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EFFECT OF INCREASED MOISTURE CONTENT ON THE SHEAR STRENGTH AT GLUE LINES OF BOX BEAMS AND ON THE GLUE-SHEAR AND GLUE-TENSION STRENGTHS OF SMALL SPECIMENS[1]

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Summary

The results of a few tests of box beams that were designed to fail by shear at the casein glue line between the yellow-poplar plywood webs and the Sitka spruce tension flanges indicate that there is no great increase or decrease in glue-shear strength when the beams have a higher moisture content at test than when constructed.

While the number of beams tested was too limited to establish trends definitely, the number of minor glue-shear specimens was sufficient to indicate that the change in the strength of the joint in shear due to an increase of moisture content of about 4 percent was not significant. The results of the tests of small plywood-to-wood glue-tension specimens, however, indicate that an increase in moisture content of about 4 percent from that at fabrication produces a significant increase in the strength of the glue line in tension when casein glue is used. This substantiates the results of tests made at the Royal Aircraft Establishment[2].

Introduction

The tests of the series of box beams and small specimens reported herein were undertaken to determine whether or not a change in the strength of glue lines in shear or tension could be expected when the moisture content was greater at the time of test than at the time of fabrication.

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[1] This mimeograph is one of a series of progress reports prepared by the Forest Products Laboratory to further the Nation's war effort. Results here reported are preliminary and may be revised as additional data become available.

[2] Pryor, M.G.M., "Effect of Dispersal Conditions on Joints Made with Casein Glue," Report No. Mat/N/2/2051, Royal Aircraft Establishment, Farnborough, England, July, 1942.

British investigators[2] found that, for the particular type of test specimen they used which involved considerable concentrations of stress at the edges of the glued joint, the failing load was higher at the higher moisture content. The specimen used in British tests was such that the glue line was placed in tension.

The series of tests herein reported was designed so that the results of the English tests in glue-tension might be compared with results from a different type of specimen and extended to include tests where the glue line was stressed in shear, as it is between the flanges and the webs of box beams.

The beams discussed in this report present some of the first results of ultimate stresses in shear at the glue line between the flanges and the webs. These beams were all designed to fail in shear at the glue lines joining the webs to the tension flanges. The stresses in the compression and tension flanges and the shear stress in the webs were not critical at the failure of the beams.

Notation

The following symbols are used in this report. Sample computations appended show methods of computing results of tests. All quantities are in inch and pound units.

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

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

f_c = calculated maximum unit stress in the extreme fiber of the compression flange.

$$= \frac{M_{(max.)}\ C_c}{I}$$

f_s = calculated maximum unit shear stress in the plywood webs.

$$= \frac{V\ Q}{I\ t} = \frac{P_u\ Q}{2\ I\ t}$$

f_{gu} = calculated ultimate unit shear stress at the glue line between the tension flange and webs.

$$= \frac{P_u\ Q_f}{4\ I\ T_t}$$

f_t = calculated maximum unit stress in the extreme fiber of the tension flange.

$$= \frac{M_{(max.)}\ C_t}{I}$$

I = moment of inertia[3] of the cross section of the beam about its neutral axis.

M = the maximum bending moment in the beam

$= 20\ P_u$

P_u = ultimate load on the beam.

Q = statical moment[3] of the area external to the shear section about the neutral axis.

Q_f = statical moment of the area of the tension flange about the neutral axis (the area external to the glue lines between the tension flange and the webs).

T_t = thickness of the tension flange.

t = total thickness of the webs.

$= 2\ t_w$

t_w = thickness of one web.

V = total shear.

Description of the Beams and Minor Specimens

The beams were 7 or 7-1/4 inches wide, 13, 15, or 17 inches high, and 10-1/2 feet long. Aircraft-grade, yellow-poplar plywood was used for the webs, and Sitka spruce was used for the flanges. Details of construction and other pertinent information for the beams are shown in figures 1 and 2.

Sitka spruce for the flanges and other incidental parts of the beams was from planks sawn from logs and kiln-dried at the Forest Products Laboratory. The annual growth rings in the flanges were oriented so that

[3] The area of the webs was transformed by using the modular ratio 1/4 both in locating the neutral axis and in calculating I and Q as specified in section 3.1151 of ANC-18, "The Design of Wood Aircraft Structures."

the edges of the flanges were nearly true radial surfaces. All flanges were laminated. The stiffeners, load blocks, and reaction blocks were of a built-up design (fig. 2). Webs were of plywood manufactured at the Laboratory from veneers rotary cut and prepared at the Laboratory. The plywood was bonded with a phenolic resin film glue set in hot presses. The face grain of the plywood webs was oriented so that it sloped 45° downwards towards the reactions. The webs for beams 1-G-1 and 1-G-2 were each nominally one-fourth inch thick with face plies one-sixteenth inch thick and the core one-eighth inch thick. The webs for the remaining four beams were each nominally three-eighths inch thick, comprised of face plies one-sixteenth inch thick, crossbands one-twelfth inch thick, and a core one-tenth inch thick.

The plywood-to-wood glue-shear minor specimen is detailed in figure 3, and the plywood-to-wood glue-tension specimen in figure 4. The grain of the wood in these specimens was oriented so that a nearly radial face was glued to the plywood. The grain of the plywood made an angle of 45° with the grain of the wood. This was done to simulate conditions in aircraft where 45° grain plywood is glued to wood members.

The glue-shear specimen had a glue line 1 inch wide and 4 inches long in shear by having the 1-inch wide solid wood portion glued to the 2-inch wide plywood portion (fig. 3). Thus, the shear stress at the glue line between the wood and plywood was greater than between plies in the plywood, insuring failure at or near the glue line joining the wood to the plywood. The glue-tension specimen had an area 2 inches square in tension.

The minor specimens were assembled in jigs and a pressure of approximately 100 pounds per square inch was maintained while the glue was setting.

Casein glue was used for all assembly gluing of beams and of minor specimens because it was believed that the effects of moisture would be greater for casein glue than for any of the synthetic-resin base glues. All curing of glue was at room temperatures.

Selection and Matching

Sitka spruce flange material was flat-sawn and was selected by examination and on the basis of results from minor tests made prior to the construction of the beams. Minor specimens used were for toughness, static bending, and compression-parallel-to-the-grain tests and were prepared from the ends of the planks.

The glue-shear and glue-tension minor specimens were prepared from the same materials as were used in the beams. The plywood for the minor specimens for each beam came from the same plywood panels as were used for the webs of the beam. The solid wood portions of the minor specimens for each beam were prepared from the side of the same plank as was used for the tension flange.

Conditioning of Material and Specimens

All material was conditioned to a low moisture content before it was fabricated into beams or minor specimens. Initial conditioning was done in a dry kiln, where the moisture was reduced to about 7-1/2 percent. Final conditioning was accomplished in a constant 80° F. - 30 percent relative humidity room. After the material became stable, it was fabricated into the beams and minor specimens. The beams and minor specimens were then returned to the 80° F.-30 percent relative humidity room until the moisture introduced by the glue had been dissipated, after which beams 1-G-1, 2-G-1, and 3-G-1 and the minor specimens for these beams were removed from the 80° F.-30 percent relative humidity room and tested.

