension flange = $M_{max}\ C_t/I.$, in pounds per square inch.

f_{su} = calculated unit shear stress, in pounds per square inch, at maximum load $= \frac{V_{max}Q}{It}$

I = moment of inertia[4] of the cross section of the beam about its neutral axis, $in.^4$

C_c = distance from neutral axis to extreme fibre of compression flange.

C_t = distance from neutral axis to extreme fibre of tension flange.

K_s = shear constant for the panel.

$K_{s\infty}$ = shear constant for an infinitely long panel.

P_u = ultimate load on beam, in pounds.

Q = statical moment[4] of the area external to shear section about the neutral axis, $in.^3$

t = total thickness of the webs, in inches.

t_w = thickness of single web, in inches.

V = total shear, in pounds.

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[4] The area of the webs was transformed by using the modular ratio 1/4 (see ANC Handbook, Sec. 3.1151) both in locating the neutral axis and in calculating I and Q.

Calculations for Beam 18

Calculations from Minor Test Data for $F_{s\theta} = F_{s45}$ (table 1, col. 41):

From formula 2:30 in "ANC Handbook"

$$F_{s\theta} = \frac{1}{\sqrt{\left(\frac{1}{(F_{tu})^2_{a\text{ or }b}} + \frac{1}{(F_{cu})^2_{b\text{ or }a}}\right)\sin^2 2\theta + \frac{\cos 2\theta}{(F_{su})^2}}}$$

When $\theta = 45°$ this reduces to

$$F_{s\theta} = F_{s45} = \frac{(F_{cu})_a}{\sqrt{1 + \left(\frac{(F_{cu})_a}{(F_{tu})_b}\right)^2}} \quad \text{or} \quad (1)$$

$$F_{s45} = \frac{(F_{cu})_b}{\sqrt{1 + \left(\frac{(F_{cu})_b}{(F_{tu})_a}\right)^2}} \quad (2)$$

depending on the direction of the grain.

Herein θ is taken positive when the grain of the face plies is parallel to the diagonal tension in the web. Hence equation (2) would be used for this case (positive grain) and equation (1) for the other case (negative grain).

For beam 18 the web grain is negative, hence from table 2 $(F_{cu})_a$ is 4060 and $(F_{tu})_b$ is 9400 pounds per square inch and equation (1) becomes

$$F_{s45} = \frac{4060}{\sqrt{1 \left(+ \frac{4060}{9400}\right)^2}} = 3720 \text{ pounds per square inch}$$

Calculations from Minor Test Data for E_L (table 1, col. 44):

For plywood with the grain of adjacent plies mutually perpendicular and made from rotary-cut veneer:

$$E_1 + E_2 = E_L \left(1 + \frac{E_T}{E_L}\right) \quad (3)$$

From table 2-5 "ANC Handbook" for yellow-poplar

$$\frac{E_T}{E_L} = 0.037.$$

The averages of the values of E_1 and E_2 for the 1/16-inch plywood are 1.595×10^6 and 0.236×10^6 pounds per square inch respectively.

Therefore $E_L = \frac{(1.595 + 0.236)\ 10^6}{1.037} = 1.766 \times 10^6$ say 1.770×10^6 pounds per square inch.

Calculations for f_{su} and $\frac{f_{su}}{F_{s45}}$ (table 1, col. 43):

The value of f_{su} was calculated from the beam data from the equation

$$f_{su} = \frac{VQ}{It} = \frac{P_uQ}{2It} \qquad (4)$$

For beam 18, $Q = 17.21$ in.^{3}, $I = 193.0$ in.^{4}, $t = 0.117$ in., and $P_u = 5485$ pounds.

Hence $f_{su} = \frac{5485 \times 17.21}{2 \times 193 \times 0.117} = 2090$ pounds per square inch

Then $\frac{f_{su}}{F_{s45}} = \frac{2090}{3720} = 0.562$

Calculations for a_o and $\frac{a}{a_o}$ (table 1, col. 42):

From the "ANC Handbook" formula 2:45

$$a_o = t_w \left(K_s \frac{E_L}{F_{s\theta}}\right)^{1/2} \qquad (5)$$

For 1:2:1 plywood, figure 2-17(b) in the ANC Handbook gives $K_{s\infty} = 0.95$ for positive grain and $K_{s\infty} = 3.21$ for negative grain; also, from the same figure $\frac{b'}{a} = 1.128$ for positive grain and 1.695 for negative grain. For beam 18, $a = 8.75$ inches parallel to flanges, $b = 10.55$ inches clear depth between flanges, $\frac{a}{b} = 0.829$, $t_w = 0.054$ inch. The grain is negative.

Hence $\frac{b'}{a} = 1.695$ and $b' = 1.695 \times 8.75 = 14.83$ inches.

$$\frac{b}{b'} = \frac{10.55}{14.83} = 0.711$$

From figure 2-14 of the Handbook

$$\frac{K_s}{K_{s\infty}} = 2.04 \text{ and } K_s = 3.21 \times 2.04 = 6.55$$

Therefore $a_o = 0.054 \left(\frac{6.55 \times 1.770 \times 10^6}{3720}\right)^{1/2} = 3.01$ inches and

$$\frac{a}{a_o} = \frac{8.75}{3.01} = 2.91$$

Table 1.—Results of individual box beam tests and related information

(Beams were tested under third-point loading over a 10-foot span; flanges were Sitka spruce; webs were three-ply yellowpoplar with grain at 45 degrees to the direction of the span; average moisture content of webs 7.4 percent.)

