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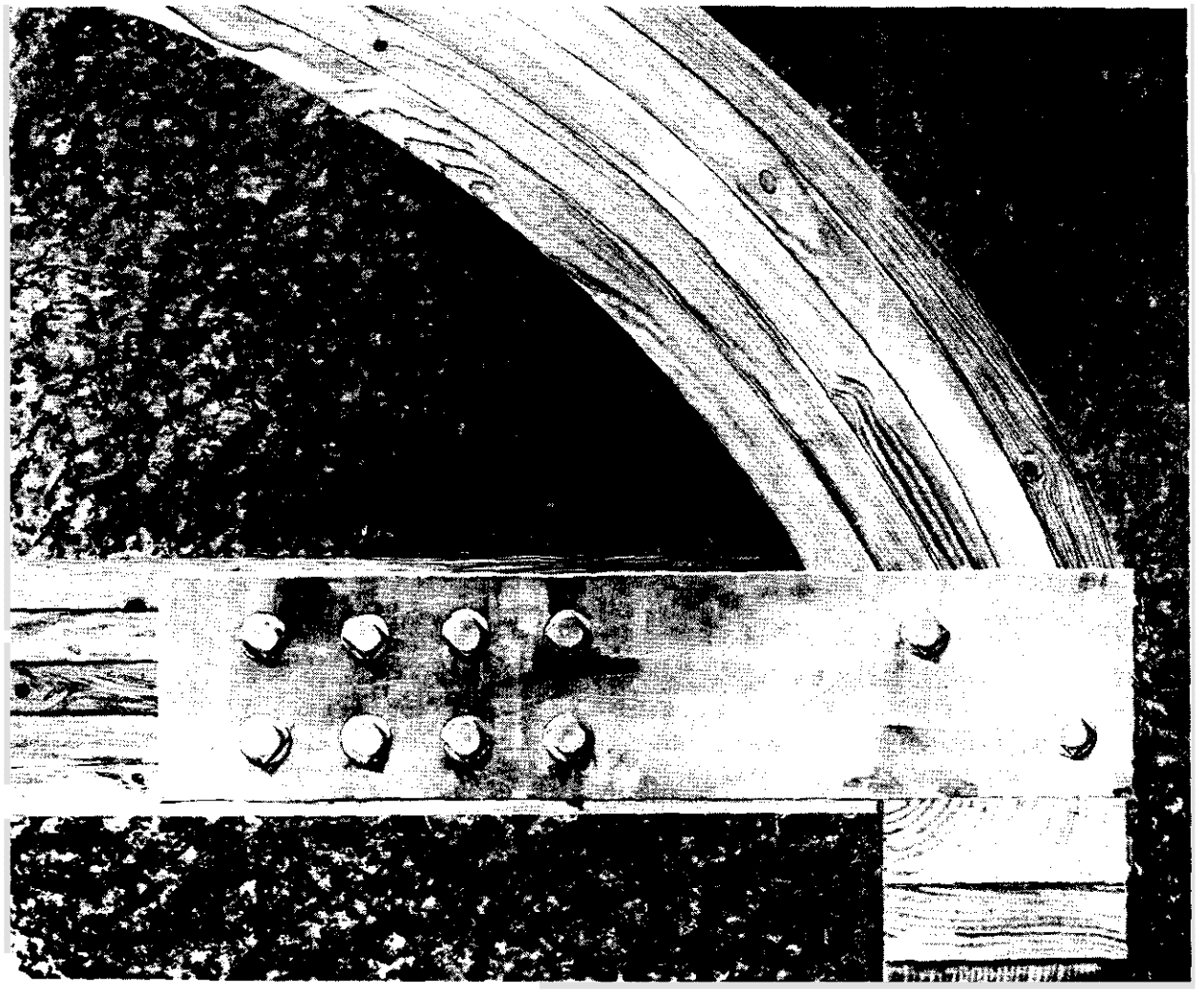
PERFORMANCE OF JOINTS WITH EIGHT BOLTS IN LAMINATED DOUGLAS-FIR



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SUMMARY

The bolt-bearing strength and behavior of joints with two rows of four bolts acting parallel to the grain in 3-1/4- by 7-1/2-inch laminated Douglas-fir members were evaluated for 1/2- and 3/4-inch machine bolts. The study appraised joints with 3 and 4-1/2 inch spacing between bolts, bolts in laminations of high and low density, and bolts in members with taperea end cuts and members with stitch bolts. Comparative data were also obtained for joints with single 1/2- and 3/4-inch bolts in closely matched material.

CONTENTS

PERFORMANCE OF JOINTS WITH EIGHT BOLTS IN LAMINATED DOUGLAS-FIR

BY D. V. DOYLE, Engineer

Forest Products Laboratory,[1] Forest Service
U. S. Department of Agriculture

INTRODUCTION

This report presents the results of research conducted at the Forest Products Laboratory to study the performance of bolted joints that are similar to the gusset plate or tension splice joints used in joining the lower chord members of a timber truss. The joints were three-member assemblies consisting of a 3-1/4- by 7-1/2-inch laminated Douglas-fir member and two steel side plates with two rows of four bolts acting in double shear parallel to the grain of the wood. Joint details commonly associated with truss connections, such as spacing between bolts, size of bolts, bolts in laminations of different density, members with tapered end cut, and stitch bolts, were investigated. Also included in the study were single-bolt tests and compression tests of material closely matched to the individual laminations of the members.

Previous studies[2,3] of bolted joints have, for the most part, been conducted on joints with from one to four bolts bearing in double shear in solid wood members. This study was designed to supplement and expand the information obtained in those studies through evaluation of joints with eight bolts in laminated wood members under tensile load.

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1 Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

2 Trayer, George W. The bearing strength of wood under bolts. U.S. Dept. Agr. Tech. Bull. 332. 40 pp., illus. Oct. 1932.

3 Doyle, D. V., and Scholten, J. A. Performance of bolted joints in Douglas-fir. U.S. Forest Service Research Paper FPL 2. 42 pp., illus. May 1963.

DESCRIPTION OF MATERIALS

The material used in the construction of the specimens was obtained from a local lumberyard, and consisted of 42 Construction Grade S4S Douglas-fir planks, 2 by 8 inches by 16 feet in size. They were graded under Section 123-bof Standard Grading and Dressing Rules No. 15 (March 1956) of the West Coast Lumber Inspection Bureau. Each plank was weighed and its density roughly determined. Thirty pieces were selected from the group for use as test material on the basis of density, position and size of knots.

The bolts were 1/2- and 3/4-inch-diameter by 6-inch-long steel machine bolts with hexagonal heads and nuts.

DESCRIPTION OF SPECIMENS

The bolted joints were similar to the gusset plate or tension splice joint used in fastening the lower chord members of a truss. They were three-member assemblies made up of a 3-1/4- by 7-1/2-inch laminated Douglas-fir member and steel side plates with two rows of four bolts acting in double shear parallel to the grain of the wood.

The laminated wood members were made up of five 1-1/2- by 3-1/4- by 94-1/4-inch Douglas-fir laminations with four bolts positioned along each of the second and fourth laminations (fig. 1). The side members were 1/2- by 6-inch steel plates with hardened-steel inserts at the boltholes. The joints were assembled with 3/4- and 1/2-inch bolts. The bolts in all specimens were placed at an end distance of 5-1/4 inches and spaced 3 inches apart in each row, except in one series with each bolt size the spacing was 4-1/2 inches. New bolts were used in each test. Steel side plates were also attached at the opposite end of each laminated member with shear plates and bolts to provide a means of applying a tensile load to the joint.

The specimens were grouped into eight series, identified as A through H (fig. 1). Three specimens of a kind, numbered 1, 2, and 3, were included in each series. The specimens in series A were constructed with end distances, side margins, bolt spacing, and net section area conforming to the requirements[4] for joints with 3/4-inch bolts. The specimens in all other series were similar to those in series A, except for certain construction details, namely: Specimens in series A through E were made with 3/4-inch bolts and series F through H with 1/2-inch bolts; series B and G had a spacing of 4-1/2-inches between bolts; series C had a 1/2- by 8-inch stitch bolt at an end distance of 3-1/4 inches; series D and H had bolts in laminations of different densities; and series E had an angular end cut of 30° with the laminations.

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[4] National Lumber Manufacturers' Association. Washington. D.C. National design specification for stress-grade lumber and its fastenings. 64 pp., illus. 1962 Edition.

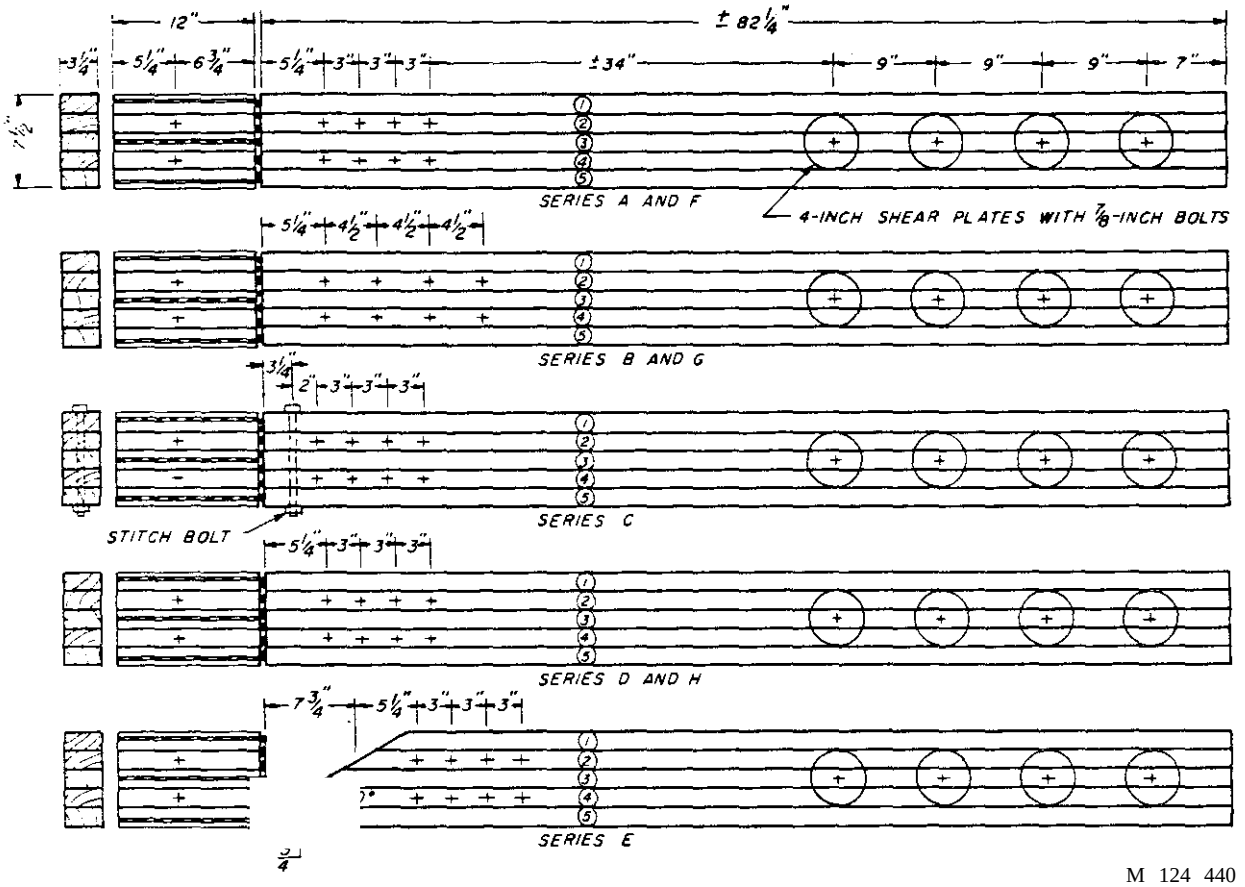

Figure 1.--Construction details for specimens with bolts in laminated members. Series A through E have 3/4-inch bolts and series F through H have 1/2-inch bolts. Stitch bolts in series C are 1/2- by 8-inch machine bolts. The encircled numbers on the specimens indicate the lamination number. In series D and H the No. 2 laminations are of higher density and the No. 4 laminations of lower density than the average. Four 4-inch shear-plate connectors on each face with four 7/8-inch bolts are used to apply the test load to the specimens. A section cut from the end of each laminated member furnished two single bolt control specimens.