Beams 1-G-2, 2-G-2, and 3-G-2 and the minor specimens for these beams were moved to a 75° F. - 64 percent relative humidity room where they were allowed to condition for several months. After these beams and minor specimens had attained practically constant moisture content (about 12 percent for the Sitka spruce), they were tested.

Methods of Test

The beams were tested in a 200,000-pound screw-type testing machine by loading at the third points of a 10-foot span. Figure 5 shows a beam, in the testing machine, ready for test with the strain- and deflection-measuring instruments in place. Visible in the figure are the scale for measuring total deflection, dial and yoke for determining the deflection of the center of the beam with respect to the load points, Huggenberger tensometers for measuring the strain in the upper and lower flanges, and the recorder for measuring the strain in the tension flange by means of electric strain gages.

Deformation was applied to the beams at standard rates[4] in predetermined increments. Loading was stopped during the early stages of each test while strains and deflections were observed. All dials and gages were removed from the beam after sufficient data on elastic behavior had been obtained. From the time the dials were removed until failure, the load was applied continuously. Centerline deflections and the corresponding loads were the only readings taken during this final stage of the tests.

The plywood-to-wood glue shear specimens were tested as shown in figure 6. Shear was introduced into the glue line by loading the specimen in compression. The ultimate load divided by the area of the glue line (nominally 4 square inches) gave the unit stress on the glue line at failure. Also shown in figure 6 is a typical failure.

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[4]As prescribed in American Society for Testing Materials Standard D198-27.

The plywood-to-wood glue-tension specimens were tested as shown in figure 7. Tensile stress was put on the glue lines by means of the hard maple loading jig shown in this figure. A loading block with a spherical seat was used on the upper head of the testing machine. Also shown in this figure is a typical failure.

Both types of specimens were loaded in a hydraulic testing machine at a rated head travel of 0.025 inch per minute.

Presentation of Data

The data from the individual tests of the box beams are presented in table 1. In column 14 is the statical moment, Q, of the area (webs and flange) external to the neutral axis, and, in column 15, the statical moment of the tension flange, Q_f, which is the area external to the glue lines joining the webs to the tension flange. The maximum shear stress in the web was computed by using Q, and the shear stress on the glue line at ultimate load by using Q_f. The calculated unit stresses in the beams at maximum load, f_c, f_t, and f_s, in columns 17, 18, and 19, respectively, are the stresses in parts of the beams that did not fail and are consequently merely the maximum stresses achieved. The calculated unit shear stresses (f_{gu}) in the glue lines at failure of the beams, in column 20, are ultimate stresses because they apply at points where failure occurred. The values in column 21 are the ratios of the calculated ultimate shear stresses in the glue lines of the beams to the average ultimate shear stresses in the glue-shear minor specimens.

Table 2 is a summary of the results of the minor plywood-to-wood glue-shear tests, and table 3 is a summary of the results of the minor plywood-to-wood glue-tension tests for all of the beams. The average values of the shear stress in the glue line at failure in column 7, table 2, are the bases of the ratios in column 21, table 1.

A comparison of the shear stresses at the glue lines at ultimate load for the box beams is presented in figure 8-A. This figure shows graphically the relation between the test results for the different beams. Figure 8-B is a similar plot of the average values of the stress on the glue lines at failure of the glue-shear minor specimens for each beam, and figure 8-C shows similar results for the glue-tension minor tests.

Modes of Failure

The beams failed suddenly, usually with little or no advance warning. Failure was accompanied by a loud report, and usually it was not possible to determine whether or not both glue lines failed simultaneously or if one preceded the other by a fraction of a second. In two of the beams, however, one web failed before the other, indicating definitely that one side was the weaker.

One of the beams (1-G-2) failed on one side only, and because of the "twist" in the beam caused by the unequal failure it was not possible to fail the other side. Beam 2-G-1 failed initially along one side at 25,670 pounds load, but with the other side sustaining nearly all of the stress did not fail completely until 27,000 pounds load had been attained.

The failure of all the beams was in rolling shear in the face ply nearest the glue line joining the web to the flange. That the glue was stronger in shear than the plywood is shown by the type of failure, which is illustrated by figures 9 and 10. In figure 9 is shown the way the tension flange of beam 1-G-1 sheared past the web. Figure 10 shows beam 1-G-1 with part of the web removed and turned up to reveal the way the fibers roll past one another in a rolling shear failure. The failure of this beam is typical of those in this series.

The failures of the glue-shear minor specimens were usually similar in appearance to those in the box beams. A typical failure is shown in figure 6. The failure of the glue-tension specimens was usually confined to an area closer to the glue line than that of the glue-shear specimens, as is shown in figure 7. The fiber transfer was good, indicating that the glue bond was adequate.

Analysis of Data

Two theories are advanced to explain the fact that glued specimens may have somewhat higher strengths when at moisture contents greater than at fabrication: (1) When a glue mixed with water is used, the moisture content of the wood adjacent to the glue line is greater while the glue is setting than it is in the rest of the specimen. This added moisture is later dissipated uniformly throughout the specimen causing some tendency for the wood next to the glue line to shrink. This tendency to shrink introduces stress in the area adjacent to the glue lines. It is possible that these initial stresses are minimized at moisture contents higher than those at fabrication. (2) It is possible that the glue may be more plastic at high than at low moisture contents, thus tending to distribute the stress more uniformly throughout the stressed area.

The ultimate shear stresses at the glue lines of the beams (f_{gu}, column 20, table 1) ranged from a minimum of 474 pounds per square inch to a maximum of 720 pounds per square inch. This variability is not excessive when the different items that can affect the test of a large complex specimen, such as a box beam, are considered. When a box beam is tested, such as in the present series, the weakest glue line of four fails. The length of glue line in shear was 40 inches for each quadrant of the beam. The theoretical stress was constant throughout the distance between load and reaction points, and any weak point along this distance adversely affected the ultimate strength. It is probable that all four of the webs and glue lines for beam 1-G-1 were of uniformly high strength; hence, the beam had nearly reached its capacity along all four glue lines at failure. This would account for the fact that the ultimate strength of beam 1-G-1 was 720 pounds per square inch. Beams 1-G-2 and 2-G-1, however, failed at calculated stresses of 474 and 515 pounds per square inch, respectively. Both failed first along one glue line. Some indication of the strength of the transversely opposite glue line of beam 2-G-1 is afforded by the fact that it sustained alone a load greater than that which caused initial failure when all glue lines were functioning. This indicates that the remaining three glue lines for each beam were probably much superior in strength to the one that failed.

The average ultimate shear strength for the beams tested at the same moisture content as when constructed (beams 1-G-1, 2-G-1, 3-G-1) was 608 pounds per square inch, and for the beams conditioned to a higher moisture content before test (beams 1-G-2, 2-G-2, and 3-G-2), 561 pounds per square inch or a difference of just under 7 percent. One beam, however, of the latter group was about 25 percent lower than its mate, while the other two were respectively 8 and 10 percent higher. In view of this, the data cannot be considered as at all conclusive with respect to the effect of moisture increase subsequent to fabrication on the shearing strength of glued joints in such a structure as a box beam.