Beam No.	Nominal depth of beam	Nominal width	Web grain	Nominal plywood thickness	Ply construction	Load end blocks	Stiffeners and spacing	Companion beam	Moisture content at test: Web	Upper flange	Lower flange	t_w both webs	t_w one web	I	I/c	I/c_1	Q	P Ultimate	f_c in flange	f_t in flange	f_{su} in web	a Vertical : Horizontal	h	a/h
(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)
	In.	In.		In.					Percent	Percent	Percent	In.	In.	In.^{4}	In.^{3}	In.^{3}	In.^{3}	Lb.	P.s.i.	P.s.i.	P.s.i.	In.	In.	
1A	12	4-1/2	−	1/4	1:2:1	Nailing	None	....	7.2	11.6	12.2	0.498	0.248	492.5	75.30	75.30	45.87	20,300	5,350	5,350	2,070	7.57V	40.00	0.189
1B	12	4-1/2	−	1/4	1:2:1	Glued	None	....	6.6	11.8	11.4	.497	.248	488.4	74.97	74.87	45.74	16,440	4,350	4,350	1,685	7.46V	34.50	.217
2A	12	4-1/4	−	1/8	1:2:1	Nailing	None	....	7.8	11.7	11.5	.230	.118	338.0	53.94	53.94	30.88	7,340	2,710	2,710	1,440	9.31V	40.00	.233
2B	12	4-1/4	−	1/8	1:2:1	Glued	None	....	6.4	11.9	11.4	.271	.134	317.1	52.61	53.18	29.94	7,690	2,980	2,830	1,345	9.27V	34.50	.269
3A	12	4-1/4	+	1/8	1:2:1	Nailing	None	....	7.8	11.1	11.3	.230	.115	322.1	53.64	53.40	30.32	5,500	2,090	2,060	1,035	9.30V	40.00	.233
3B	12	4-1/4	+	1/8	1:2:1	Glued	None	....	6.7	11.7	11.6	.230	.115	322.0	53.60	53.60	30.44	5,760	2,150	2,150	1,090	9.25V	34.50	.264
4A	12	4-1/6	−	1/12	1:2:1	Nailing	None	....	6.7	10.6	11.1	.173	.085	250.1	41.64	41.61	22.86	4,800	2,020	2,020	1,115	10.02V	40.00	.251
4B	12	4-1/6	−	1/12	1:2:1	Glued	None	....	7.1	10.6	11.1	.174	.086	247.4	41.36	41.36	22.71	5,010	2,480	2,480	1,320	9.98V	34.50	.289
5	12	4-1/3	−	1/6	1:2:1	do	None	....	6.8	12.0	....	.342	.171	485.5	81.83	62.66	43.20	19,000	4,640	6,040	2,820	7.47V	36.00	.208
6	12	4-1/4	−	1/8	1:2:1	do	5 at 5-1/2"	....	8.8	12.0	....	.257	.128	296.4	61.66	41.49	28.16	12,440	4,030	6,000	2,300	5.13H	9.19	.558
7	12	4-1/4	+	1/8	1:2:1	do	3 at 6"	....	6.9	12.2	12.3	.257	.128	297.1	61.82	41.53	28.21	13,420	4,350	6,460	2,440	5.63H	9.21	.611
8 Mod.	12	4-1/4	+	1/8	1:2:1	do	2 at 12"	....	9.0	12.7	12.5	.258	.128	632.4	92.35	92.62	54.69	20,980	2,400	2,370	1,825	9.29V	11.63	.799
9 Mod.	12	4-1/4	+	1/8	1:2:1	do	8 at 4"	....	8.6	12.1	12.0	.263	.132	402.0	66.77	61.79	36.88	15,980	4,660	5,050	2,720	3.75H	9.87	.405
10	12	4-1/4	−	1/8	1:2:1	do	8 at 4"	....	9.0	12.6	11.9	.255	.128	404.6	66.91	62.34	37.12	19,000	5,670	6,100	3,480	3.75H	9.26	.405
11	12	4-1/6	+	1/12	1:2:1	do	5 at 5-1/2"	....	9.3	12.5	12.5	.178	.088	235.1	46.95	32.88	21.57	8,070	3,330	4,900	2,080	5.61H	9.95	.562
12	12	4-1/6	+	1/12	1:2:1	do	2 at 11"	....	9.2	12.1	11.7	.175	.085	236.2	49.14	33.23	21.83	6,130	2,490	3,690	1,605	9.99V	10.63	.940
13	12	4-1/8	+	1/16	1:2:1	do	None	14	7.3	....	....	.118	.056	192.5	36.40	28.64	17.24	2,700	1,440	1,890	1,085	10.49V	35.75	.293
14	12	4-1/8	−	1/16	1:2:1	do	None	13	7.4	11.5	11.9	.106	.052	189.1	36.81	27.83	16.90	2,900	1,600	2,090	1,220	10.53V	35.75	.295
15	12	4-1/8	+	1/16	1:2:1	do	2 at 12"	16	5.4	8.0	11.5	.113	.055	189.6	36.51	27.82	16.97	3,700	2,030	2,660	1,470	10.51V	11.75	.894
16	12	4-1/8	−	1/16	1:2:1	do	2 at 12"	15	5.8	10.5	9.5	.114	.054	187.3	36.51	27.16	16.74	4,860	2,660	3,570	1,900	10.53V	11.75	.896
17	12	4-1/8	+	1/16	1:2:1	do	3 at 9"	18	6.4	10.0	11.0	.117	.057	190.3	36.61	27.90	17.02	4,720	2,580	3,380	1,800	8.75H	10.55	.832
18	12	4-1/8	−	1/16	1:2:1	do	3 at 9"	17	5.2	10.0	10.0	.117	.058	193.6	36.91	28.26	17.21	5,440	2,970	3,880	2,090	8.75H	10.55	.829
19	12	4-1/8	+	1/16	1:2:1	do	4 at 4-5/8"	20	4.6	9.5	8.0	.118	.055	184.6	36.08	26.74	16.50	6,900	3,600	4,870	2,460	3.75H	10.55	.355
20	12	4-1/8	−	1/16	1:2:1	do	4 at 4-5/8"	19	5.6	9.0	8.0	.113	.055	184.7	36.20	26.70	16.90	8,980	4,700	6,360	3,360	3.75H	10.55	.355