CONSTRUCTION OF SPECIMENS

The laminated wood members were constructed of five laminations which provided a means of matching the material among individual specimens. The 2- by 8-inch by 16-foot Douglas-fir planks were quartered into 2- by 4-inch by 8-foot pieces and the individual pieces assigned a particular location in the laminated members in accordance with the cutting diagram illustrated in figure 2. In the selection of the second and fourth laminations of all members, an attempt was made to provide reasonably clear wood in the area to be occupied by the bolts. The heaviest and the lightest planks of the group were incorporated in the members of series D and H so that each row of four bolts would bear in laminations of comparatively high and low density, respectively.

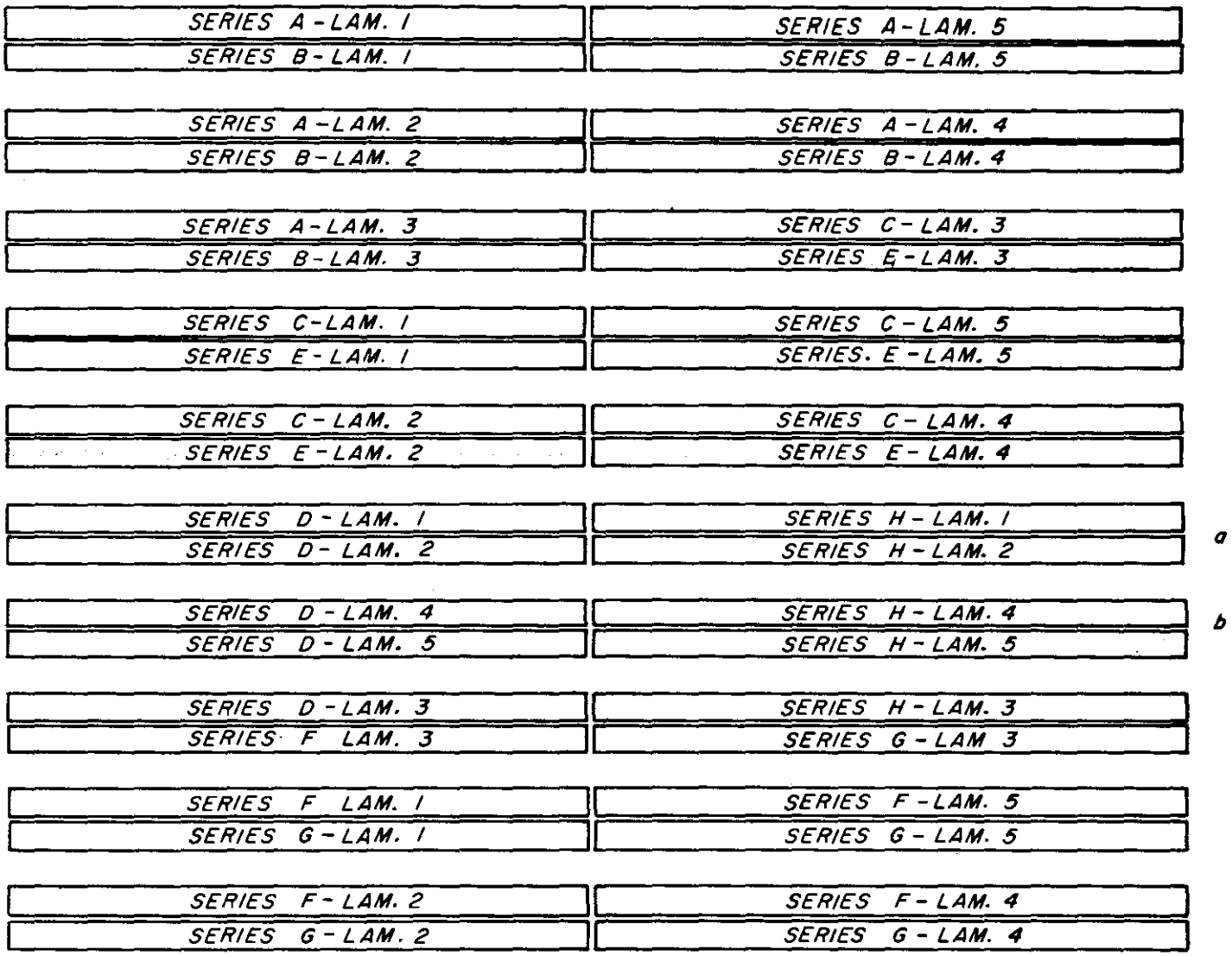

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Figure 2.--Diagram showing scheme used in cutting andmatching the 2– by 8–inch by 16–foot Douglas–fir planks used in construction of the laminated members. Plank "a" was in the high density range and plank "b" in the low range of density for the species. All other planks were in the approximate intermediate range of density. The four pieces cut from each plank were incorporated in the laminated members in accordance with the construction details shown in figure 1.

After the planks were quartered, the individual pieces were open–piled in a controlled atmospheric condition of 75° F. and 63 percent relative humidity until representative pieces had attained a relatively constant weight. All pieces were then surfaced to 1–1/2 inches in thickness and the laminated members assembled and glued in accordance with the arrangement given in figure 2. After the glue had set, the members were surfaced on their wide faces to a thickness of 3–1/4 inches. A section12 inches in length was cut from the joint end of each laminated member and made into two 3–1/4– by 3–1/4–inch single–bolt control specimens. The control specimens, identified as Nos. a–2 and a–4 in

series A and similarly through series H, were centered about the second and fourth laminations. Photographs of the ends of the specimens (figs. 12 to 15) are included in Appendix A to show the difference in growth rate and position of annual rings. The laminated members were drilled for four bolts in each of the second and fourth laminations, respectively, at an end distance of 5-1/4 inches and spaced as shown in figure 1. They were also drilled and dapped at the opposite end for four 4-inch shear-plate connectors on each face and 7/8-inch bolts. In the single-bolt specimens, the holes were drilled through the second and fourth laminations at an end distance of 5-1/4 inches (fig. 1).

All boltholes in the laminated members and the single-bolt specimens were drilled 1/16 inch larger than the bolt diameter with a wood bit at a speed of 475 r.p.m. and a feed of 0.004 inch per revolution. The boltholes in the hardened steel inserts of the steel side plates were also 1/16 inch larger than the bolt diameter. All holes in the laminated members were accurately positioned and alined with the holes in the steel plates.

EXPERIMENTAL PROCEDURE

The laminated members were loaded in tension with the bolts bearing parallel to the grain of the second and fourth laminations, as shown in figure 3. The fittings at the upper end of the specimen, consisting of eight shear plates and two steel side plates, were bolted to the member and the assembly hung in the testing machine. The steel side plates were then bolted to the lower end of the member. The nuts were tightened with a wrench, then loosened and made finger-tight. This assembly procedure assured that the bolts were in initial bearing from the weight of the attachments when the test loading was begun.

The slip in the bolted joint between the lower steel side plates (fig. 3) and the laminated member was measured with dial gages, graduated to 0.001 inch, after an initial load of 1,000 pounds was placed on the specimen. The movable crosshead of the testing machine was driven at a rate of 0.028 inch per minute, and readings of joint slip were taken at 2,000-pound load increments. Upon completion of the tests, a specimen for determining moisture content and specific gravity was cut from each lamination. A 1- by 1- by 4-inch specimen for determining the compression-parallel-to-the-grain properties of the wood was also cut from the second and fourth laminations.

Measurement of Strain

Strains were measured at two locations on each of five specimens by measuring the strain at each load increment during test with electrical-resistance type strain gages, bonded to the specimen. The strain gages were oriented parallel and perpendicular to the grain and on laminations with and without bolts, as shown in figure 4. Upon completion of the bolted-joint tests, a section of the lamination, 1-1/2 by 3-1/4 by 6 or 8 inches in length, with the strain gage located at its approximate midsection, was cut from the members. These specimens were later loaded in compression parallel to

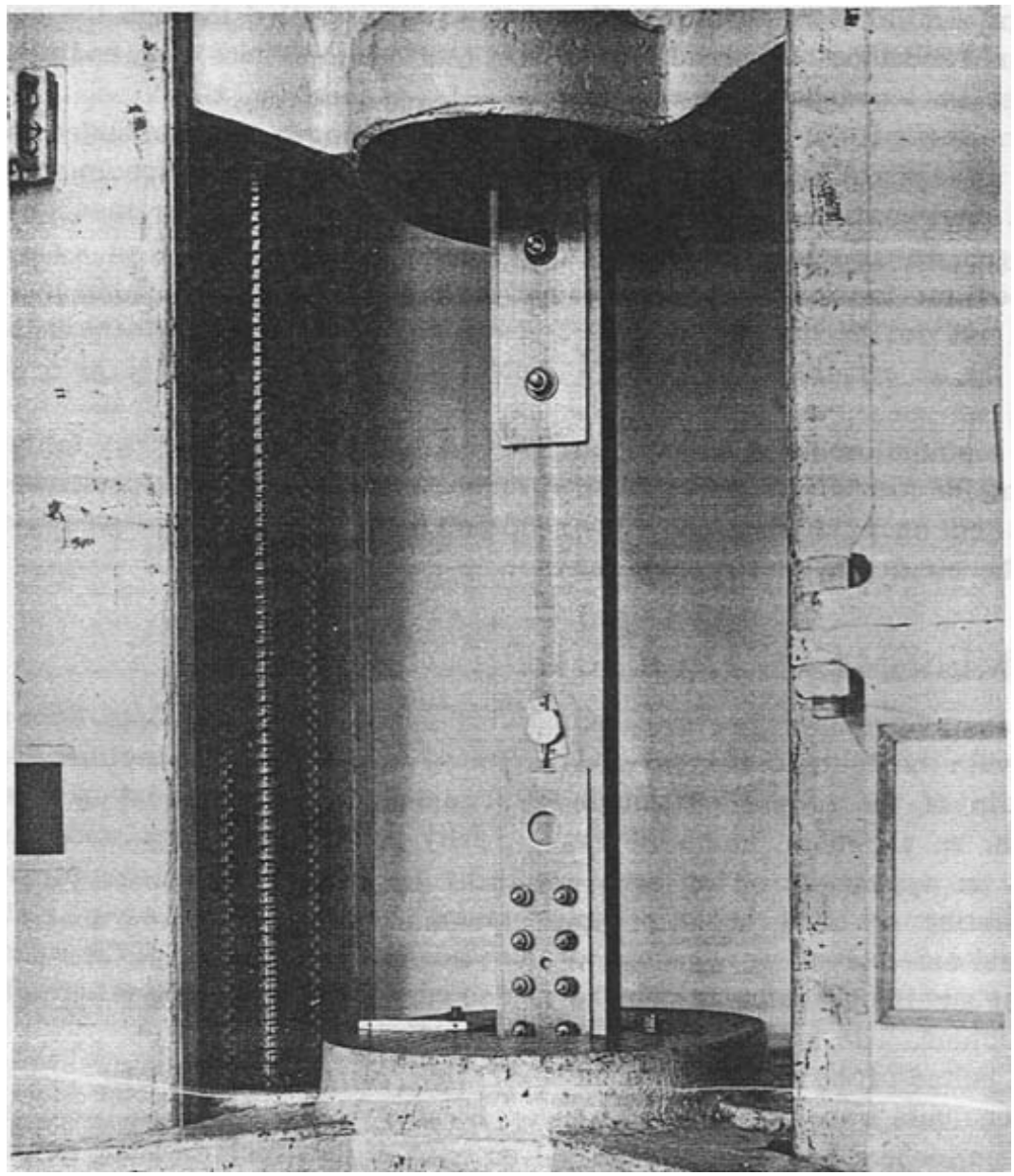

Figure 3.--Experimental setup for a joint with eight bolts. The joint was loaded in tension and the slip between the laminated wood member and steel side plates was measured with dial gages. M 120 134

the grain, and the stress–strain relationship was determined by measuring the strain, with the same gage, at each 1,000–pound increment of load. The data obtained provided a basis for studying the elastic behavior of the material during the loading of the bolted joints.