The plywood-to-wood glue-shear test results further indicate differences that do not appear to be significant. This is shown in the summary of plywood-to-wood shear test results in table 2 and in figure 8-B. The differences for the groups were -5, +3, and -7 percent, respectively, as is shown in column 9 of table 2. These differences might readily occur as the result of variability of the material. Similarly, a comparison of the mean value for all specimens tested at the lower moisture content with the mean for all specimens conditioned to the higher moisture content before test indicates that the differences in the shear strengths are not significant. The average ultimate shear strength for the specimens from beams 1-G-2, 2-G-2, and 3-G-2 was 3-1/2 percent less than the average for specimens from beams 1-G-1, 2-G-1, and 3-G-1. This difference is so small that it might well be due to the variability of the material. Thus, the conclusion that an increase in moisture content of approximately 4 percent over that at fabrication does not significantly increase or decrease the glue-shear strength seems warranted.

In contrast to the data from the beams and from the plywood-to-wood glue-shear tests, the results of the plywood-to-wood glue-tension tests, indicate significant differences in strength between the specimens that were conditioned to the higher moisture content before test and those tested at the lower moisture content. The specimens tested with the higher moisture content failed at stresses greater than those that were tested at the lower moisture content. The percentages of differences are shown in column 9, table 3, and in figure 8-C.

It may be noted that for average maximum and minimum values shown in table 3 differences are consistently in the same direction although they vary considerably in magnitude. The ultimate stresses in glue tension were 21 percent greater for the minor specimens from beam 1-G-2 than those from beam 1-G-1, 5 percent greater for those from beam 2-G-2 than those from beam 2-G-1, and 30 percent greater for those from beam 3-G-2 than those from beam 3-G-1. These increases in strength may be somewhat in error because only a relatively few specimens were tested and the averages were therefore not necessarily representative.

The average glue-tension strength for all specimens for beams 1-G-2, 2-G-2, and 3-G-2 was 18 percent greater than the average for all specimens for beams 1-G-1, 2-G-1, and 3-G-1. This difference is much greater than is at all likely to be caused by differences in the material, and the conclusion that the increase in moisture of 4 percent over that at fabrication actually increased the strength of the glue line in tension seems fully warranted. This conclusion is in agreement with that derived from tests made at the Royal Aircraft Establishment[2].

Ultimate strength values given in tables 2 and 3 are relative. Concentrations of stress and other factors relating to the size and shape of the specimens affect the ultimate strengths of the specimens. An example of this is the comparison between the unit shear stresses at the glue lines in the box beams at failure and the unit shear stresses at the glue lines in the minor specimens in table 1, column 21. In all instances, the ultimate stresses in the large beams are less than in the small specimens.

Conclusions

The tests of a few box beams, with yellow-poplar plywood webs glued to Sitka spruce flanges with casein glue, indicated that there was no significant change in strength in shear at the glue line between the flanges and webs when the moisture content at test was approximately 4 percent greater than at fabrication. The number of beams tested was too small to establish the trend definitely, but there were sufficient small associated plywood-to-wood specimens to show that an increase in moisture content of about 4 percent from that at fabrication did not materially change the ultimate shear strength of the glued joints.

The results of tests on small plywood-to-wood glue-tension specimens are in agreement with the results of tests made at the Royal Aircraft Establishment[2] inasmuch as they show that the glue-tensile strengths of specimens which before test were conditioned to a moisture content about 4 percent higher than at fabrication were greater than those of specimens which were tested at the same moisture content as they had when fabricated.

APPENDIX

Sample Calculations

The following methods were used for computing the values of f_{gu} appearing in the tables and figure in this report:

The results from beam 1-G-1 are used in this calculation; values for the other beams were calculated in a like manner.

(1) The formula for determining the unit shear stress on the glue line is obtained by substituting appropriate terms in the familiar $f_s = \frac{V\,Q}{I\,b}$ formula, where

f_s = unit shear stress

V = total vertical shear

Q = statical moment of the area external to the shear section about the neutral axis

I = moment of inertia of the section about the neutral axis

b = width of the area in shear

(2) In determining the unit shear stress at the glue line, which has been designated "f_{gu}":

V = the total vertical shear, which is constant from load point to reaction = $\frac{P}{2}$.

Q = Q_f because the tension flange is the area external to the glue lines.[5]

b = 2 T_t because the width in shear is the sum of the two widths of glue line or twice the thickness of the tension flange.

Therefore, the formula for unit shear becomes:

$$f_{gu} = \frac{P_u\,Q_f}{4\,I\,T_t} \;.$$

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[5] A similar situation arises in steel plate girder design when it is necessary to determine the required number of rivets between flanges and webs. This is discussed in section 3-6d, page 306 of Hool and Kinne's "Steel and Timber Structures" published by McGraw-Hill, 1942.

(3) The ultimate load for beam 1-G-1 was 27,000 pounds, the statical moment of the tension flange was 43.2 inches^3, the moment of inertia was 534.6 inches^4, and the thickness of the tension flange was 0.760 inch. Hence,

$$f_{gu} = \frac{P_u\ Q_f}{4\ I\ T_t} = \frac{27{,}000 \times 43.2}{4 \times 534.6 \times 0.760} = 720 \text{ pounds per square inch}$$

Table 1.--Results of individual tests of box beams that were designed to fail in shear at or near the glue lines joining the webs and tension flanges[1]

Beam number	Construction details: Measured dimensions: Depth of beam	Width of beam	Depth of compression flange	Depth of tension flange	Thickness[3] of plywood web (t_w)	Nominal thickness of veneers in web	Moisture content at test[2]: Webs	Compression flange	Tension flange	Cross-section properties: I	$\frac{I}{Q_b}$	$\frac{I}{Q_t}$	Q	Q_t	Stresses at failure of the beams: P_m	f_c[4]	f_t[4]	f_s[4]	f_{gn}	Ratio of $f_{gn(major)}$ to $f_{gn(minors)}$[5]	Remarks on failure of beam
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
	Inches	Inches	Inches	Inch	Inch	Inch	Percent	Percent	Percent	Inches	Inches	Inches	Inches	Inches	Pounds	P.s.i.	P.s.i.	P.s.i.	P.s.i.		
1-0-1	12.97	6.99	3.521	0.760	0.246	1/16, 1/8, 1/16	5.1	7.2	7.2	534.6	139.4	58.5	46.4	43.2	27,000	3,870	9,230	2,480	780	0.95	Failed in rolling shear in the plywood at the glue lines between the tension flange and the webs, and was confined to the face plies next to the glue lines.
1-0-2	13.10	7.06	3.652	.782	.253	1/16, 1/8, 1/16	10.9	11.2	12.0	562.7	144.4	61.2	50.5	45.2	14,500	2,560	6,050	1,640	474	.66	Failed in rolling shear in the plywood in one web only at the glue line between the tension flange and web. A large percentage of wood failure indicated that the side that failed was probably weaker than the one that did not fail.
2-0-1	15.00	7.26	4.035	.875	.393	1/16, 1/12, 1/10, 1/12, 1/16	4.7	7.4	7.2	852.3	188.2	81.4	67.6	56.9	27,000	2,870	6,630	1,360	515	.74	Failed initially at 25,670 pounds total load on one side in rolling shear in face ply next to the glue line. This side was obviously weaker than the other.
2-0-2	15.02	7.36	4.054	.896	.398	1/16, 1/12, 1/10, 1/12, 1/16	11.0	11.2	12.3	878.9	192.4	84.1	69.7	58.8	29,970	3,120	7,130	1,490	559	.78	Failed in rolling shear in the plywood at the glue lines between the tension flange and the webs, and was confined to the face plies next to the glue lines.
3-0-1	17.01	7.22	4.526	1.010	.351	1/16, 1/12, 1/10, 1/12, 1/16	5.4	7.8	8.0	1,250.2	243.3	105.4	87.1	74.8	40,000	3,290	7,590	1,990	590	.72	Failed in rolling shear in the plywood at the glue lines between the tension flange and the webs, and was confined to the face plies next to the glue lines.
3-0-2	17.00	7.31	4.550	1.012	.372	1/16, 1/12, 1/10, 1/12, 1/16	11.2	11.7	12.6	1,264.9	245.6	106.8	86.4	75.3	44,180	3,600	6,270	2,070	650	.86	Failed in rolling shear in the plywood at the glue lines between the tension flange and the webs, and was confined to the face plies next to the glue lines.
Average for beams tested at the same low moisture content as when constructed. (Beams 1-0-1, 2-0-1, and 3-0-1)							5.1	7.5	7.5										608	.80	
Average for beams conditioned to the higher moisture content before being tested. (Beams 1-0-2, 2-0-2, and 3-0-2)							11.0	11.4	12.4										561	.77	