21 Mod.	12	4-1/8	+	1/16	1:2:1	do	8 at 4"	22	8.0	13.0	13.0	.124	.058	285.3	39.43	52.94	24.72	7,680	3,900	2,980	2,680	3.75H	10.51	.357
22	12	4-1/8	−	1/16	1:2:1	do	8 at 4"	21	9.3	12.0	....	.119	.058	190.4	36.67	28.01	17.04	8,130	4,430	5,810	3,060	3.75H	10.51	.357
30	12	4-1/4	−	1/8	1:2:1	do	2 at 12"	....	7.8	....	....	.220	.104	316.4	62.49	45.99	30.00	10,950	3,390	4,650	2,280	9.13V	11.63	.785
31	12	4-1/4	+	1/8	1:2:1	do	5 at 6"[1]	....	8.8	....	....	.226	.104	318.9	63.00	45.76	30.11	9,380	2,960	4,070	2,045	9.14V	35.75	.256
32	12	4-1/4	+	1/8	1:2:1	do	5 at 6"[2]	....	8.8	....	....	.230	.111	316.6	62.94	45.67	30.02	8,970	2,750	3,750	1,765	5.63H	9.13	.617
33	12	4-1/4	+	1/8	1:2:1	do	5 at 6"	34	9.4	12.0	12.0	.229	.105	319.9	62.81	46.00	30.23	12,170	3,960	4,860	2,305	4.88H	9.15	.533
34	12	4-1/4	−	1/8	1:2:1	do	5 at 6"	33	9.0	13.0	12.0	.239	.115	316.8	62.77	45.83	30.16	16,640	5,310	7,260	3,895	4.88H	9.16	.533
37	12	4-1/4	+	1/8	1:2:1	do	7 at 4-5/8"	38	8.4	12.0	12.5	.235	.115	322.3	63.21	46.36	30.45	13,440	4,260	5,800	2,705	3.75H	9.16	.409
38	12	4-1/4	−	1/8	1:2:1	do	7 at 4-5/8"	37	8.0	12.0	12.0	.233	.115	311.3	61.35	44.81	29.51	17,380	5,660	7,760	3,535	3.75H	9.13	.411
40	13-1/2	4-1/2	−	1/4	1:2:1	do	None	41	6.6	....	....	.460	.230	687.1	119.11	88.60	63.42	31,170	5,240	7,120	3,125	7.94V	35.75	.211
41	13-1/2	4-1/2	+	1/4	1:2:1	do	None	40	7.2	....	....	.468	.234	686.6	118.70	88.70	63.37	19,000	3,200	4,280	1,875	7.94V	35.75	.211
42	13-1/2	4-1/2	−	1/4	1:2:1	do	2 at 12"	43	6.0	9.0	9.0	.447	.222	676.6	117.61	87.62	62.70	35,800	5,980	8,040	3,650	7.46V	10.81	.688
43	13-1/2	4-1/2	+	1/4	1:2:1	do	2 at 12"	42	5.5	11.0	8.5	.439	.216	673.7	117.28	87.00	62.33	27,760	4,710	6,380	2,930	7.90V	10.81	.689
44	13-1/2	4-1/2	+	1/4	1:2:1	do	5 at 6"	45	7.4	13.0	12.0	.494	.224	683.1	118.46	88.22	63.10	32,800	5,440	7,300	3,270	5.44H	7.51	.723
45 Mod.	13-1/2	4-1/2	−	1/4	1:2:1	do	5 at 6"	44	7.4	12.0	11.0	.475	.232	913.1	153.95	100.52	76.99	41,700	5,420	8,300	3,680	5.44H	7.51	.723
50	18	4-1/4	−	1/8	1:2:1	do	5 at 6"	....	8.2	10.5	11.5	.243	.121	617.7	104.08	80.94	50.24	20,800	4,000	5,140	2,630	5.63H	14.97	.376
51	18	4-1/4	+	1/8	1:2:1	do	5 at 6"	....	8.6	13.0	13.0	.228	.110	626.1	105.01	81.69	50.61	17,820	3,400	4,360	2,400	4.88H	14.97	.326
52	18	4-1/4	+	1/8	1:2:1	do	2 at 12"	53	7.4	11.5	....	.238	.118	620.1	104.06	81.20	50.30	12,900	2,400	3,080	1,610	10.88H	14.99	.726
53	18	4-1/4	−	1/8	1:2:1	do	2 at 12"	52	6.3	8.0	10.0	.229	.111	636.3	103.18	84.84	51.41	16,840	3,190	3,830	2,180	10.88H	14.90	.730
54	18	4-1/4	−	1/8	1:2:1	do	None	....	7.5	10.0	9.6	.219	.109	608.7	103.83	79.66	49.70	10,105	1,990	2,540	1,415	14.96V	35.75	.418
55	18	4-1/4	−	1/8	1:2:1	do	7 at 4-5/8"	....	6.9	10.0	9.8	.227	.113	796.2	102.00	78.63	48.90	24,020	4,710	6,110	3,250	3.75H	15.00	.250
56	18	4-3/8	−	3/16	1:1:1	do	7 at 4-5/8"	....	6.2	9.4	9.4	.347	.173	820.3	104.24	81.46	50.74	35,620	6,830	8,740	3,770	3.75H	14.96	.251
60	18	5-1/2	−	1/4	1:2:1	do	None	61	9.9	14.0	12.0	.476	.234	1465.5	184.17	149.56	95.52	14,420	2,690	3,850	1,695	13.25V	34.75	.381
61	18	5-1/2	+	1/4	1:2:1	do	None	60	6.4	10.0	9.0	.449	.224	1466.5	185.12	148.86	95.39	19,000	2,050	2,550	1,395	13.27V	34.75	.382
62	18	5-1/2	+	1/4	1:2:1	do	2 at 12-3/8"	63	6.4	9.0	11.0	.495	.227	1473.3	183.21	147.77	94.99	30,515	3,330	4,130	2,194	11.25H	13.27	.848
63	18	5-1/2	−	1/4	1:2:1	do	2 at 12-3/8"	62	6.6	10.5	12.0	.467	.232	1477.7	183.96	148.33	94.88	42,000	4,580	5,660	2,885	11.25H	13.27	.848
64	18	5-1/2	+	1/4	1:2:1	do	5 at 6"	65	5.5	10.0	8.6	.462	.230	1471.2	183.51	147.40	94.44	41,535	4,520	5,640	2,885	4.88H	13.26	.368
65	18	5-1/2	−	1/4	1:2:1	do	5 at 6"	64	6.2	11.0	11.0	.448	.223	1470.5	182.95	147.76	94.50	45,670	5,020	6,200	3,295	4.88H	13.26	.368