Single-Bolt Control Specimen

The single–bolt control specimens were tested under a compressive load (fig. 5). Steel side plates, 1/2 by 4 by 12 inches in size, with hardened–steel inserts were bolted to each specimen and the nut made finger–tight. The movable

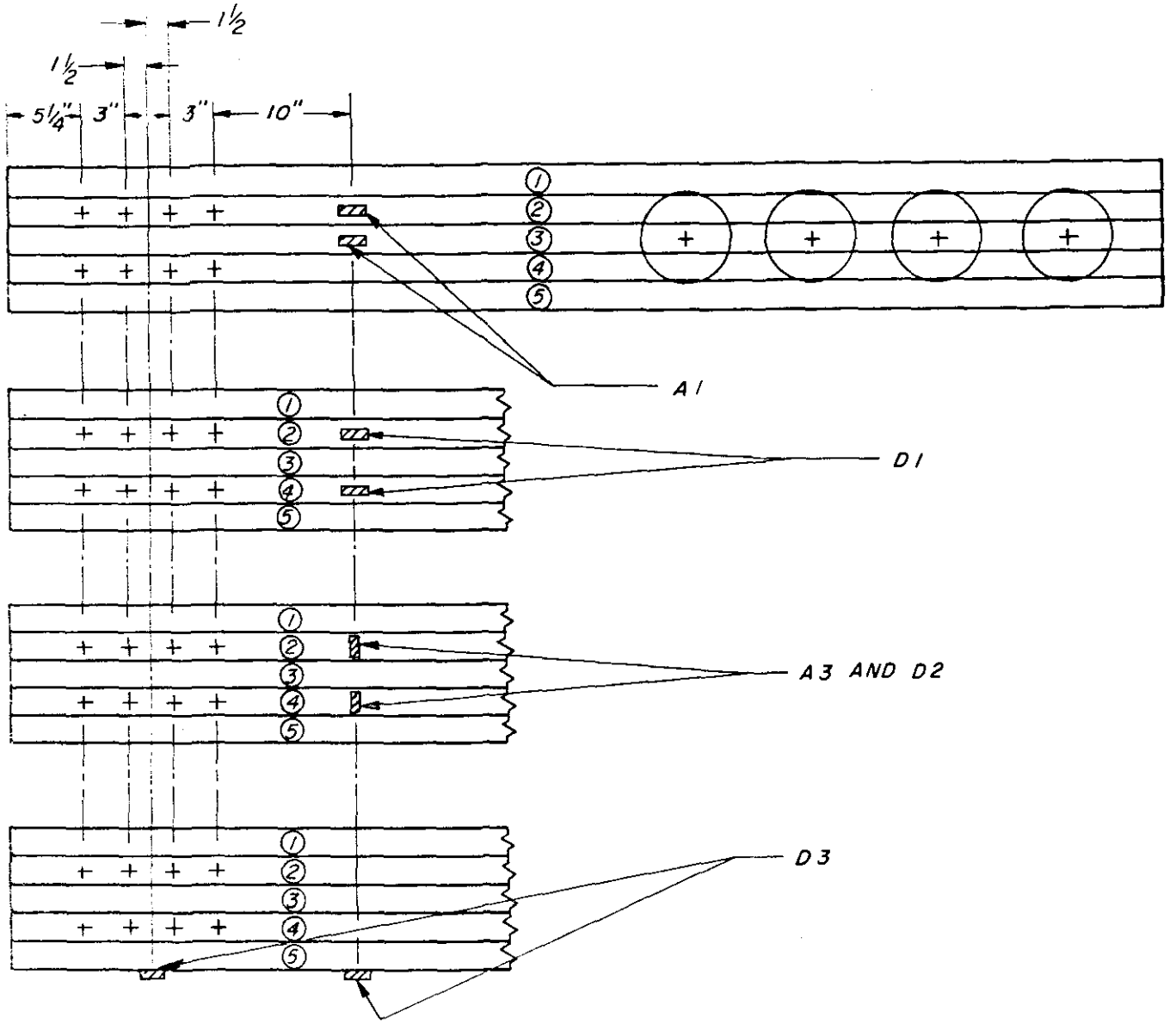

Figure 4.--Sketch showing location of strain gages on laminated Douglas-fir specimens Nos. A1, A3, D1, D2: and D3. In the specimen number, the letter designates the series and the numeral designates the number of the test in the series.

crosshead of the testing machine was driven at a rate of 0.032 inch per minute. The specimens were preloaded to 200 pounds to assure firm bearing of the test apparatus prior to the application of the test load. The slip in the joint was measured automatically with an electro-mechanical deformationgage, that transfers deformations to a linear-differential transformer coupled to a chart recorder so that load deformation curves are obtained directly.

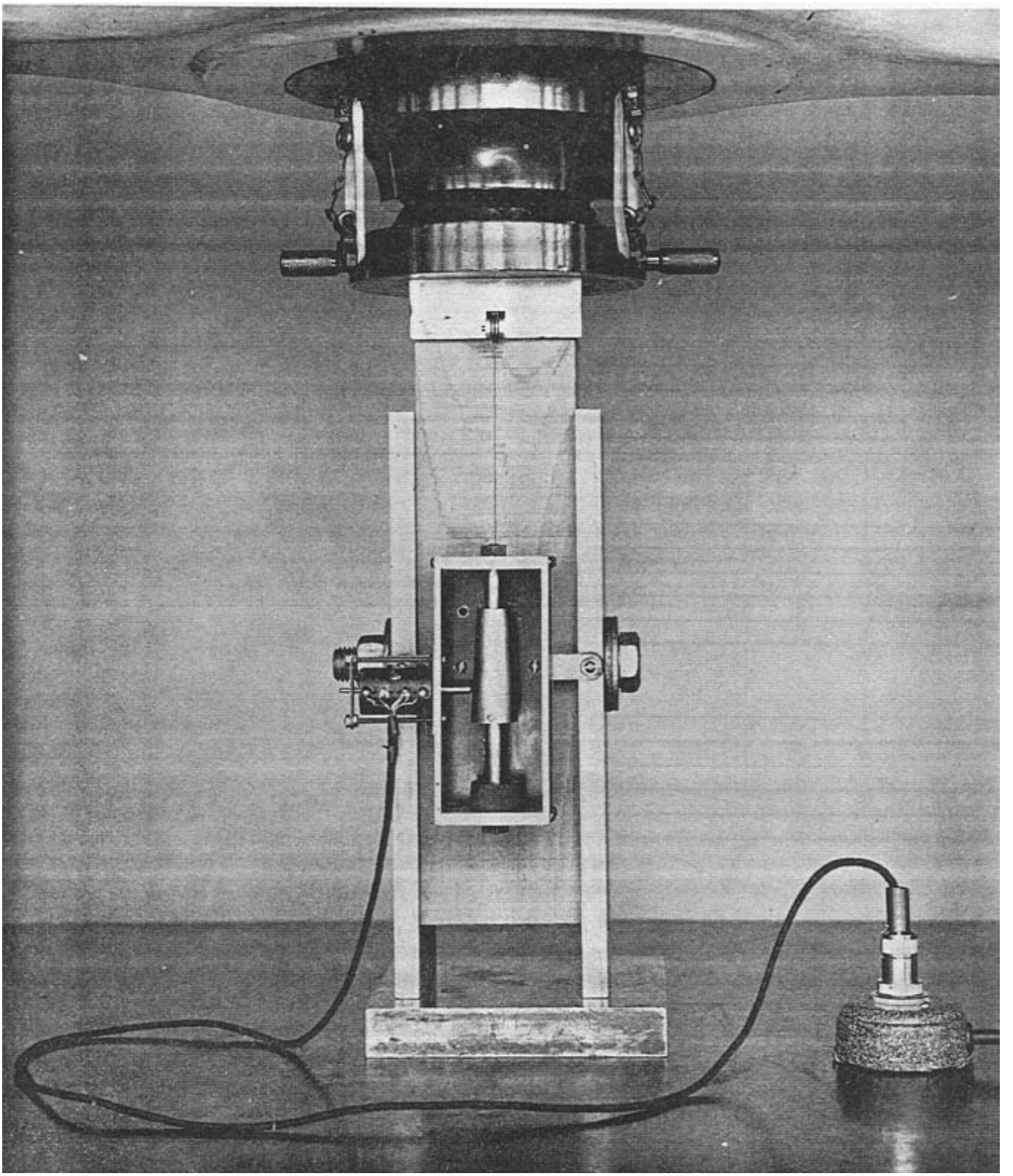

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Figure 5.--Experimental setup for joint with a single bolt showing electromechanical device for measuring slip.

DISCUSSION OF RESULTS

The results of the bolt-bearing study with 1/2- and 3/4-inch bolts are presented in table 1 and figures 6 and 7. The values listed in the table are the values obtained in test, divided by the number of bolts in the joint, and are the average values obtained from three eight-bolt and six single-bolt specimens of a kind. The joint load-slip curves (figs. 6 and 7) were plotted from these values. The results obtained from the individual specimens are presented in tables 3 to 10 in Appendix A.

Comparison of Eight-Bolt and Single-Bolt Joints

The eight-bolt joints are compared on a per bolt basis with their matched single-bolt joints in columns 14 and 15 of table 1. At the proportional limit these data show that the eight-boltjoints have a bearing stress of 94 to 107 percent that of the single-bolt joints when 3/4-inch bolts are used, and from 103 to 124 percent when 1/2-inchbolts are used. These percentages are more or less approximate as the load-slip curves obtained in the tests with the eight-bolt joints were somewhat irregular and did not all show a well defined proportional limit. It is possible that greater frictional resistance in the eight-bolt joints caused these joints to show more pronounced irregularity of the load-slip curves than the joints with single bolts, and also that part of the load recorded at the proportional limit of the eight-bolt joints resulted from frictional resistance in the joints. The ultimate bearing stress per bolt of the joints with eight bolts was from 61 to 78 percent that of the single-bolt joints with 3/4-inch bolts, and from 79 to 93 percent with 1/2-inch bolts. The lower ultimate bearing stress associated with the joints with eight bolts indicates that factors such as splitting, shear along the grain, tension both parallel and perpendicular to the grain, and possibly non-uniform bearing of all bolts influenced failure before the ultimate bearing strength of the wood was attained. Specimens C2 and G3 failed in tension at the shear plate connector joint (figs. 8 and 9). The results of all tests except those of specimen G3 were included in the summary of test results (table 1), even though a few of the specimen failures were not directly associated with the bolted joint. Specimen G3 also showed very little joint slip throughout the test. Specimen C2 gave a load-slip curve somewhat similar to those of the other specimens in the series and was included in the summary.