[1] Beams were tested under third-point loading over a 10-foot span. Flanges were Sitka spruce; webs were yellow-poplar, and casein glue was used for assembly gluing.

[2] All beams were constructed from material conditioned to a low moisture content. Beams 1-0-1, 2-0-1, and 3-0-1 were tested at the same moisture as when constructed. Beams 1-0-2, 2-0-2, and 3-0-2 were conditioned to a higher moisture content before test.

[3] Grain in the plywood was oriented at 45 degrees to the axis of the beams with the grain in the face plies sloping downward toward the reactions.

[4] These stresses are calculated from the maximum load and are in parts of the beams where the stresses were not critical at the failure of the beams.

[5] Values of f_{gn} for minor tests are summarized in column 7, table 2.

Table 2.--Summary of results of minor tests on plywood-to-wood glue-shear specimens[1]

Beam number[2]	Number of minor specimens	Average moisture content at test		Shear stress on glue line at failure			Coefficient of variation	Increase or decrease in ultimate strength from dry to wet condition
		Wood	Plywood	Minimum	Maximum	Average		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Percent	Percent	P.s.i.	P.s.i.	P.s.i.	Percent	Percent
1-G-1	12	6.8	6.2	547	990	762	15.5	....
1-G-2	12	10.8	9.0	650	840	721	10.6	-5
2-G-1	11	6.7	5.6	594	824	698	9.4	....
2-G-2	9	10.8	8.7	596	792	720	11.7	+3
3-G-1	11	7.1	6.9	628	981	818	12.5	....
3-G-2	10	10.8	8.5	670	866	759	9.7	-7
Summary for 1-G-1, 2-G-1, and 3-G-1	34	6.9	6.2	547	990	760	14.1	....
Summary for 1-G-2, 2-G-2, and 3-G-2	31	10.8	8.8	596	866	733	10.6	-3-1/2

[1]Plywood was yellow-poplar with the grain oriented at 45° to the grain in the wood, which was Sitka spruce. See figures 3 and 6 for details of test specimen. Plywood was bonded to wood with casein glue set at room temperature under approximately 100 pounds per square inch pressure.

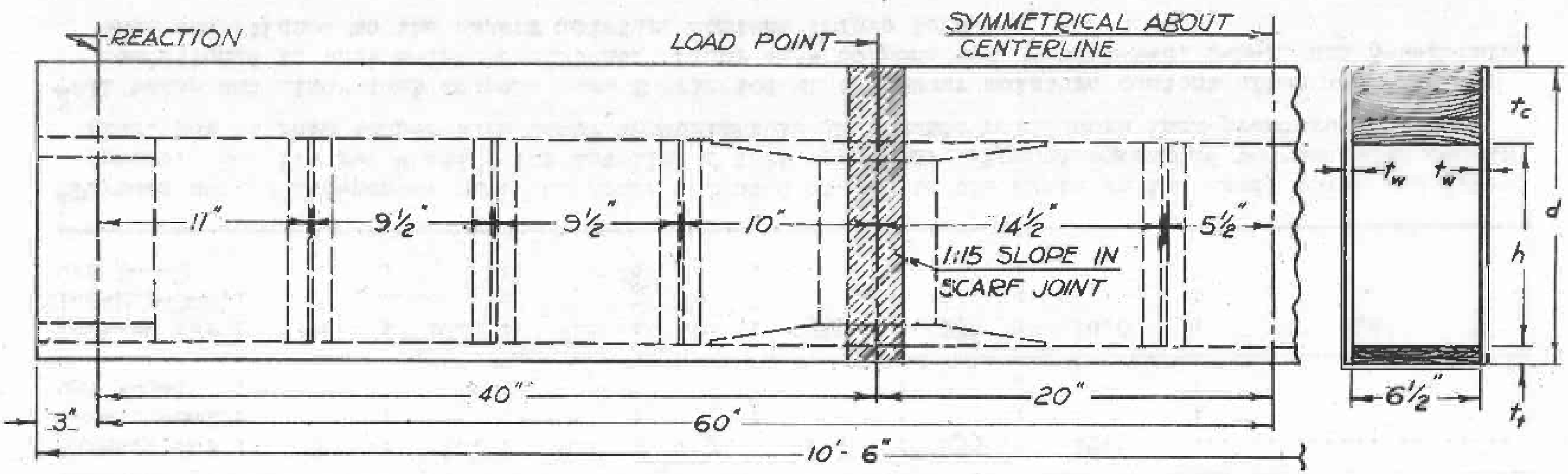
[2]All beams and minor test coupons were fabricated at the lower moisture content after the material was conditioned to that moisture content. Minor test coupons for beams 1-G-2, 2-G-2, and 3-G-2 were then conditioned to higher moisture content before test.

Table 3.--Summary of results of minor tests on plywood-to-wood glue-tension specimens[1]

Beam number[2]	Number of minor specimens	Average moisture content: Wood	Average moisture content: Plywood	Tensile stress on glue line at failure: Minimum	Tensile stress on glue line at failure: Maximum	Tensile stress on glue line at failure: Average	Coefficient of variation	Increase or decrease in ultimate strength from dry to wet condition
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Percent	Percent	P.s.i.	P.s.i.	P.s.i.	Percent	Percent
1-G-1	12	6.7	6.1	182	297	257	13.6	....
1-G-2	12	10.9	9.0	249	358	312	11.3	+21
2-G-1	12	7.0	5.6	169	277	237	14.1	....
2-G-2	12	10.7	8.4	219	286	248	7.7	+5
3-G-1	12	7.6	6.7	173	245	206	8.8	....
3-G-2	12	10.9	8.4	196	297	267	10.4	+30
Summary for 1-G-1, 2-G-1, and 3-G-1	36	7.1	6.1	169	297	233	15.5	....
Summary for 1-G-2, 2-G-2, and 3-G-2	36	10.9	8.6	196	358	276	14.0	+18

[1] Plywood was yellow-poplar with the grain oriented at 45° to the grain in the wood, which was Sitka spruce. See figures 4 and 7 for details of test specimen. Plywood was bonded to wood with casein glue, set at room temperature under approximately 100 pounds per square inch pressure.