[1] Stiffeners did not restrain webs.

[2] Stiffeners on outside of web.

[3] Assume

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Information from minor tests															Calculations				
E_1 x10^6	E_2 x10^6	E_L x10^6	E_L Compression x10^6	E_R Compression x10^6	E_L Tension x10^6	E_R Tension x10^6	$(F_{cu})_a$	Moisture content $(F_{cu})_a$	$(F_{cu})_b$	Moisture content $(F_{cu})_b$	$(F_{tu})_a$	Moisture content $(F_{tu})_a$	$(F_{su})_b$	Moisture content $(F_{su})_b$	F_{cu} Average from others	[illegible]	f_{cm}/F_{cu}	E_L Average from minor tests x10^6	Remarks
(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)	(45)
P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.			P.s.i.	
1.656	0.270	1.856	1.069	0.853	1.312	0.947	3,940	9.4	3,820	9.1	9,090	7.3	10,100	7.5	3,560	0.72	0.582	1.910	Compression flange failure. Do not use.
1.769	.260	1.956	1.070	.952	1.152	.916	3,880	8.7	3,750	9.0	10,420	7.1	7,010	7.2	3,560	.71	.474	1.910	Compression flange failure. Do not use.
1.417	.346	1.699	.771	.952	.797	1.078	3,325	9.8	3,560	8.9	7,860	7.2	11,630	6.5	3,410	2.12	.433	1.940	Web failure in outer third.
1.874	.340	1.556	.749	.984	.803	.768	3,440	9.0	3,840	9.0	7,160	6.9	6,000	7.5	3,410	1.79	.392	1.940	Web failure in outer third.
1.194	.319	1.480	.719	1.074	.834	1.208	3,070	8.9	3,580	9.7	8,410	7.9	12,230	8.4	3,560	3.63	.291	1.940	Web failure in outer third.
1.196	.307	1.452	.760	.797	.735	.895	3,360	9.0	3,810	9.6	6,990	7.4	6,480	7.0	3,560	3.60	.306	1.940	Web failure in outer third.
1.644	.303	1.877	1.030	1.092	....	....	3,800	9.2	4,460	5.6	....	....	....	....	3,680	2.89	.308	1.760	Web failure in outer third.
1.537	.852	1.785	1.012	.903	1.046	.917	3,280	9.1	3,220	8.4	8,090	7.6	8,580	7.8	3,620	2.82	.364	1.760	Web failure in outer third.
1.719	.339	1.985	1.088	1.082	1.310	1.317	4,530	6.5	4,840	6.6	10,600	6.4	12,820	7.7	4,270	1.11	.661	1.980	Web failure in outer third.
1.162	.361	1.466	.764	1.190	.964	1.896	3,600	6.8	4,750	7.1	6,870	6.4	12,610	7.9	3,410	.89	.675	1.940	Tension flange failure. Do not use.
1.390	.328	1.618	.838	1.178	.872	1.881	4,270	7.4	4,900	7.3	8,010	6.3	13,790	8.2	3,560	1.98	.697	1.940	Web failure in outer third.
1.448	.894	1.679	.872	.976	.848	1.094	3,880	9.1	4,480	6.9	8,890	6.2	8,640	7.9	3,560	3.05	.518	1.940	Web failure in outer third.
1.373	.842	1.557	.796	.978	.851	1.113	4,060	6.9	3,940	7.1	7,615	7.6	11,700	9.9	3,960	1.36	.765	1.940	Do not use because of modification.
1.846	.845	1.438	.802	.944	.876	.780	3,580	6.6	4,120	6.8	7,580	7.5	8,050	9.9	3,410	.72	1.002	1.940	Web failure in outer third.
1.952	.270	1.757	.982	.971	1.064	1.277	4,880	6.3	4,140	6.6	7,135	7.8	12,420	8.2	3,610	2.95	.576	1.760	Web failure in outer third.
1.500	.859	1.696	.968	.970	1.110	1.170	3,990	6.3	4,860	6.6	9,480	8.1	10,960	9.6	3,610	4.31	.445	1.760	Web failure in outer third.
1.578	.224	1.732	.944	.846	1.026	.896	4,000	6.4	3,700	4.5	8,510	7.2	9,470	7.0	3,380	4.26	.303	1.770	Web failure in outer third.
1.582	.244	1.760	.979	....	1.057	.828	4,080	5.8	....	....	9,210	7.8	9,220	7.4	3,720	4.94	.328	1.770	Web failure in outer third.
1.647	.806	1.787	1.044	.919	.993	.895	4,840	6.3	3,740	4.1	8,840	7.1	9,360	7.6	3,380	7.01	.434	1.770	Web failure in outer third.
1.491	.228	1.656	.995	.928	.941	.910	3,780	6.0	3,490	3.9	7,310	7.4	8,820	7.2	3,720	5.88	.511	1.770	Web failure in outer third.
1.704	.236	1.871	1.048	.892	1.019	.968	4,510	5.7	3,780	4.4	8,600	6.8	10,980	7.2	3,380	5.80	.533	1.770	Tension flange failure. Web highly stressed showed signs of failing.
1.611	.290	1.785	1.014	.890	1.042	.933	3,950	6.0	3,700	4.0	8,720	7.4	9,130	7.4	3,720	2.91	.962	1.770	Web failure in outer third.
1.584	.231	1.692	.948	.871	.960	.896	3,940	5.6	3,890	4.2	8,140	7.2	9,120	7.3	3,380	2.78	.728	1.770	Web failure in outer third.
1.558	.233	1.727	.966	.889	1.029	.851	3,670	5.5	3,570	4.1	9,030	8.6	9,210	8.1	3,720	1.63	.904	1.770	Web failure in outer third.