A comparison of the bolt-bearing characteristics of joints with one and eight bolts is also shown by the load-slip curves for 3/4-inch bolts (series A through E) in figure 6 and for 1/2-inch bolts (series F through H) in figure 7. The curves show that the joints with single bolts gave higher loads for a given slip than the joints with eight bolts, the difference being greater for 3/4- than for 1/2-inch bolts, probably because the 1/2-inch bolts were less stiff and came into more uniform bearing at lower loads than did the 3/4-inch bolts. In general, the load-slip curves of the eight-bolt joints with different construction variables all followed the same general pattern, and the variation between the individual curves was generally no greater than the variation shown by the

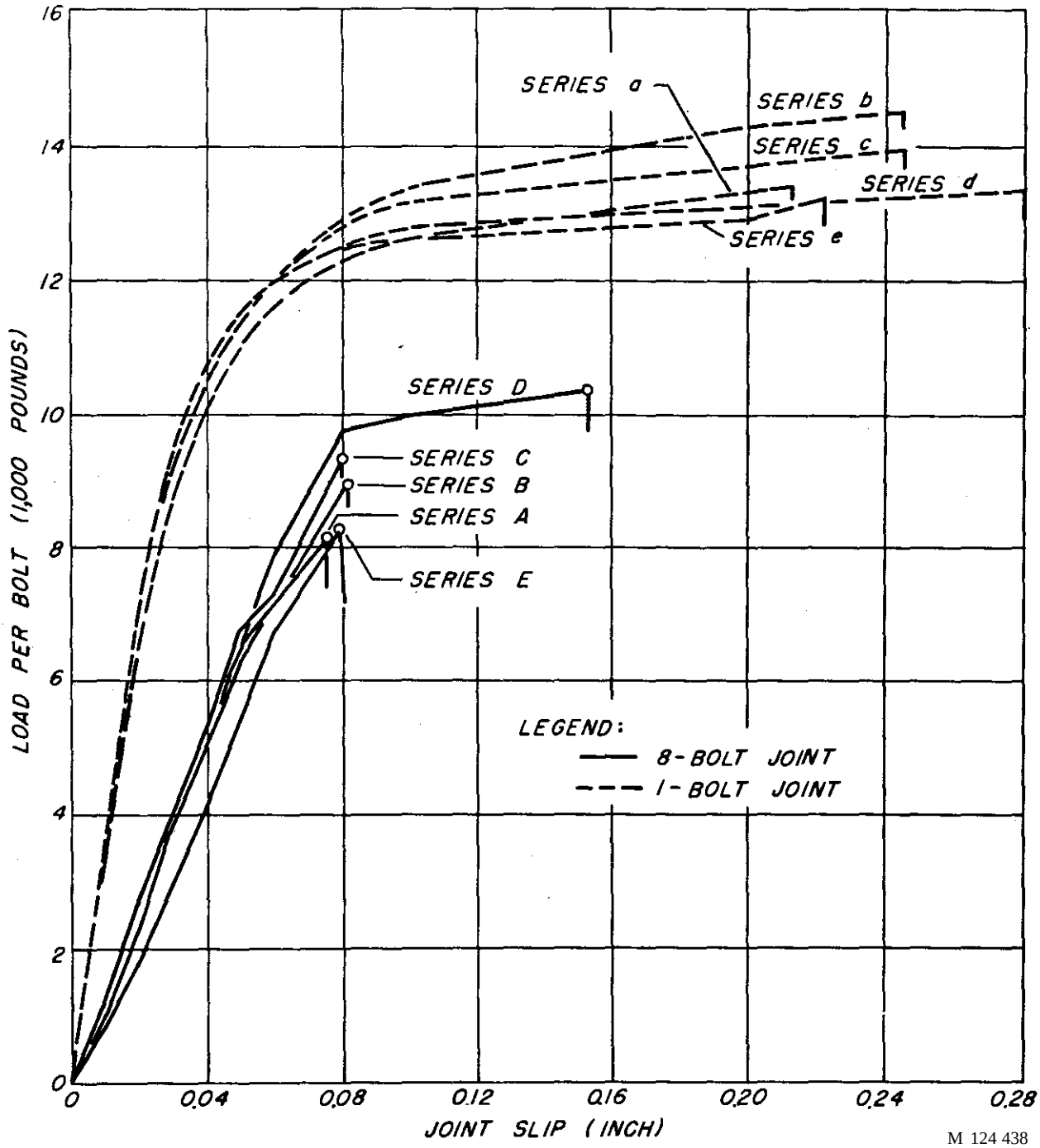

Figure 6.--Load-slip curves for five series of joints with eight 3/4-inch bolts in laminated Douglas-fir members (series A through E) and their matching single-bolt control joints (series a through e). The curves are composite load-slip curves derived from tests of three specimens of a kind for the eight-bolt joints and six specimens of a kind for the one-bolt joints: Series A, 3-inch bolt spacing; B, 4-1/2-inch bolt spacing; C, stitch bolts; D, difference in densities; and E, tapered end.

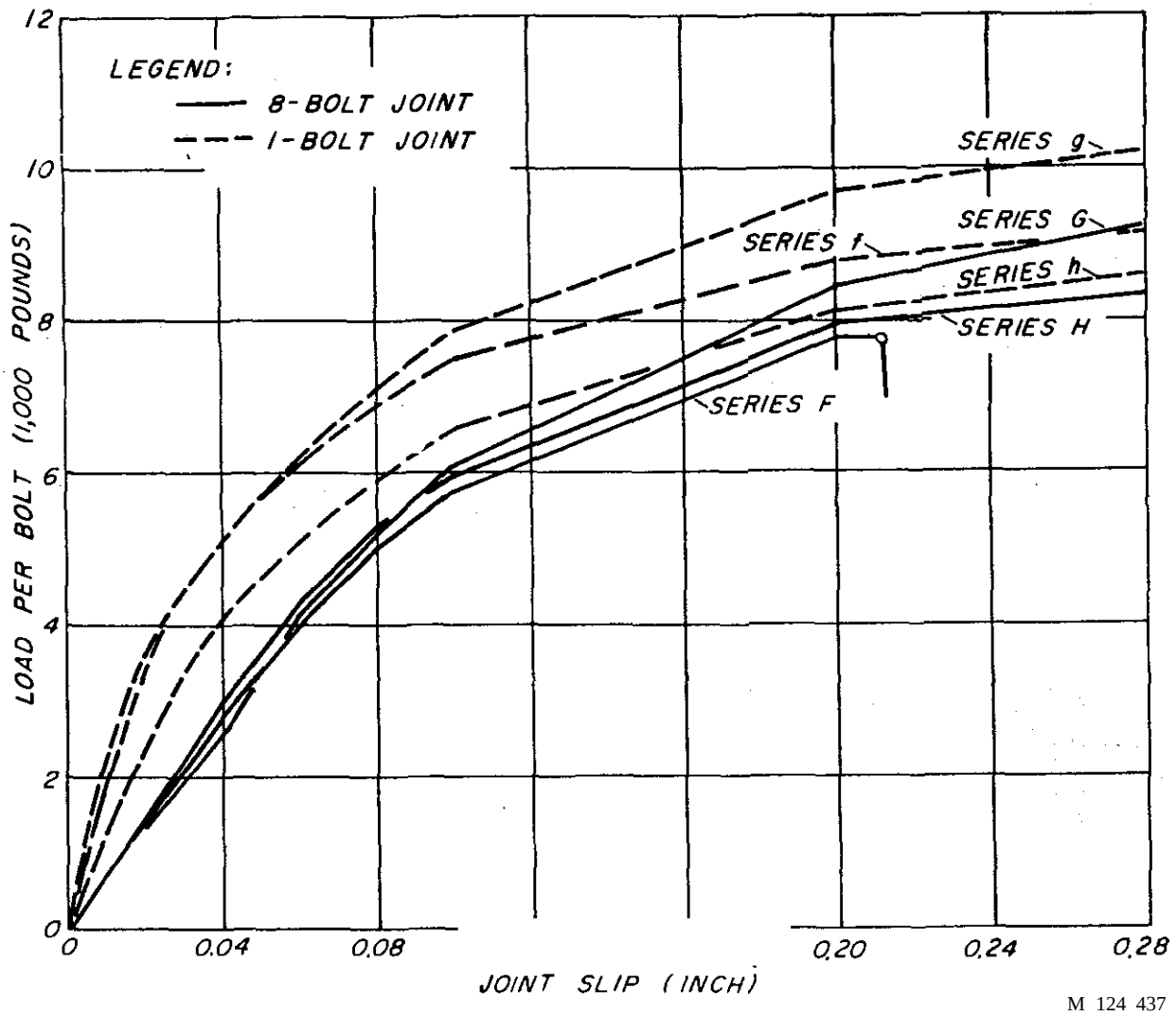

Figure 7.--Load-slip curves for three series of joints with eight 1/2-inch bolts in laminated Douglas-fir members (series F through H) and their matching single-bolt control joints (series f through h). The curves are composite load-slip curves derived from tests of three specimens of a kind for the eight-bolt joints and six specimens of a kind for the one-bolt joints: Series F, 3-inch bolt spacing; G, 4-1/2-inch bolt spacing; and H, difference in densities.

load–slip curves of joints with one bolt.

Joint Slip

The joint slip at the proportional limit with both 1/2– and 3/4–inch bolts was about 0.02 inch for the single–bolt joints and about 0.04 inch for the eight–bolt joints. This difference in behavior of joints with single and eight bolts reflects the amount of movement necessary to bring the eight bolts into bearing. At ultimate load the joint slip was about 0.24 inch for the single–bolt joints and about 0.09 inch for the eight–bolt joints when 3/4–inch bolts were used and about 0.48 inch for single–bolt joints and about

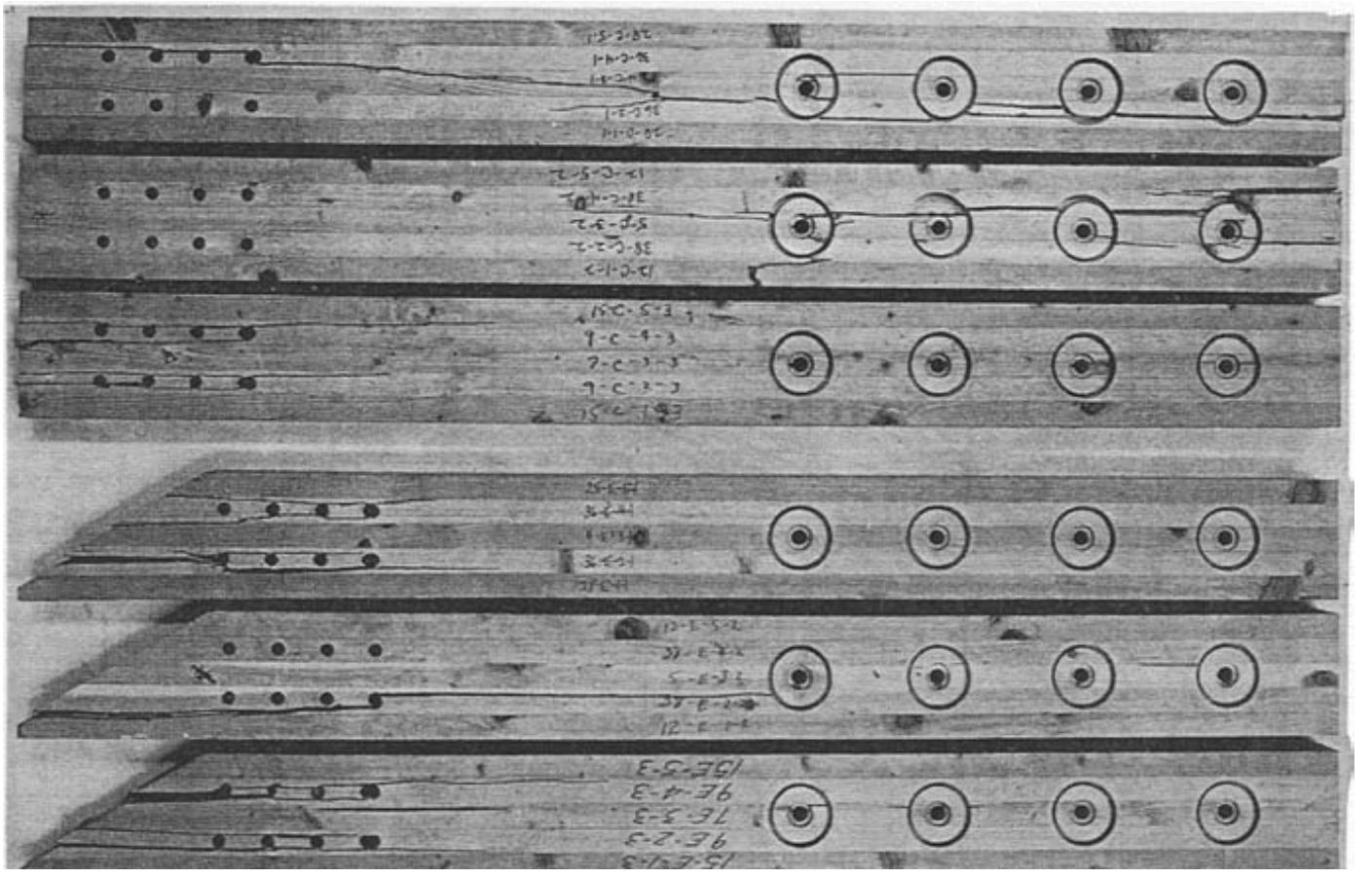

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Figure 8--Joints with eight 3/4-inch bolts after test. The upper three are series C specimens (1/2-inch stitch bolt) and the lower three are series E specimens (tapered end cut). The stitch bolts were removed before photograph was taken. The end distance in all tests was 5-1/4 inches except that for one row of bolts in series E, the end distance was greater than 5-1/4 inches.