[2] All beams and minor test coupons were fabricated at the lower moisture content after material was conditioned to that moisture content. Minor test coupons for beams 1-G-2, 2-G-2, and 3-G-2 were then conditioned to the higher moisture content before test.

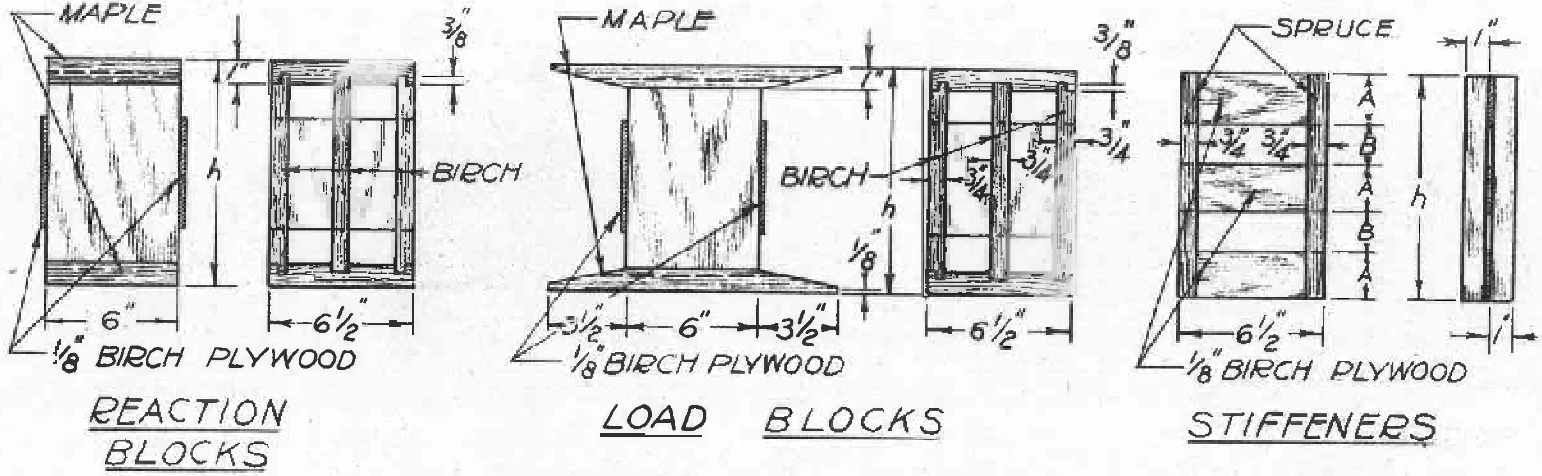


SITKA SPRUCE FLANGES WERE ALL LAMINATED.
YELLOW-POPLAR PLYWOOD WEBS HAD FACE GRAIN SLOPING 45 DEGREES DOWN TOWARD THE REACTIONS.
CASEIN GLUE WAS USED FOR ALL ASSEMBLY GLUING.

BEAM NO.	d	h	t_c	t_t	t_w
1-G-1 & 1-G-2	13"	8¾"	3½"	¾"	1/16" + 1/8" + 1/16" = 1/4"
2-G-1 & 2-G-2	15"	10⅛"	4"	⅞"	1/16" + 1/12" + 1/10" + 1/12" + 1/16" = 3/8"
3-G-1 & 3-G-2	17"	11½"	4½"	1"	1/16" + 1/12" + 1/10" + 1/12" + 1/16" = 3/8"

Figure 1.--Construction details of box beams designed to fail in shear at the glue lines between the tension flange and the webs. (Beam assemblies.)

Z M 64291 F



BEAM NO.	h	A	B
1-G-1, & 1-G-2	8 3/4"	1 3/4"	1 3/4"
2-G-1, & 2-G-2	10 1/8"	2 1/8"	1 7/8"
3-G-1, & 3-G-2	11 1/2"	2 1/2"	2"

Figure 2.--Construction details of box beams designed to fail in shear at the glue lines between the tension flange and the webs. (Details of reaction blocks, load blocks, and stiffeners.)

Z M 64292 F

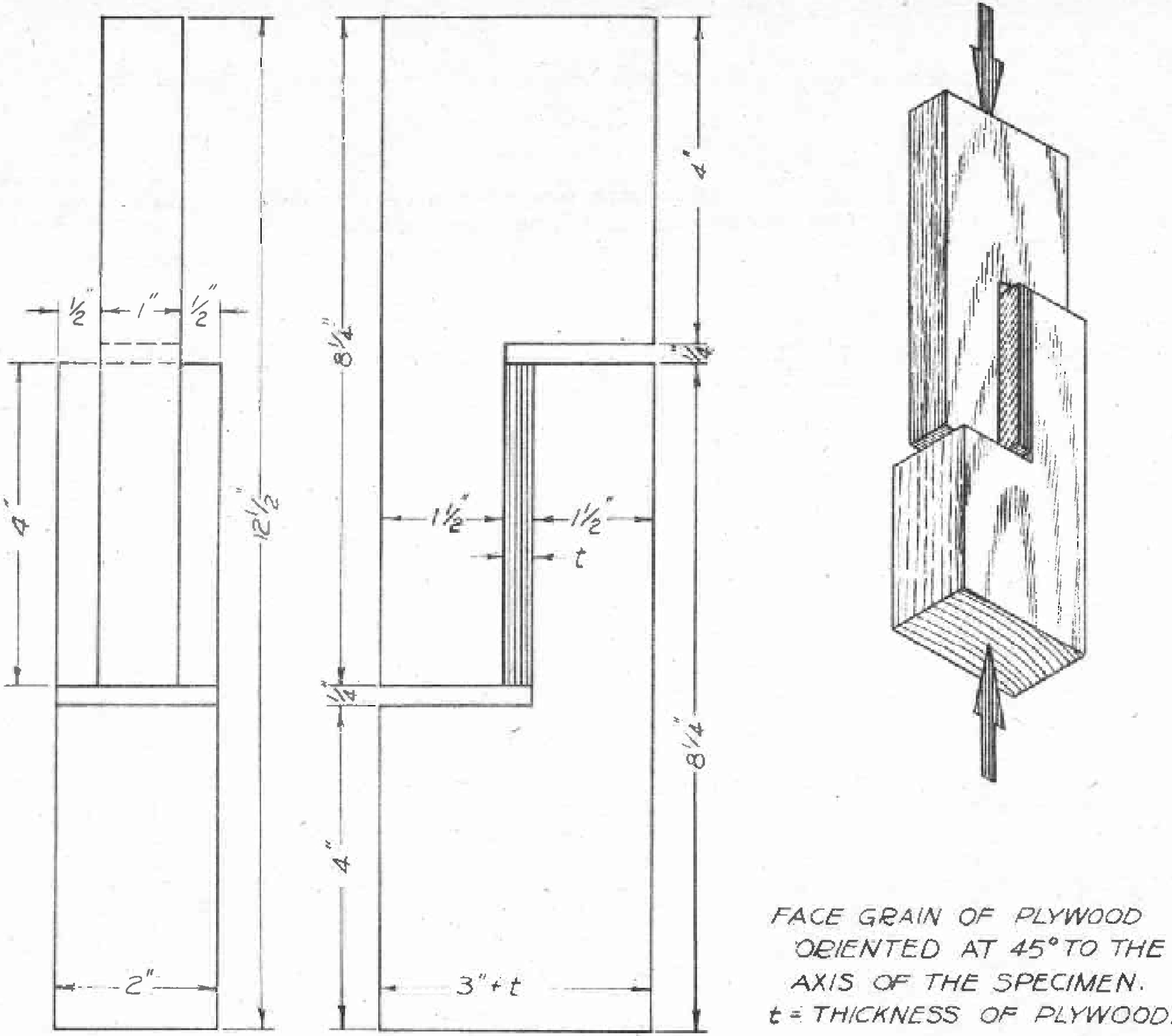


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Figure 3.--Details of plywood-to-wood glue-shear specimen.