1.653	.264	1.846	1.118	.844	1.038	.899	4,510	5.8	3,880	4.6	9,080	7.1	9,730	7.4	3,380	2.78	.794	1.770	Web failure in outer third.
1.609	.252	1.795	1.131	.880	.976	.909	4,120	5.7	3,690	4.9	7,800	7.3	9,390	7.3	3,720	1.52	.823	1.770	Compression flange failure. Web buckled considerably before flange failed.
1.494	.266	1.697	.827	.886	.866	.788	3,570	7.2	3,560	7.1	7,430	8.6	8,990	8.3	3,410	1.51	.669	1.710	Defect in web. Ultimate should be higher.
1.426	.274	1.629	.811	.887	.840	.961	3,520	6.2	3,640	5.8	6,390	8.4	9,630	8.0	3,370	3.81	.607	1.710	Special design. Do not use point.
1.496	.266	1.699	.819	.834	.859	.795	3,640	5.2	3,630	5.4	7,480	8.0	8,150	7.9	3,370	2.09	.524	1.710	Special design. Do not use point.
1.540	.287	1.762	.835	.849	.892	.801	3,670	5.2	4,120	5.6	7,570	7.9	6,400	7.7	3,370	1.90	.684	1.710	Web failure in outer third. Wide range in E_R and $(F_{cu})_b$.
1.466	.292	1.695	.888	.971	.858	1.162	3,790	6.0	3,960	7.5	6,550	7.9	11,260	7.6	3,410	.88	.967	1.710	Web failure in outer third.
1.376	.280	1.596	.774	.940	.866	1.034	3,510	5.6	3,820	5.9	7,540	8.2	11,210	7.7	3,370	1.40	.803	1.710	Web failure in outer third.
1.458	.320	1.715	.912	1.034	.916	1.059	4,020	5.5	4,010	5.5	6,790	7.9	11,280	6.7	3,410	.74	1.035	1.710	Web failure in outer third.
1.462	.294	1.693	.892	.992	.870	.942	4,115	7.0	4,200	6.7	7,190	8.0	10,100	8.5	3,550	.82	.881	1.710	Web failure in outer third.
1.610	.284	1.791	.927	.875	.839	.956	3,840	6.7	4,020	6.9	7,680	8.0	8,690	7.7	3,560	1.50	.527	1.710	Web failure in outer third.
1.569	.280	1.782	.905	.956	.986	.944	3,690	6.1	4,400	5.9	8,610	8.9	8,470	8.4	3,550	.65	1.028	1.710	Web failure in middle third.
1.756	.280	1.962	1.068	.910	1.124	.982	4,470	6.8	3,960	6.4	9,400	8.6	9,490	8.1	3,560	1.44	.822	1.710	Web failure in outer third.
1.513	.231	1.739	.876	.970	1.032	.930	3,970	6.5	3,864	6.4	8,290	7.7	6,610	7.5	3,560	1.02	.919	1.710	Web failure in outer third.
[illegible]	.283	1.669	.847	.897	.928	.939	3,670	7.0	3,840	7.0	8,440	7.9	7,000	8.2	3,550	.47	1.036	1.710	Web failure in outer third.
1.601	.295	1.776	.850	.880	.869	.979	3,600	7.8	3,580	7.5	7,295	8.4	10,980	8.0	3,410	1.07	.772	1.710	Do not use point. Glue area failure between stiffeners and web. Web failure in outer third.
[illegible]	.275	1.988	.916	.887	.877	.830	3,720	6.9	3,944	6.6	7,710	7.9	5,820	7.2	3,370	1.98	.712	1.710	Web failure in outer third.
[illegible]	.262	1.708	.830	.921	.807	.959	3,940	7.0	3,871	7.1	7,110	8.4	9,960	9.5	3,370	3.75	.478	1.710	Web failure in outer third.
[illegible]	.311	1.658	.835	.926	.812	.854	3,610	7.0	3,928	6.2	5,520	8.7	9,780	9.1	3,410	1.83	.640	1.710	Web failure in outer third. Ultimate could be higher. Beam unevenly loaded.
[illegible]	.290	1.641	.891	.778	.896	.790	3,610	6.6	3,434	6.0	7,460	9.0	7,400	8.1	3,410	3.11	.415	1.710	Web failure in outer third.
[illegible]	.305	1.661	.879	.986	.888	.900	3,960	6.2	4,251	6.1	7,970	6.1	9,250	6.4	3,410	.80	.953	1.710	Lapped core ply failure. Do not use.
[illegible]	.195	1.571	1.218	.662	1.265	.574	5,480	6.0	2,910	6.2	10,580	5.0	4,360	5.0	3,400	.522	.934	1.690	End block failure. Do not use.
[illegible]	[illegible]	1.692	.824	....	.803	.729	3,400	6.8	....	....	7,210	7.3	7,350	8.8	3,550	1.34	.465	1.710	Lapped core ply failure. Do not use.
[illegible]	.260	1.617	.832	.899	.859	.809	3,650	6.2	3,420	6.4	7,410	8.2	6,490	8.1	3,560	2.69	.381	1.710	Web failure in outer third.
[illegible]	[illegible]	1.718	.919	.837	.862	.934	4,380	5.8	4,240	5.6	7,685	4.9	6,800	4.9	3,560	1.93	.606	1.710	Web failure in outer third.
[illegible]	[illegible]	1.786	.944	.841	.972	.946	4,380	6.4	3,880	6.1	8,120	8.0	10,130	7.9	3,550	.84	.813	1.710	Compression buckle failure. Do not use.
[illegible]	.315	1.673	.881	.923	.941	.748	4,010	6.4	4,430	6.2	7,120	6.4	6,870	6.8	3,560	.96	.810	1.710	Compression buckle failure. Do not use.
[illegible]	[illegible]	1.389	.818	.746	.958	.687	3,970	6.6	3,540	6.3	7,940	6.4	6,150	6.6	3,550	.52	.928	1.710	Lapped core ply failure. Do not use.