0.29 inch for eight-bolt joints when 1/2-inch bolts were used. The difference in the amount of slip between the single and eight-bolt joints at ultimate load gives further indication that failure of the eight-bolt joints occurred before the ultimate bearing stress of the wood was attained.

The initial slip which occurred in a joint while the bolts were coming into firm bearing was, for the most part, nonelastic in nature. Prior to the start of the tests, a small initial load was applied to the joint with the testing machine and by the weight of the attachments. The nonelastic slip (data in tables 3 to 10 of Appendix A) ranged from zero to 0.01 inch, with an average of about 0.002 inch for the joints with one bolt, and from zero to 0.02 inch, with an average of about 0.004 inch, for the joints with eight bolts. The nonelastic portion of the load-slip curves filleted into the elastic portion of the curves at an average slip of about 0.003 inch for the joints with one 1/2- and 3/4-inch bolt, and about 0.011 and 0.017 inch for the joints with eight 1/2- and 3/4-inch bolts. The joints with tapered end cut (series E) showed greater nonelastic slip than the joints of the other series.

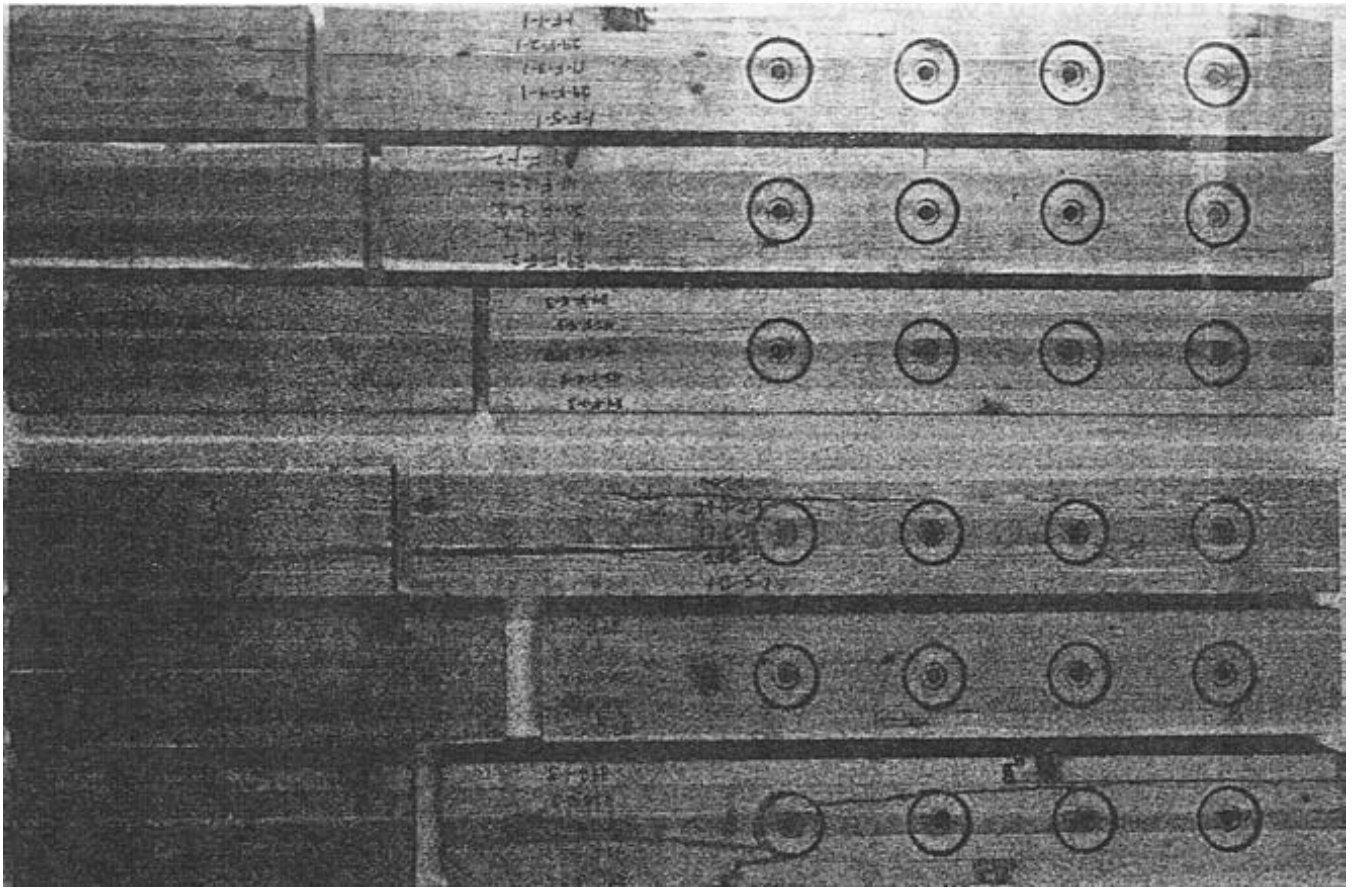

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Figure 9.--Joints with eight 1/2-inch bolts after test. The upper three are series F specimens (3-inch spacing between bolts) and the lower three are series G specimens (4-1/2-inch spacing between bolts). The end distance in all tests was 5-1/4 inches.

Effect of Construction Variables

The bearing stress at the proportional limit and at ultimate of the joints with 3/4-inch bolts in series B through E are compared in columns 16 and 17 of table 1 with those of series A (the joints with 3/4-inch bolts and constructed in accordance with specification requirements [4]). Series A was taken as 100 percent. These data indicate that for the most part the bolt-bearing properties of the joints with the different construction variables did not differ greatly from those of series A. The joints in series D (with 3/4-inch bolts in laminations of different density) exhibited the greatest increase in maximum bearing stress over the control joint, but this difference may not be significant in view of the wide spread in values obtained for the individual specimens (tables 6 and 10, Appendix A). The bearing stress properties of the joints with 1/2-inch bolts in series F through H are also compared with those of series A to illustrate the effect of variations in their construction. These data with 1/2-inch bolts show that the bolt-bearing stress at the proportional limit of the joints with different construction variables did not vary greatly from one another, but the bearing stress at ultimate was somewhat greater for the joints of series G (4-1/2-inch bolt spacing) and

series H (laminations of different density) than the joints in series F (3–inch bolt ,spacing). The bolt–bearing properties of the single–bolt joints of series B through H are also compared in a similar manner with those of series A (columns 16 and 17 of table 1). These data provide a measure of the variation in bearing stress and should be considered along with the data for the joints with eight bolts when comparing the effects of construction variables.

Comparison of Bolt- Bearing Properties and Compressive Properties of Wood

A comparison of the bolted joints is also given by the relationship of the bearing strength properties to the compression-parallel-to-the-grain properties of the wood in columns 18 to 20 in table 1. Column 18 lists the relationship of the bearing strength at the proportional limit to the proportional–limit crushing strength of the wood, as obtained from the small clear specimens cut from the laminations. These data show that this relationship is about 60 percent for the single– and eight–bolt joints with 3/4–inch bolts and about 45 percent for the single–bolt and 50 percent for the eight–bolt joints with 1/2–inch bolts. Column 19 lists the relationship of the maximum bearing strength to the maximum crushing strength of the wood. These data show that this relationship is about 80 and 90 percent, respectively, for the joints with single 3/4– and 1/2–inch bolts and about 55 and 75 percent, respectively, for the joints with eight 3/4– and 1/2–inch bolts. Column 20 lists the relationship of the bearing strength at the proportional limit to the maximum crushing strength of the wood. These data show that the relationship for joints with single and eight bolts is about 35 percent for 3/4–inch bolts and about 30 percent for 1/2–inch bolts. In previous studies[2] with single bolts of similar size with four species of wood, the relationship of the bearing strength at the proportional limit to the maximum crushing strength was about 50 and 33 percent, respectively.

Strain Distribution

The results of a small exploratory study to investigate the strain distribution in five laminated bolted specimens (figs. 4, 10, and 11) are listed in table 2. Also listed in the table are the strains obtained for control specimens which were cut from the bolted specimens. The results show that at a stress chosen below the proportional limit of 1,960 pounds per square inch (chosen as one being below the proportional limit in all tests), the strain measured parallel to the grain of laminations with and without bolts, at points 10 inches above the fourth row of bolts, was approximately the same in all laminations. They also show that the strains measured on the bolted specimens were in reasonably close agreement with those obtained at the same stress on the control specimens. These data show that while stresses may be concentrated at the bolt-holes, they are about uniformly distributed at a point 10 inches above the bolts. In general, stress and strain at ultimate for the bolted specimens were roughly one half those obtained in the control specimens.

The strain at a given stress measured on the narrow face of bolted specimen D3 at a point 10 inches above the fourth row

Table 1.--Summary of results with bolts bearing parallel to the grain in laminated Douglas-fir members

Specimen group description	No. of bolts[1]	Specimen type[2]	Average specific gravity[3]	Average joint strength: Proportional limit: Load	Proportional limit: Slip	Ultimate: Load	Ultimate: Slip	Average bearing stress[4]: Proportional limit	Average bearing stress[4]: Maximum	Average crushing strength[5]: Proportional limit	Average crushing strength[5]: Maximum	Average crushing strength[5]: Modulus of elasticity	Ratio of bearing stress, 8-bolt joint/1-bolt joint: Proportional limit	Ratio of bearing stress, 8-bolt joint/1-bolt joint: Maximum	Ratio of bearing stress of joints to series A joints: Proportional limit	Ratio of bearing stress of joints to series A joints: Maximum	Ratio of bearing stress to crushing strength: col. (9)/col. (11)	Ratio of bearing stress to crushing strength: col. (10)/col. (12)	Ratio of bearing stress to crushing strength: col.(9)/col. (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
				Lb.	In.	Lb.	In.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	Percent	Percent	Percent	Percent	Percent	Percent	Percent
JOINTS WITH 3/4-INCH BOLTS (L/d=4-1/3)																			
Boltspacing 3 inches	1	a	0.48	5,580	0.016	13,350	0.213	2,280	5,460	4,180	6,600	1,930					55	83	34
	8	A[6]	.48	5,750	.045	8,110	.075	2,360	3,320				103	61			56	50	36
Boltspacing 4-1/2 inches	1	b	.52	6,270	.017	14,480	.246	2,570	5,940	4,230	7,430	2,460			113	109	61	80	35
	8	B	.48	6,500	.049	8,990	.082	2,660	3,690				103	62	113	111	63	50	36
Stitch bolts	1	c	.50	6,130	.017	13,930	.247	2,510	5,710	3,500	6,760	2,156			110	105	72	84	37
	8	C	.49	6,080	.041	9,640	.080	2,490	3,950				99	69	106	119	71	58	37
Laminations of high and low density	1	d	.50	6,130	.017	13,320	.282	2,500	5,440	4,400	6,880	1,891			110	100	57	79	36
	8	D	.50	6,550	.043	10,350	.153	2,680	4,230				107	78	114	127	61	61	39
Tapered end cut	1	e	.49	6,600	.019	13,180	.222	2,700	5,390	4,590	6,940	2,128			118	99	59	78	39
	8	E	.47	6,210	.043	8,290	.079	2,540	3,400				94	63	108	102	55	49	37
Average	1		.50	6,140	.017	13,650	.243	2,510	5,590	4,180	6,920	2,113					61	81	36
Average	8		.48	6,220	.044	9,080	.094	2,550	3,720				101	67			61	54	37
JOINTS WITH 1/2-INCH BOLTS (L/d=6-1/2)																			
Boltspacing 3 inches	1	f	.48	2,830	.014	9,800	.477	1,740	6,010	3,910	6,180	2,009			76	110	44	97	28
	8	F	.49	3,500	.049	7,730	.212	2,150	4,740				124	79	91	143	55	77	35
Boltspacing 4-1/2 inches	1	g	.52	3,170	.018	12,130	.552	1,940	7,440	5,340	8,070	2,620			85	136	36	92	24
	8	G	.51	3,630	.046	10,520	.441	2,230	6,470				115	87	95	195	42	77	28
Laminations of high and low density	1	h	.51	3,220	.029	9,330	.398	1,980	5,730	3,750	6,810	2,019			87	105	53	84	29
	8	H	.51	3,330	.043	8,630	.327	2,050	5,310				103	93	87	160	55	78	30
Average	1		.50	3,070	.020	10,420	.476	1,890	6,390	4,330	7,020	2,216					44	91	27
Average	8		.50	3,490	.046	8,960	.327	2,140	5,510				114	85			51	77	31

[1] All values for single-bolt joints are the average of 6 tests. Values for the 8-bolt joints are the values obtained in test divided by the number of bolts, and are the average of 3 tests except for series G which included only 2 tests.