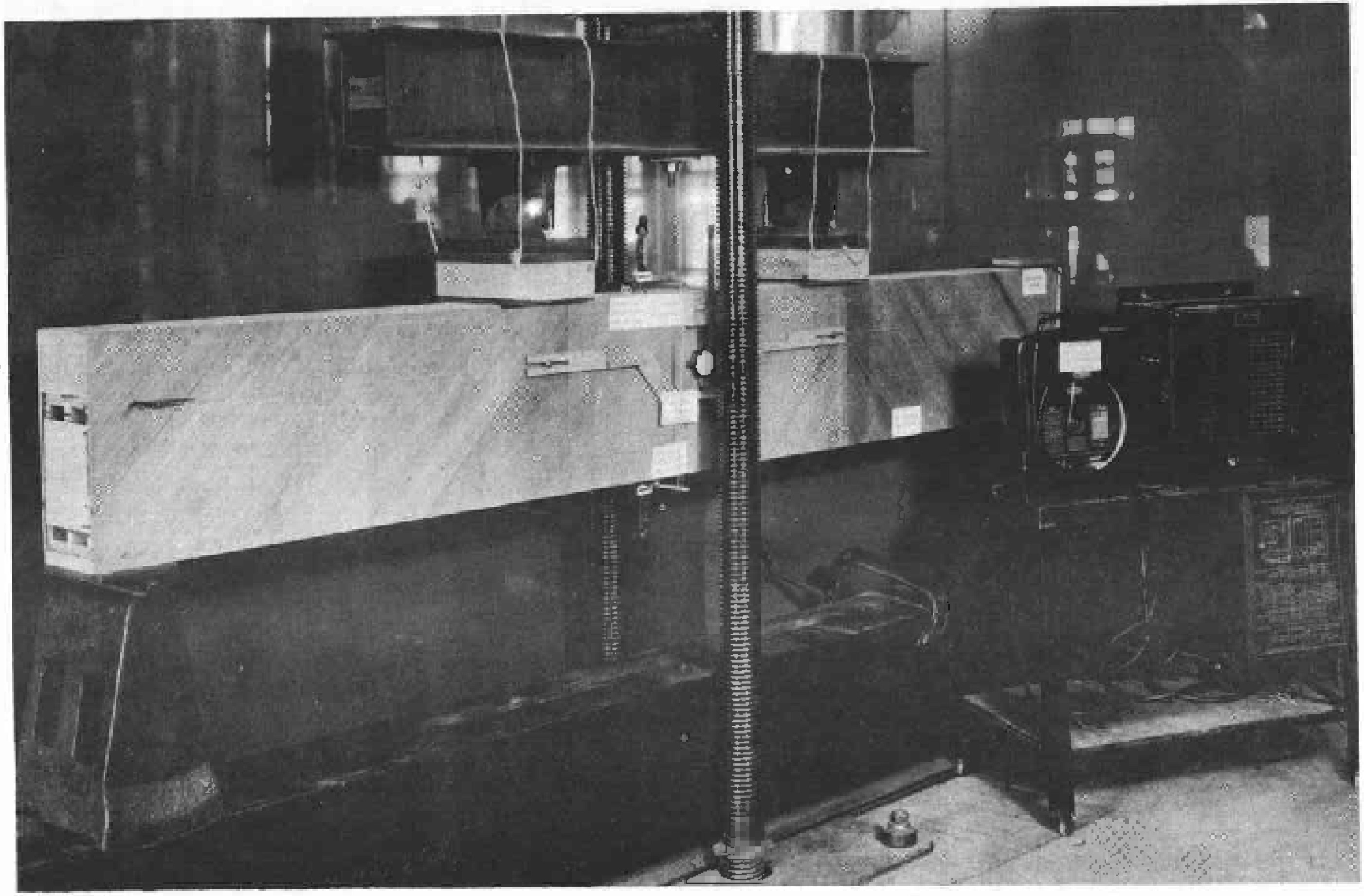

Figure 5.--Test set-up showing box beam, with strain- and deflection-measuring instruments attached, in testing machine. (The 48-point electric strain recorder was used to determine variation of strain in the tension flange.)

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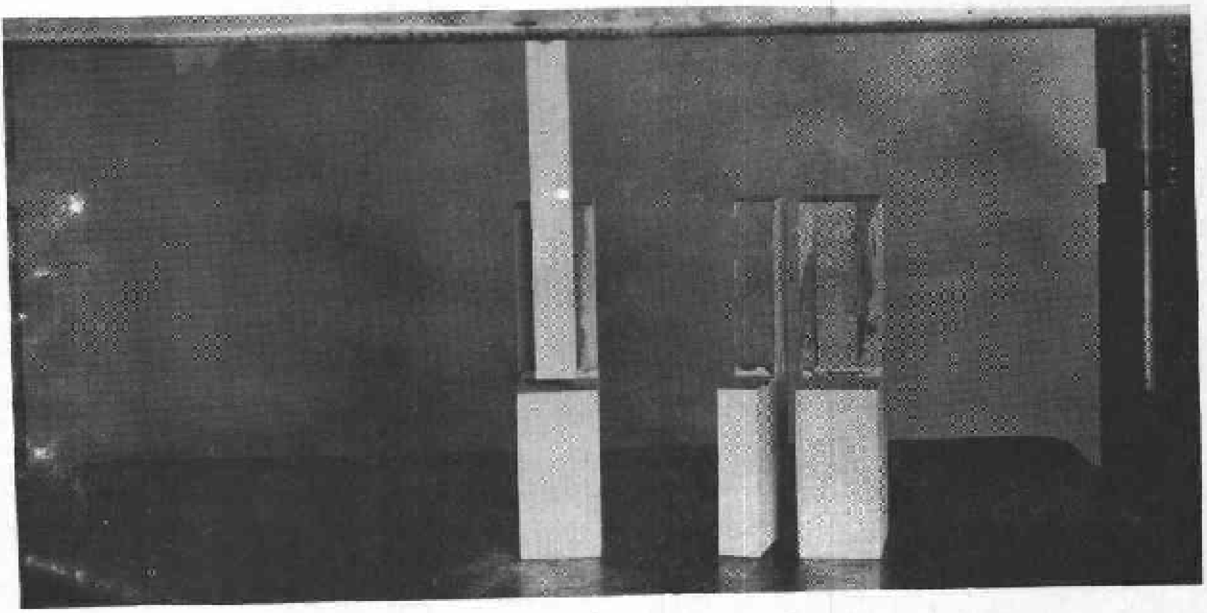

Figure 6.--Plywood-to-wood glue-shear specimen in testing machine showing method of applying load. Also included is a specimen after test showing a typical failure.