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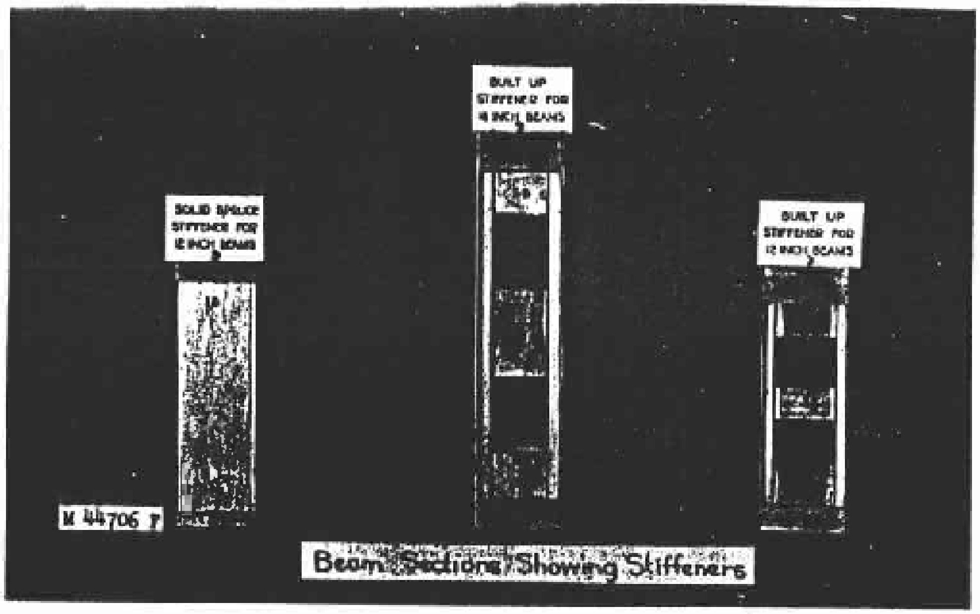
Table 2.--Average values of $F_{s45°}$ and E_L uncorrected for moisture content

Beam numbers	Nominal plywood thickness	Average $(F_{cu})_a$	Average moisture content	Average $(F_{cu})_b$	Average moisture content	Average $(F_{tu})_a$	Average $(F_{tu})_b$	$F_{s45°}$ using $(F_{cu})_a$ $(F_{tu})_b$	$F_{s45°}$ using $(F_{cu})_b$ $(F_{tu})_a$	Average E_L $x10^6$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	In.	p.s.i.	Percent	p.s.i.	Percent	p.s.i.	p.s.i.	p.s.i.	p.s.i.	p.s.i.
2A-2B-3A-3B 6-10 incl.	1/8	3,610	8.2	4,040	8.0	7,570	10,130	3,410	3,560	1,540
4A-4B-11-12	1/12	3,840	7.7	4,020	6.8	8,220	10,520	3,620	3,610	1,760
13-22 incl.	1/16	4,060	5.9	3,670	4.3	8,520	9,400	3,720	3,380	1,770
30-38 incl. 50-55 incl.	1/8	3,660	6.3	3,820	6.3	7,140	9,420	3,410	3,370	1,710
40-45 incl. 60-65 incl.	1/4	3,960	6.5	3,980	6.4	7,920	8,010	3,550	3,560	1,710