[2] The cross section of the single-bolt specimens was 3-1/4 by 3-1/4 inches, and for the 8-bolt specimens was 3-1/4 by 7-1/2 inches. The end distance in all specimens was 5-1/4 inches.

[3] Specific gravity based on ovendry weight and volume. Values listed for single-bolt joints are the average values for the laminations containing the bolts. Values for the multi-bolt joints are the average values of all the laminations in the specimens.

[4] Average bearing stress is the joint strength divided by the area under bolts.

[5] Compression parallel-to-grain properties were obtained from tests of 1- by 1- by 4-inch specimens that were cut from the laminations holding the bolts.

[6] The 8-bolt joints of series A were constructed in accordance with the requirements of the National Design Specifications for Stress Grade Lumber and Its Fastenings.

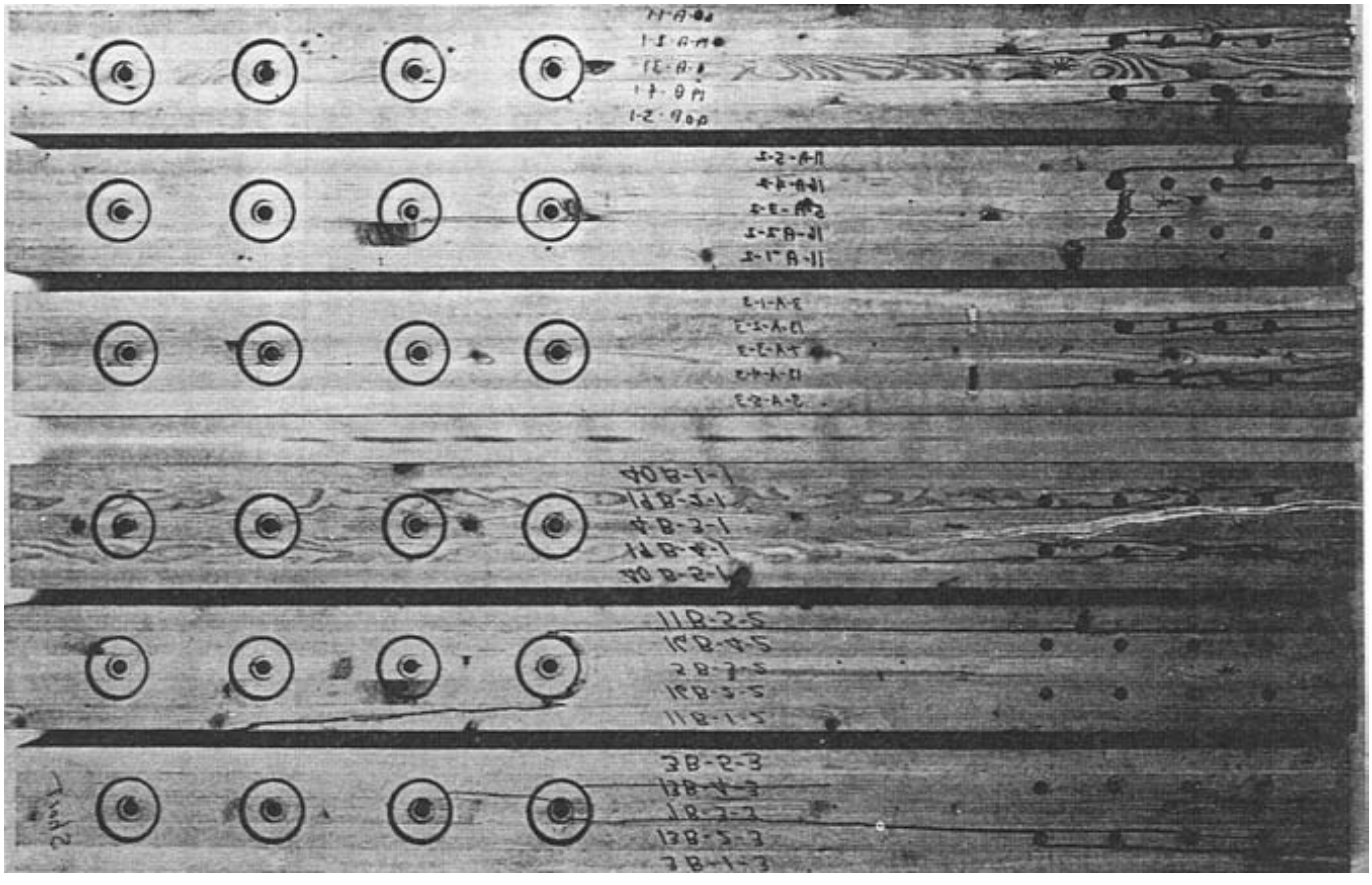

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Figure 10.--Joints with eight 3/4-inch bolts after test. The upper three are series A specimens with 3-inch spacing between bolts and the lower three are series B specimens with 4-1/2-inch spacing between bolts. End distance in all tests was 5-1/4 inches.

of bolts (figs. 4 and 11) was about double that measured on the same face of the member midway between the second and third row of bolts. This indicates that the bolts in the joint were carrying their proportionate share of the load.

The strain gages bonded perpendicular to the grain of the second and fourth laminations of bolted members A3 and D2 recorded compressive strain across the grain while a tensile stress was being applied along the grain, thus conforming to the principles of Poisson's ratio. This shows that the bolts produced little, if any, outward lateral force and that stitch bolts such as those used in series C may not be subjected to load. The elastic properties computed from the average data listed in columns 7 and 10 of table 2 give values of modulus of elasticity (E_L) of 2,200,000 and 2,420,000 pounds per square inch, and values of Poisson's ratio (μ_{LR}) of 0.28 and 0.34 respectively. These values are in close agreement with results of previous studies of Douglas-fir[5] that gave average values of E_L of 2,280,000 pounds per square inch and μ_{LR} of 0.29.

Joint Failures

The failures that resulted in the individual laminated members with eight

[5] McBurney, R. S., and Drow, J. T. The elastic properties of wood--Young's moduli and Poisson's ratio of Douglas-fir and their relations to moisture content. FPL Report No. 1528-D, Nov. 1946.

Table 2.--Strain data measured on bolted and control specimens

Specimen No.	Lamination No.	Orientation of strain gage to wood grain	Bolted joint test[1]: Specific gravity[3]	Bolted joint test[1]: Stress at ultimate[4]	Bolted joint test[1]: Strain at ultimate	Bolted joint test[1]: Strain at 1,960 p.s.i.	Control test (compression): Stress at ultimate[4]	Control test (compression): Strain at ultimate	Control test (compression): Strain at 1,960 p.s.i.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				P.s.i.	In./in.[5]	In./in.[5]	P.s.i.	In./in.[5]	In./in.[5]
A1	3	Parallel	0.52	2,640	+.00114	+.00084	6,240	-.00193	-.00072
	2	Parallel	.44	2,640	+.00123	+.00098	5,900	-.00387	-.00109
D1	2	Parallel	.62	4,370	+.00185	+.00082	6,760	-.00297	-.00074
	4	Parallel	.40	4,370	+.00198	+.00099			
D3	5	Parallel	.40	3,440	+.00156	+.00083	7,500	-.00400	-.00069
	5	[6]Parallel	.40	3,440	+.00088	+.00040			
Average				3,480	+.00155	+.00089	6,600	-.00319	-.00081
A3	2	[7]Perpendicular	.50	2,500	-.00015	-.00014			
	4	[7]Perpendicular	.47	2,500	-.00072	-.00062	6,580	+.00163	+.00027
D2	2	[7]Perpendicular	.59	2,320	-.00014	-.00013	9,050	+.00220	+.00021
	4	[7]Perpendicular	.44	2,320	-.00044	-.00038	5,720	+.00107	+.00024
Average				2,410	-.00038	-.00032	7,120	+.00163	+.00024

[1]Specimens were 3-1/4 by 7-1/2 by 82-1/4 inches with 2 rows of four 3/4-inch bolts.

[2]Specimens were 1-1/2 by 3-1/4 by 6 or 8 inches, and cut from the bolted-laminated members with the strain gages in place.

[3]Based on ovendry weight and volume.

[4]Stress at ultimate is based on the full cross-sectional area of the member.

[5]+ indicates tensile strain and - indicates compressive strain.

[6]Strain gage was located between second and third row of bolts. Values are not included in the average.

[7]The strain was measured across the growth rings (radial direction).

bolts are shown in figures 8 to 11. All specimens failed suddenly. The ultimate failures were of three general types or a combination of types, namely: (1) Shearing of the wood below and between the boltholes, (2) splitting of the wood through the boltholes, and (3) tension parallel to the grain of one or more laminations, generally accompanied by splitting in other laminations. In the members with high- and low-density laminations (series D and G), failure in four of the six specimens was by splitting and shear in the lamination with high density, with no failure other than crushing of the wood beneath the bolts in the lamination with low density. The members with 3/4-inch bolts showed very slight bending of the bolts and only slight crushing of the wood beneath the bolts. Most specimens with 3/4-inch bolts failed at a joint slip of about 0.09 inch. The members with 1/2-inch bolts showed considerable bending of the bolts and crushing of the wood beneath the bolts. They generally failed at a joint slip of about 1/4 to 1/2 inch. In most of the tests, creaking of the bolted joint was observed throughout the major portion of the test, indicating that friction between the wood member and the steel plates developed early in the test, even though the nuts were initially only finger-tight, or that minor failures were developing as the test progressed before ultimate failures terminated the test.