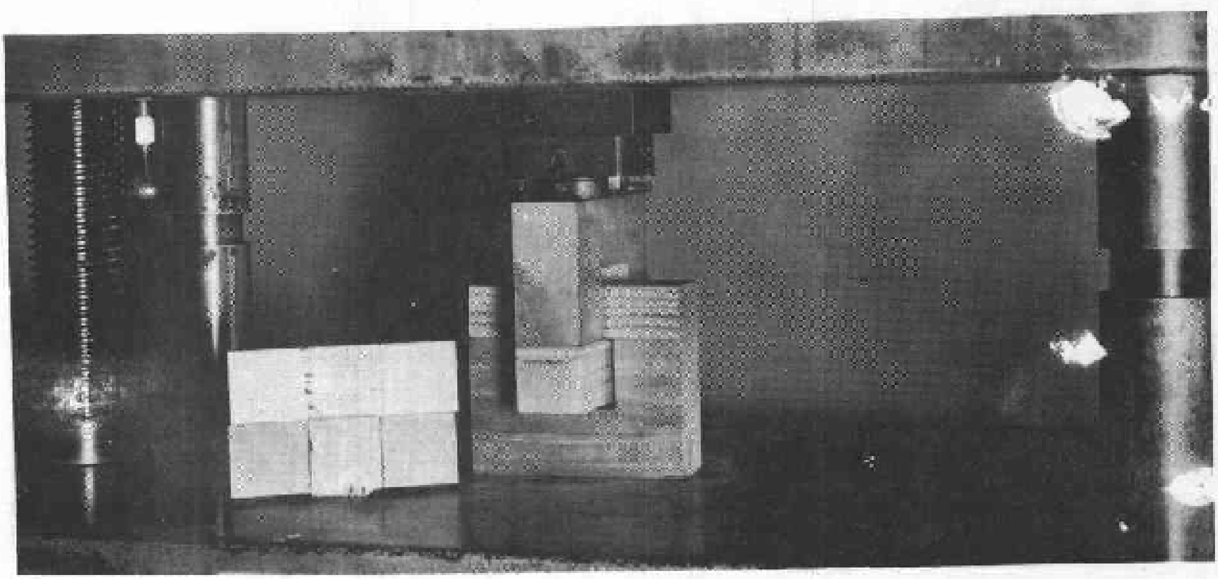

Figure 7.--Plywood-to-wood glue tension-specimen in testing machine showing method of applying load. Also included is a specimen after test showing a typical failure.

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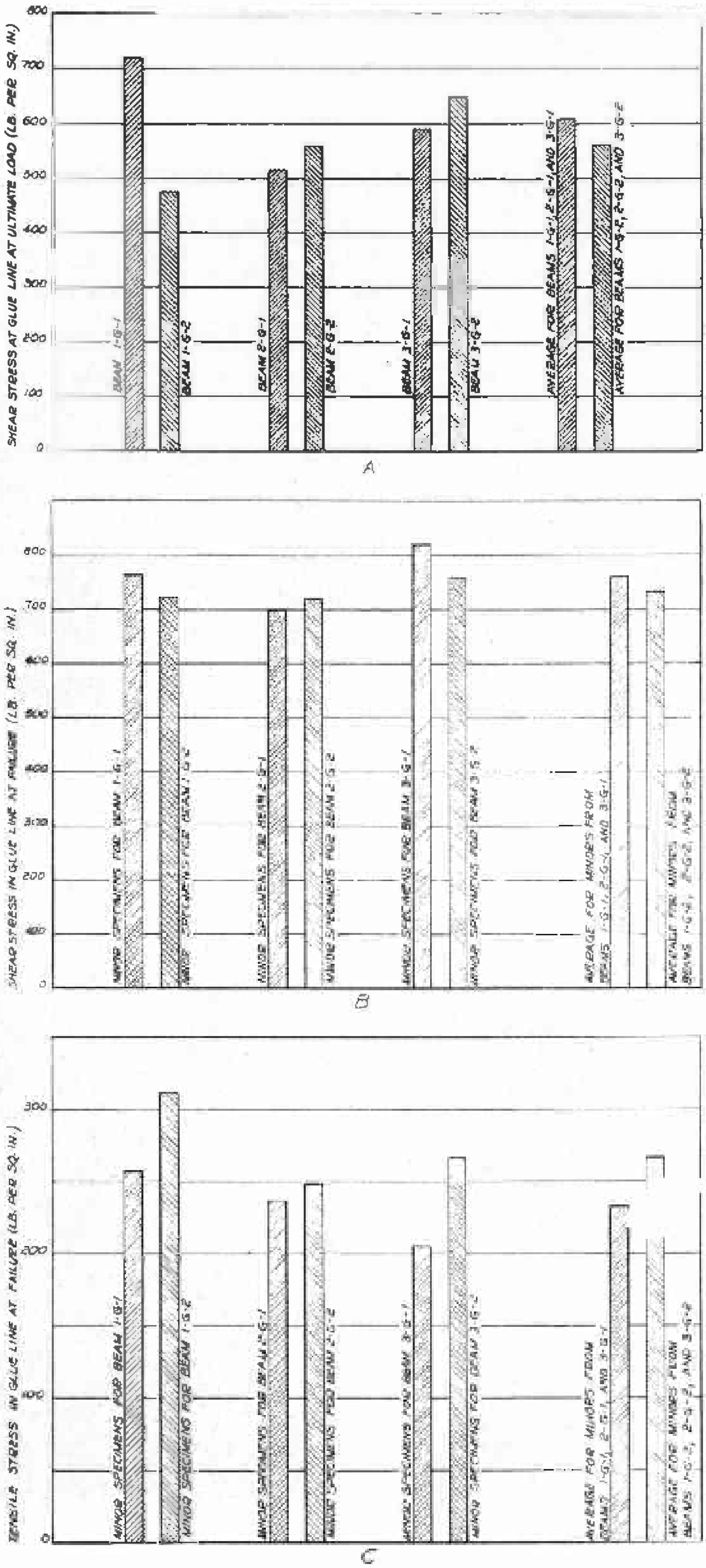

Figure 8.--Comparison of stresses at failure in box beams and plywood-to-wood glued test specimens. (A) Shear stresses at the glue lines at ultimate load for the box beams, (B) stresses at failure in the plywood-to-wood glue-shear specimens, and (C) stresses at failure in plywood-to-wood glue-tension specimens.

All beams and specimens were prepared from material conditioned to a low moisture content. Beams 1-G-1, 2-G-1, and 3-G-1, and the minor specimens for these beams were tested at the low moisture content. Beams 1-G-2, 2-G-2, and 3-G-2 and the minor specimens for these beams were conditioned to a higher moisture content before test.