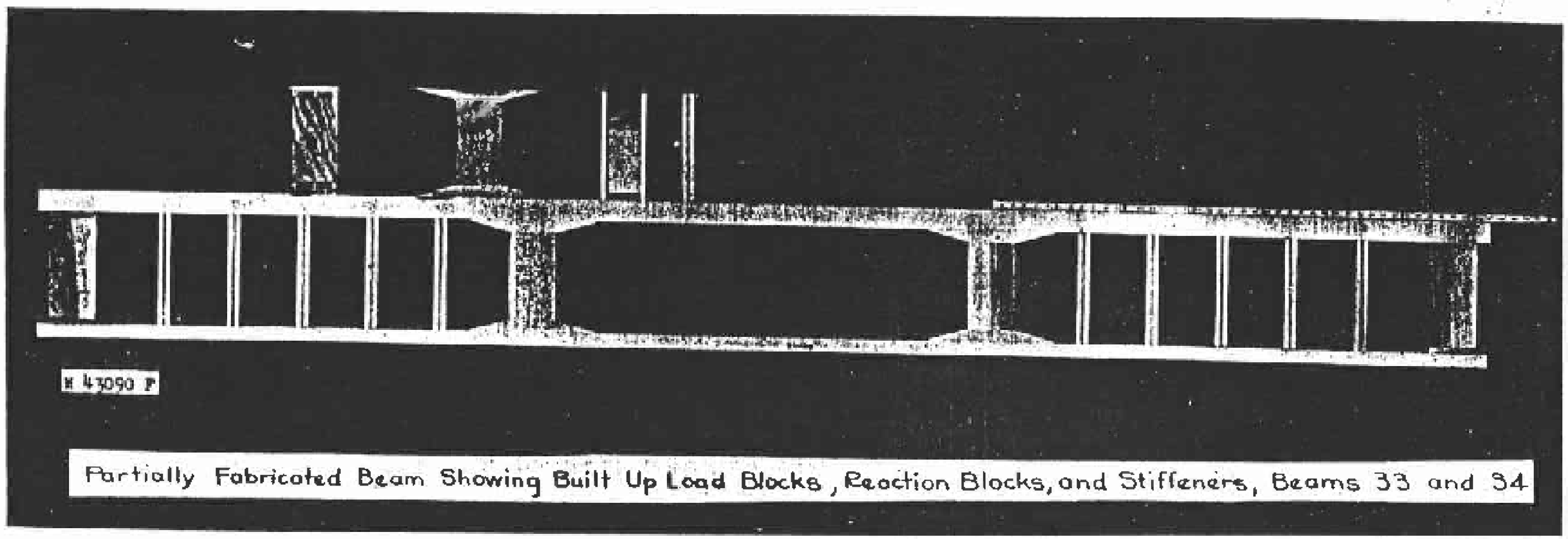


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FIGURE 1 DETAILS OF BEAMS

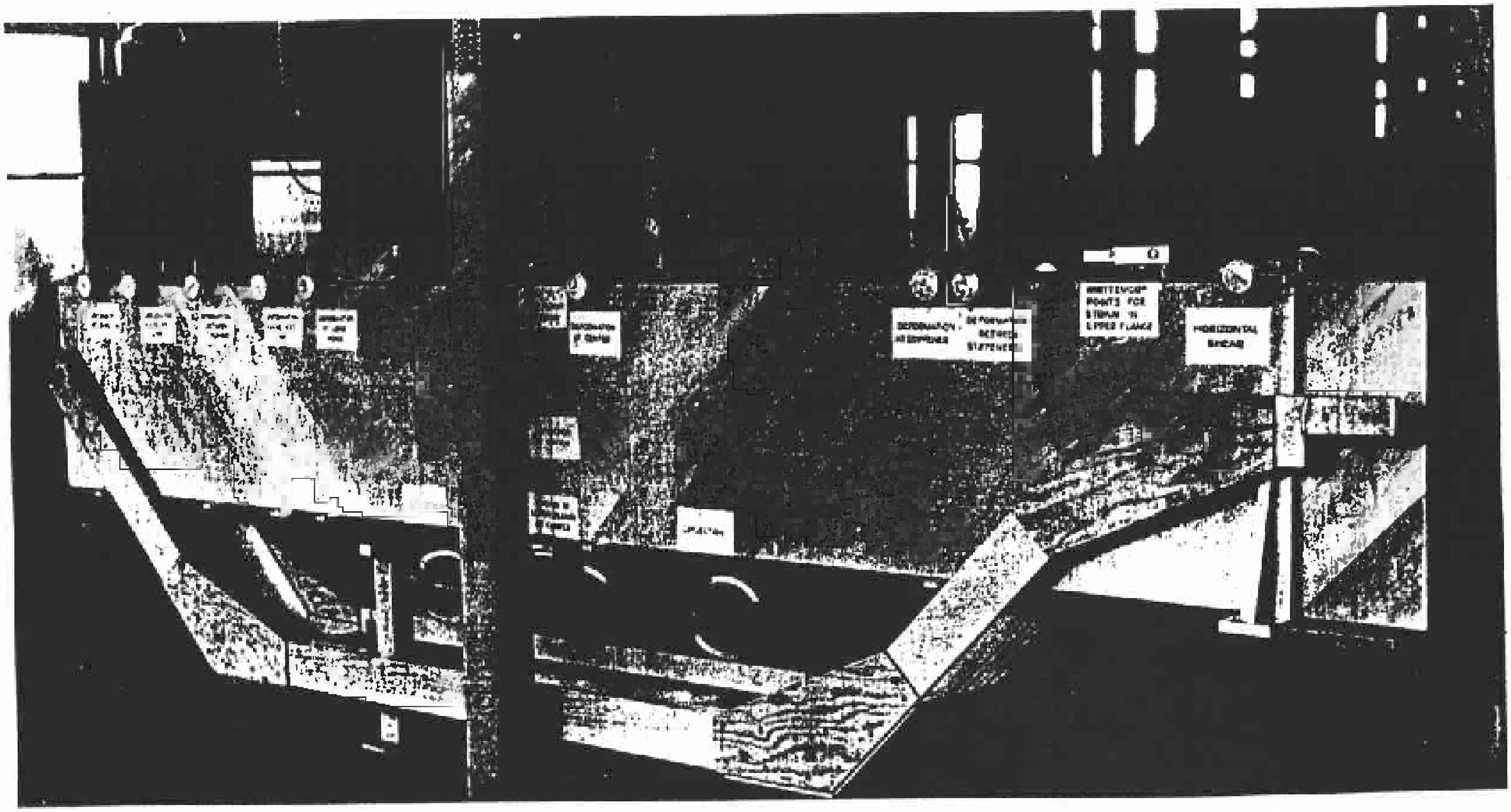

FIGURE 2 TYPICAL TEST SETUP

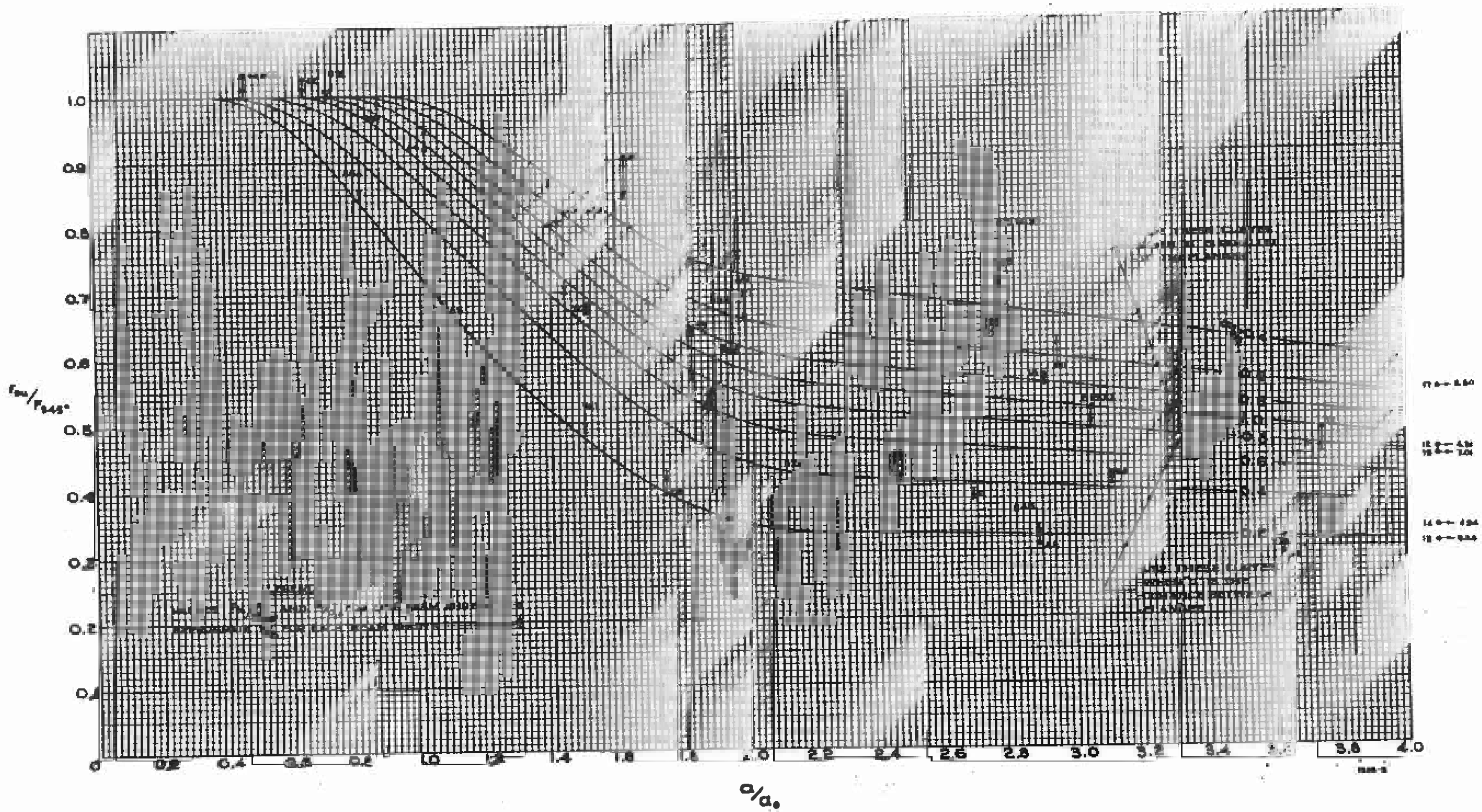

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Figure 3.