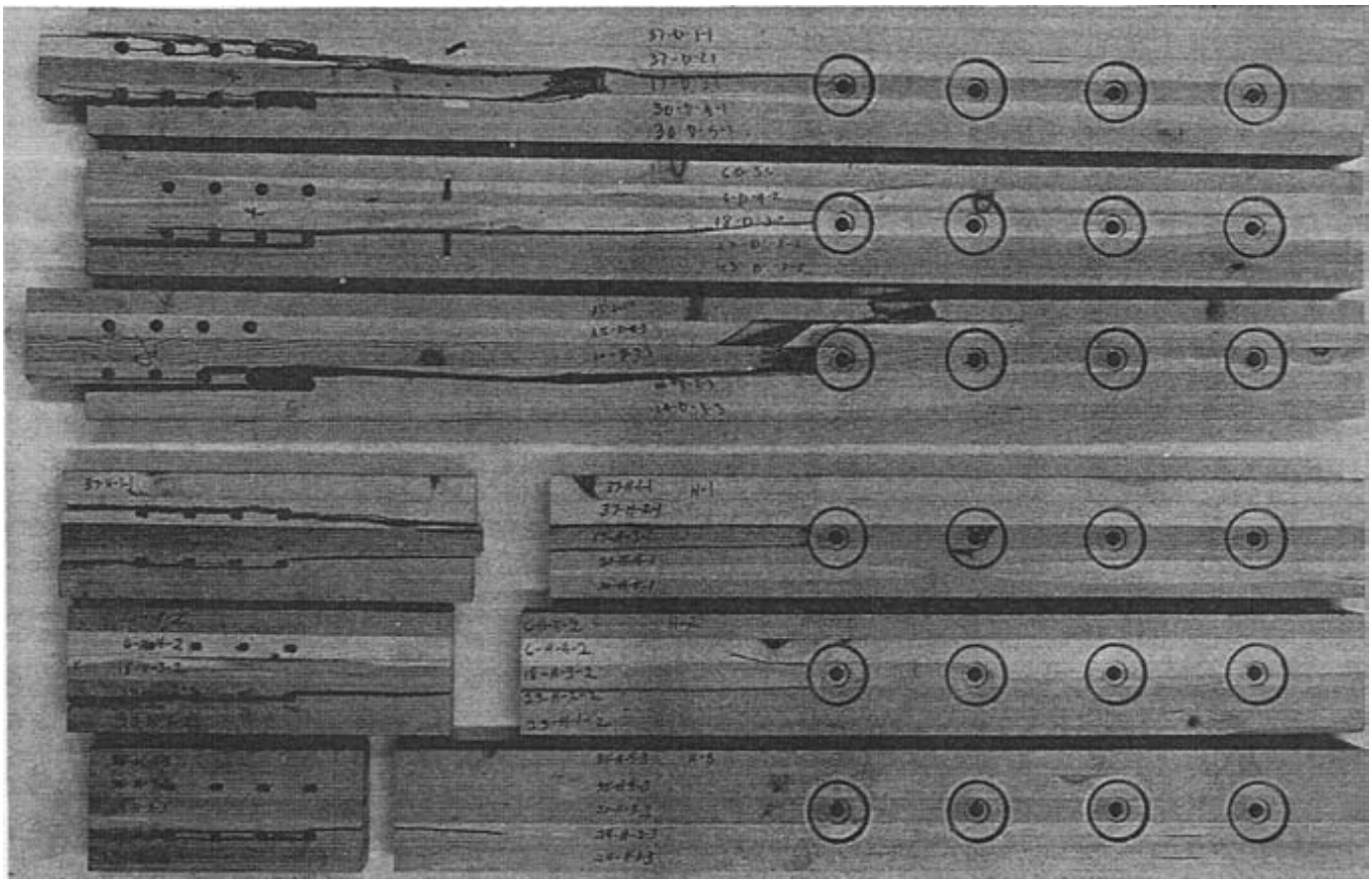

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Figure 11.--Joints with eight 3/4–and 1/2–inch bolts after test. Upper three are series D specimens (3/4–inch bolts inlaminations of different densities) and the lower three are series H specimens (1/2-inch bolts in laminations of different densities). End distance in all tests was 5–1/4 inches and the spacing between bolts 3 inches. Strain gages are shown on the edges of the second and fourth lamina–tions of the two upper specimens and on the face of the bottom lamination of the third specimen.

CONCLUSIONS

1. The bearing stress at the proportional limit for joints with two rows of four 3/4-inch bolts in laminated Douglas-fir members is about the same as that for similar joints with one bolt, but the ultimate bearing stress is about one–third lower. With 1/2–inch bolts, the bearing stress at the proportional limit is about 15 percent higher, presumably due to greater joint friction than that for the joints with single bolts, and the ultimate bearing stress is about 15 percent lower.

2. Joints with the eight bolts under tensile load slip from 2 to 3 times more at the proportional limit than joints with a single bolt, but joints with a single bolt slip about twice as much at ultimate load as joints with eight bolts.

3. The strength and behavior of joints with eight 3/4–inch bolts[4] are not appreciably affected by such modifications in

construction as bolt spacing of 4-1/2 inches, stitch bolts, tapered end cut, or bolts in laminations of high and low density.

4. The bearing stress at the proportional limit of bolted joints is about 35 percent that of the maximum crushing strength of the wood when 3/4–inch bolts are used, and about 30 percent when 1/2–inch bolts are used.

APPENDIX A

The results obtained from the tests of individual multiple–bolted joints, single–bolt joints, and compression–parallel–to–the–grain specimens are listed in tables 3 to 10.

The rate of growth, orientation of growth rings and other features of the wood in the laminated members are shown in the photographs of the ends of the single–bolt control specimens in figures 12 to 15. The small checks that are visible on the ends of some of the specimens are due to seasoning and were not present when the tests were made.

Table 3.--Series A results with 3/4-inch bolts bearing parallel to the grain in laminated Douglas-fir members

Specimen No.	Specific gravity[1]	Moisture content	Load at slip of 0.01 inch	0.02 inch	0.03 inch	0.04 inch	0.05 inch	0.06 inch	0.08 inch	0.10 inch	0.20 inch	0.30 inch	Proportional limit: Load	Proportional limit: Slip	Maximum Load	Maximum Slip	Initial non-elastic slip	Slip when curve is straight	Bearing stress: Proportional limit	Bearing stress: Maximum	Properties of material[2]: Specific gravity[3]	Moisture content	Stress at proportional limit	Maximum crushing strength	Modulus of elasticity
(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)
		Percent	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	In.	Lb.	In.	In.	In.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	1,000 p.s.i.
JOINTS WITH ONE BOLT[4]																									
a2-1	0.438	12.9	2,700	5,500	7,800	9,300	10,300	11,000	11,500	11,700	12,100	.....	5,000	0.017	12,120	0.160	0.001	0.003	2,040	4,950	0.395	12.4	4,200	4,920	1,850
a4-1	.449	13.1	3,100	6,200	8,400	9,800	10,500	11,100	11,800	12,200	13,000	.....	5,500	.017	12,960	.200	.001	.002	2,250	5,300	.425	12.8	5,130	6,360	1,981
Av.	.444	13.0	2,900	5,850	8,100	9,550	10,400	11,050	11,650	11,950	12,550	.....	5,250	.017	12,540	.180	.001	.002	2,140	5,120	.410	12.6	4,660	5,640	1,920
a2-2	.515	13.3	3,200	6,300	8,400	9,700	10,700	11,400	12,300	12,600	13,400	13,700	5,800	.018	13,760	.290	0	0	2,370	5,630	.488	11.9	3,650	7,360	2,088
a4-2	.500	13.3	2,700	5,800	8,200	9,800	10,800	11,600	12,600	13,100	13,800	.....	5,600	.018	13,780	.200	.001	.003	2,290	5,640	.536	11.7	4,180	8,000	2,325
Av.	.508	13.3	2,950	6,050	8,300	9,750	10,750	11,500	12,450	12,850	13,600	.....	5,700	.018	13,770	.245	.001	.002	2,330	5,640	.512	11.8	3,920	7,680	2,200
a2-3	.500	12.9	3,400	6,700	9,000	10,300	11,200	11,800	12,300	12,500	13,100	.....	5,600	.016	13,240	.250	.001	.003	2,290	5,410	.524	11.9	3,470	6,080	1,361
a4-3	.467	13.2	3,100	6,900	9,500	11,000	12,100	12,800	13,500	13,600	14,200	.....	6,000	.015	14,240	.180	.002	.007	2,450	5,810	.442	12.5	4,450	6,900	1,985
Av.	.484	13.0	3,250	6,800	9,250	10,650	11,650	12,300	12,900	13,050	13,650	.....	5,800	.0155	13,740	.215	.001	.005	2,370	5,610	.483	12.2	3,960	6,490	1,670
Average:	.478	13.1	3,030	6,230	8,550	9,980	10,930	11,600	12,300	12,600	.....	.....	5,580	.0168	13,350	.213	.001	.003	2,280	5,460	.468	12.2	4,180	6,600	1,930
JOINTS WITH EIGHT BOLTS[5]																									
A1	.466	13.0	1,120	2,200	3,350	4,350	5,290	6,250	7,520	.....	.....	.....	5,500	.056	8,050	.092	0	.006	2,260	3,290	.....	.....	.....	.....	.....
A2	.496	13.1	1,340	3,750	5,500	7,120	8,500	.....	.....	.....	.....	.....	6,000	.033	8,660	.054	0	0	2,460	3,540	.....	.....	.....	.....	.....
A3	.479	13.4	1,000	2,120	3,250	4,370	5,620	6,390	.....	.....	.....	.....	5,750	.046	7,630	.078	.002	.014	2,360	3,120	.....	.....	.....	.....	.....
Average:	.480	13.2	1,150	2,690	4,030	5,280	6,470	.....	.....	.....	.....	.....	5,750	.045	8,110	.075	.001	.007	2,360	3,320	.....	.....	.....	.....	.....

[1] Specific gravity based on ovendry weight and volume. Values listed for single-bolt joints are for the laminations containing the individual bolts. Values for the multiple-bolted specimens are the average of the five laminations comprising the specimens.

[2] Data from 1- by 1- by 4-inch specimens tested with compression parallel to the grain. Specimens were cut from the laminations containing the bolts.

[3] Specific gravity based on ovendry weight and volume at test.

[4] Specimens were 3-1/4 by 3-1/4 by 12 inches with the bolt at an end distance of 5-1/4 inches, and located in the same laminations that contained a row of bolts in multi-bolted joints.

[5] Specimens were 3-1/4 by 7-1/2 by 82-1/4 inches with two rows of four bolts at an end distance of 5-1/4 inches and a spacing of 3 inches between bolts.

Table 4.--Series B results with 3/4-inch bolts bearing parallel to the grain in laminated Douglas-fir members

Specimen No.	Specific gravity[1]	Moisture content	Load at slip of 0.01 inch	0.02 inch	0.03 inch	0.04 inch	0.05 inch	0.06 inch	0.08 inch	0.10 inch	0.20 inch	0.30 inch	Proportional limit: Load	Proportional limit: Slip	Maximum Load	Maximum Slip	Initial non-elastic slip	Slip when curve is straight	Bearing stress: Proportional limit	Bearing stress: Maximum	Properties of material[2]: Specific gravity[3]	Moisture content	Stress at proportional limit	Maximum crushing strength	Modulus of elasticity
(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)
		Percent	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	In.	Lb.	In.	In.	In.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	1,000 p.s.i.
JOINTS WITH ONE BOLT[4]																									
b2-1	0.508	13.0	3,200	6,500	9,000	10,400	11,200	11,900	13,000	13,900	15,600	.....	6,200	0.017	15,600	0.200	0.002	0.004	2,540	6,380	0.464	12.0	5,900	7,250	1,951
b4-1	.520	13.1	3,600	6,800	8,800	9,800	10,600	11,300	12,400	13,400	15,500	.....	6,000	.017	16,120	.175	0	0	2,450	6,600	.474	11.9	3,190	7,430	3,225
Av.	.514	13.0	3,400	6,650	8,900	10,100	10,900	11,600	12,700	13,650	15,550	.....	6,100	.017	15,860	.188	.001	.002	2,500	6,490	.469	12.0	4,540	7,340	2,588
b2-2	.584	13.3	3,900	7,300	9,800	11,300	12,300	13,100	14,200	14,400	14,800	.....	6,200	.016	14,960	.243	0	0	2,540	6,140	.523	11.9	3,620	8,780	2,578
b4-2	.582	13.4	3,400	6,900	9,500	11,100	12,200	13,100	14,400	15,200	16,000	.....	7,200	.021	16,360	.280	0	0	2,950	6,720	.516	12.0	2,980	8,710	2,985
Av.	.583	13.4	3,650	7,100	9,650	11,200	12,250	13,100	14,300	14,800	15,400	.....	6,700	.018	15,660	.262	0	0	2,740	6,430	.520	12.0	3,300	8,740	2,782
b2-3	.480	12.8	4,300	7,500	9,600	10,800	11,600	12,300	12,900	13,000	13,200	.....	5,800	.014	13,300	.280	.....	.....	2,380	5,460	.485	11.3	5,700	7,280	2,052
b4-3	.432	13.6	3,300	6,300	8,400	9,600	10,100	10,300	10,400	10,400	10,450	.....	6,200	.019	10,540	.295	0	0	2,540	4,320	.404	11.7	3,970	5,150	1,984
Av.	.456	13.2	3,800	6,900	9,000	10,200	10,850	11,300	11,650	11,700	11,820	.....	6,000	.016	11,920	.288	0	0	2,460	4,890	.444	11.5	4,840	6,220	2,018
Average	.518	13.2	3,620	6,880	9,180	10,500	11,330	12,000	12,880	13,380	14,260	.....	6,270	.017	14,480	.246	0	.001	2,570	5,940	.478	11.8	4,230	7,430	2,460
JOINTS WITH EIGHT BOLTS[5]																									
B1	.461	13.1	1,060	2,440	3,840	5,250	6,620	7,820	9,380	.....	.....	.....	5,750	.041	9,480	.084	.002	.009	2,360	3,890	.....	.....	.....	.....	.....
B2	.533	13.3	1,380	3,000	4,660	6,160	7,500	.....	.....	.....	.....	.....	7,250	.047	7,800	.051	.001	.005	2,970	3,200	.....	.....	.....	.....	.....
B3	.454	13.3	962	1,750	2,650	3,500	4,630	5,750	7,720	9,200	.....	.....	6,500	.059	9,700	.112	.004	.025	2,660	3,970	.....	.....	.....	.....	.....
Average	.483	13.2	1,130	2,400	3,720	4,970	6,250	.....	.....	.....	.....	.....	6,500	.049	8,990	.082	.002	.013	2,660	3,690	.....	.....	.....	.....	.....