Z M 64298 F

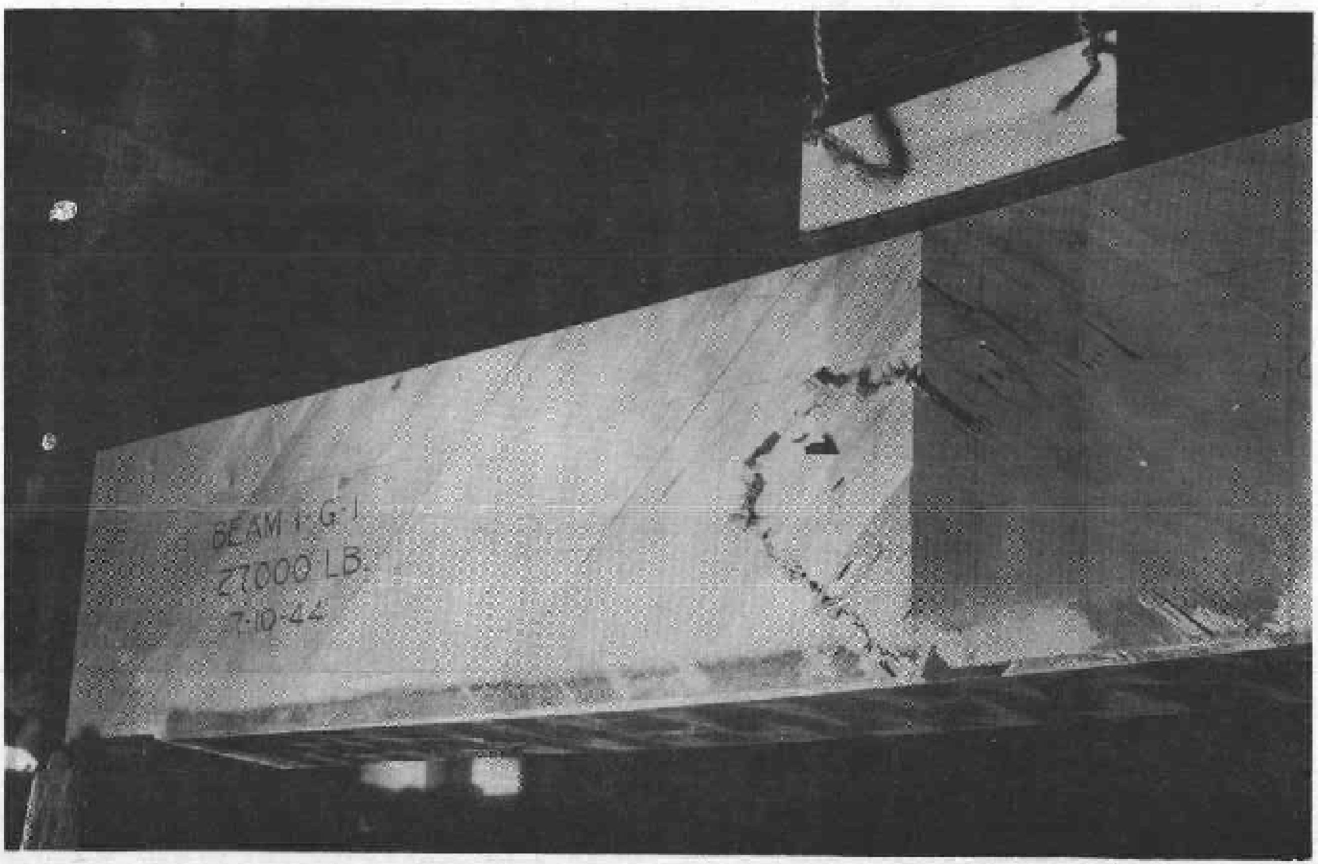

Figure 9.--Box beam 1-G-1 after test showing the typical shear failure in the face ply of the yellow-poplar plywood web at the glue line between the Sitka spruce tension flange and the web. (The tearing of the web near the load block is secondary and occurred after the failure between the flange and the web.

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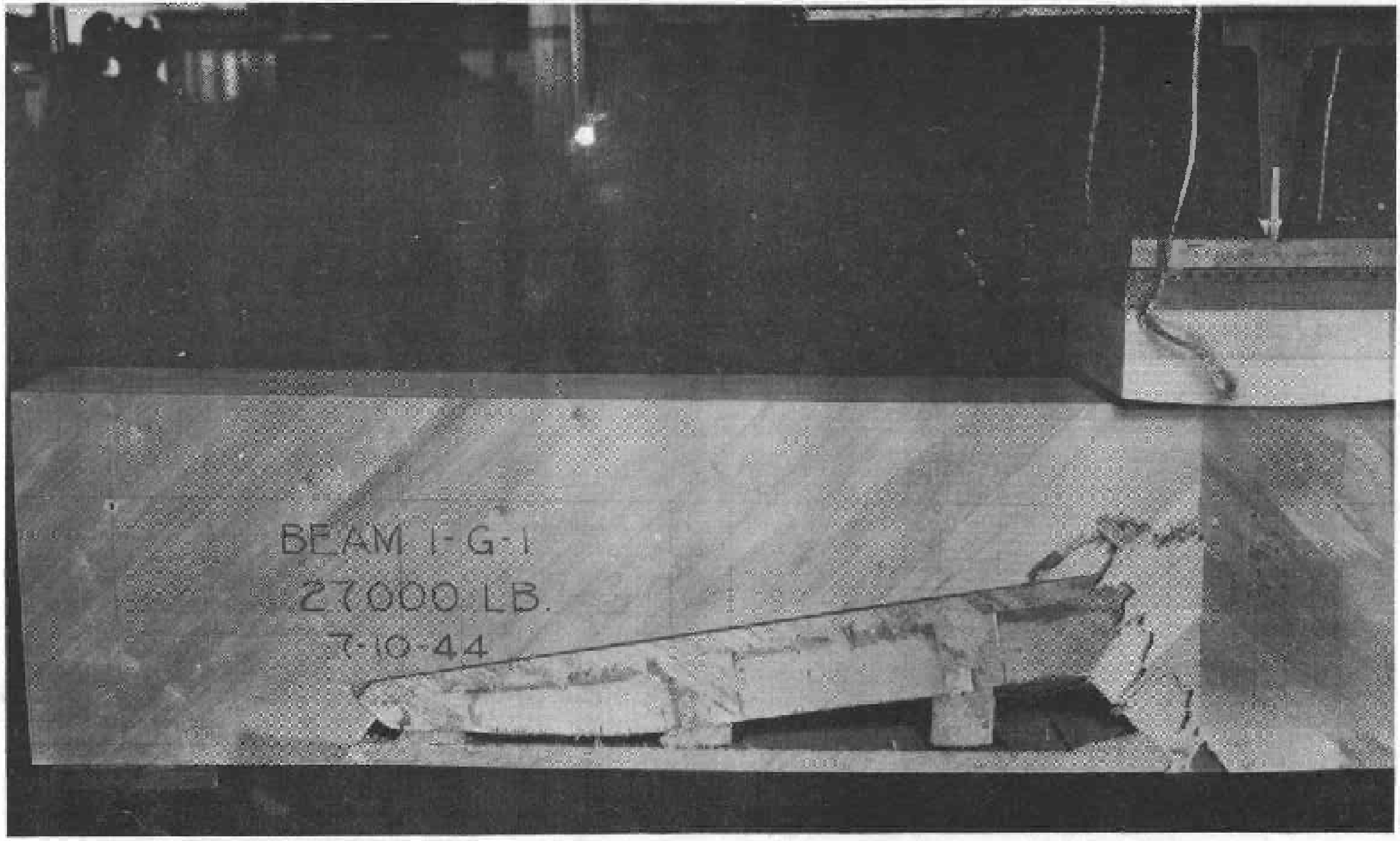

Figure 10.--Box beam 1-G-1 after test with part of the web removed and turned up to show the rolling-shear type of failure in the plywood web.

Z M 64300 F