--Relation of test results of box beams to suggested design criteria for allowable shear in plywood webs.
F_{s0} and a_e based on average minor test values.

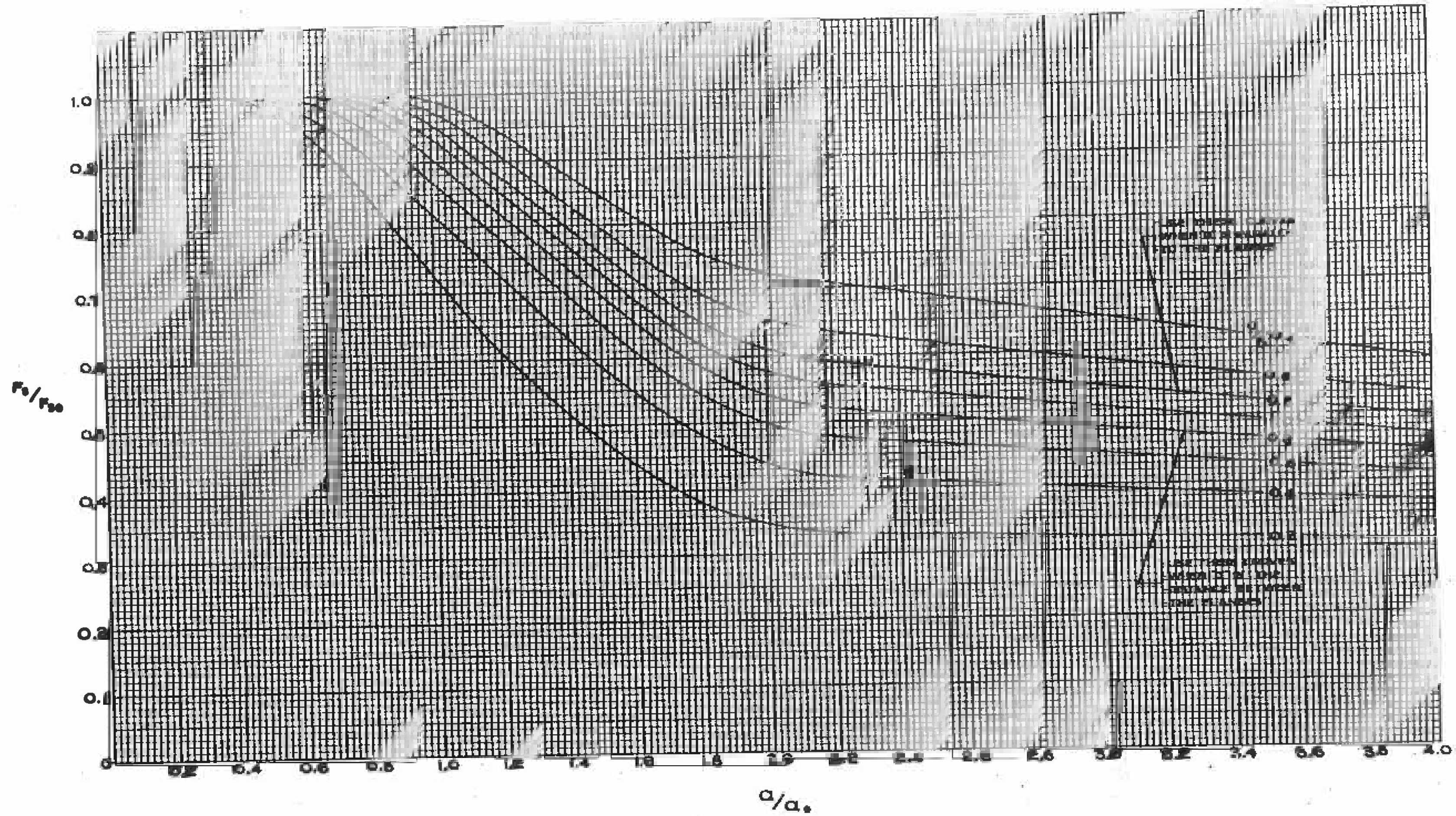

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Figure 6.--Allowable shear curves for plywood webs.