[1] Specific gravity based on ovendry weight and volume. Values listed for single-bolt joints are for the laminations containing the individual bolts. Values for the multiple-bolted specimens are the average of the five laminations comprising the specimens.

[2] Data from 1- by 1- by 4-inch specimens tested with compression parallel to the grain. Specimens were cut from the laminations containing the bolts.

[3] Specific gravity based on ovendry weight and volume at test.

[4] Specimens were 3-1/4 by 3-1/4 by 12 inches with the bolt at an end distance of 5-1/4 inches, and located in the same laminations that contained a row of bolts in multi-bolted joints.

[5] Specimens were 3-1/4 by 7-1/2 by 82-1/4 inches with two rows of four bolts at an end distance of 5-1/4 inches and a spacing of 4-1/2 inches between bolts.

Table 5.--Series C results with 3/4-inch bolts bearing parallel to the grain in laminated Douglas-fir members

Specimen No.	Specific gravity[1]	Moisture content	Load at slip of 0.01 inch	0.02 inch	0.03 inch	0.04 inch	0.05 inch	0.06 inch	0.08 inch	0.10 inch	0.20 inch	0.30 inch	Proportional limit: Load	Proportional limit: Slip	Maximum Load	Maximum Load: Slip	Initial non-elastic slip	Slip when curve is straight	Bearing stress: Proportional limit	Bearing stress: Maximum	Properties of material[2]: Specific gravity[3]	Moisture content	Stress at proportional limit	Maximum crushing strength	Modulus of elasticity
(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)
		Percent	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	In.	Lb.	In.	In.	In.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	1,000 p.s.i.
JOINTS WITH ONE BOLT[4]																									
c2-1	0.481	13.8	3,600	6,600	8,400	9,400	10,100	10,600	11,200	11,400	12,100		5,800	0.018	12,100	0.212			2,380	4,970	0.397	13.3	2,490	5,300	1,934
c4-1	.406	13.9	2,700	5,600	7,800	9,200	9,800	10,100	10,400	10,500	10,200	10,500	5,000	.016	10,820	.172	0.002	0.003	2,040	4,430	.409	13.2	4,600	5,750	1,515
Av.	.444	13.8	3,150	6,100	8,100	9,300	9,950	10,350	10,800	10,950	11,150	10,500	5,400	.017	11,460	.192	.001	.002	2,210	4,700	.403	13.2	3,540	5,520	1,724
c2-2	.527	13.1	3,800	7,200	9,500	10,900	12,000	12,800	14,200	14,900	15,800		6,600	.018	15,900	.230	0	0	2,710	6,520	.482	12.7	3,210	7,010	2,005
c4-2	.578	12.8	3,700	7,400	10,100	11,600	12,500	13,400	14,900	16,000	17,200		7,200	.019	17,380	.235	.001	.002	2,940	7,110	.591	12.4	4,020	8,800	2,715
Av.	.552	13.0	3,750	7,300	9,800	11,250	12,250	13,100	14,550	15,450	16,500		6,900	.018	16,640	.232	.001	.001	2,820	6,820	.536	12.6	3,620	7,900	2,360
c2-3	.529	12.8	4,000	7,200	9,600	10,800	11,700	12,300	13,000	13,200	13,500	13,600	6,000	.016	14,000	.380	.001	.002	2,450	5,730	.484	11.9	2,240	6,720	2,518
c4-	.480	12.6	2,900	6,500	9,000	10,600	11,600	12,400	13,100	13,000	13,200	11,600	6,200	.016	13,400	.252	.002	.004	2,530	5,460	.464	12.1	4,440	7,010	2,250
Av.	.504	12.7	3,450	6,850	9,300	10,700	11,650	12,350	13,050	13,100	13,350	12,600	6,100	.016	13,700	.316	.001	.003	2,490	5,600	.474	12.0	3,340	6,860	2,384
Average:	.500	13.2	3,450	6,750	9,070	10,420	11,280	11,930	12,800	13,170	13,670	11,550	6,130	.017	13,930	.247	.001	.002	2,510	5,710	.471	12.6	3,500	6,760	2,156
JOINTS WITH EIGHT BOLTS[5]																									
C1	.464	13.2	688	1,560	2,810	4,340	5,820	7,160	9,320				5,250	.035	9,840	.092	.009	.025	2,150	4,040					
C2	.491	13.0	1,410	3,250	5,000	6,660	8,220						6,750	.040	8,940	.055	.002	.005	2,770	3,670					
C3	.506	13.3	1,000	2,160	3,620	4,900	6,190	7,440	9,340				6,250	.049	10,130	.094	.003	.012	2,560	4,130					
Average:	.487	13.2	1,030	2,320	3,810	5,300	6,740	7,300	9,330				6,080	.041	9,640	.080	.005	.014	2,490	3,950					

[1] Specific gravity based on ovendry weight and volume. Values listed for single-bolt joints are for the laminations containing the individual bolts. Values for the multiple-bolted specimens are the average of the five laminations comprising the specimens.

[2] Data from 1- by 1- by 4-inch specimens tested with compression parallel to the grain. Specimens were cut from the laminations containing the bolts.

[3] Specific gravity based on ovendry weight and volume at test.

[4] Specimens were 3-1/4 by 3-1/4 by 12 inches with the bolt at an end distance of 5-1/4 inches, and located in the same laminations that contained a row of bolts in multi-bolted joints.

[5] Specimens were 3-1/4 by 7-1/2 by 82-1/4 inches with two rows of four bolts at an end distance of 5-1/4 inches and a spacing of 3 inches between bolts. A 1/2- by 8-inch stitch bolt with washers was placed through the member at a distance of 3-1/4 inches from the end.

Table 6.--Series D results with 3/4-inch bolts bearing parallel to the grain in laminated Douglas-fir members

Specimen No.	Specific gravity[1]	Moisture content	Load at slip of 0.01 inch	0.02 inch	0.03 inch	0.04 inch	0.05 inch	0.06 inch	0.08 inch	0.10 inch	0.20 inch	0.30 inch	Proportional limit: Load	Proportional limit: Slip	Maximum Load	Maximum Slip	Initial non-elastic slip	Slip when curve is straight	Bearing stress at proportional limit	Maximum	Properties of material[2]: Specific gravity[3]	Moisture content	Stress at proportional limit	Maximum crushing strength	Modulus of elasticity
(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)
		Percent	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	In.	Lb.	In.	In.	In.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	1,000 p.s.i.
JOINTS WITH ONE BOLT[4]																									
d2-1	0.620	14.0	3,900	7,300	9,700	11,300	12,400	13,200	14,400	15,100	16,400	17,000	5,800	0.015	17,060	0.410	0	0	2,370	6,980	0.570	13.9	4,930	7,430	2,252
d4-1	.405	13.0	2,600	5,600	7,800	9,000	9,800	10,300	10,800	11,000	11,200	11,200	5,400	.018	11,240	.375	.001	.003	2,210	4,600	.384	12.6	4,210	5,400	1,403
Av.	.512	13.5	3,250	6,450	8,750	10,150	11,100	11,750	12,600	13,050	13,800	14,100	5,600	.016	14,150	.392	.001	.002	2,290	5,790	.477	13.2	4,570	6,420	1,828
d2-2	.594	13.4	3,400	7,000	9,700	11,600	12,700	13,600	14,800	15,100	15,100	.....	7,400	.020	15,400	.255	.001	.002	3,020	6,280	.579	12.1	.....	9,900	2,988
d4-2	.438	13.4	3,200	6,400	8,800	10,400	11,200	11,600	11,900	12,200	12,800	.....	6,000	.017	12,800	.230	.001	.002	2,450	5,220	.419	12.8	4,440	6,410	1,631
Av.	.516	13.4	3,300	6,700	9,250	11,000	11,950	12,600	13,350	13,650	13,950	.....	6,700	.018	14,100	.242	.001	.002	2,740	5,750	.499	12.4	4,440	8,160	2,310
d2-3	.534	14.6	3,300	6,900	9,400	10,900	11,700	12,200	12,600	12,700	12,400	12,500	6,600	.018	12,700	.120	.002	.003	2,690	5,180	.528	13.2	5,180	7,160	1,716
d4-3	.399	13.3	3,100	6,100	8,300	9,600	10,000	10,300	10,400	10,500	10,700	10,700	5,600	.018	10,720	.300	0	0	2,280	4,380	.376	13.0	3,170	4,950	1,353
Av.	.466	14.0	3,200	6,500	8,850	10,250	10,850	11,250	11,500	11,600	11,550	11,600	6,100	.018	11,710	.210	.001	.002	2,480	4,780	.452	13.1	4,180	6,060	1,534
Average:	.498	13.6	3,250	6,550	8,950	10,470	11,300	11,870	12,480	12,770	13,100	12,850	6,130	.017	13,320	.282	.001	.002	2,500	5,440	.476	12.9	4,400	6,880	1,891
JOINTS WITH EIGHT BOLTS[5]																									
D1	.508	13.5	1,000	2,150	3,380	4,820	6,250	7,560	9,340	10,450	.....	.....	6,880	.048	13,300	.306	.004	.020	2,820	5,440	.....	.....	.....	.....	.....
D2	.506	14.1	1,060	2,410	4,000	5,560	6,650	.....	.....	.....	.....	.....	6,000	.039	7,240	.059	.004	.015	2,460	2,960	.....	.....	.....	.....	.....
D3	.483	13.6	875	2,120	3,690	5,250	6,880	8,250	10,100	9,560	.....	.....	6,750	.043	10,500	.095	.006	.020	2,770	4,300	.....	.....	.....	.....	.....
Average:	.499	13.7	980	2,230	3,690	5,210	6,590	7,900	9,720	10,000	.....	.....	6,550	.043	10,350	.153	.005	.018	2,680	4,230	.....	.....	.....	.....	.....

[1] Specific gravity based on ovendry weight and volume. Values listed for single-bolt joints are for the laminations containing the individual bolts. Values for the multiple-bolted specimens are the average of the five laminations comprising the specimens.

[2] Data from 1- by 1- by 4-inch specimens tested with compression parallel to the grain. Specimens were cut from the laminations containing the bolts.

[3] Specific gravity based on ovendry weight and volume at test.

[4] Specimens were 3-1/4 by 3-1/4 by 12 inches with the bolt at an end distance of 5-1/4 inches, and located in the same laminations that contained a row of bolts in multi-bolted joints.

[5] Specimens were 3-1/4 by 7-1/2 by 82-1/4 inches with two rows of four bolts at an end distance of 5-1/4 inches and a spacing of 3 inches between bolts. The laminated members were assembled with each row of bolts bearing in laminations of relatively high and low density respectively.

Table 7.--Series E results with 3/4-inch bolts bearing parallel to the grain in laminated Douglas-fir members

Specimen No.	Specific gravity[1]	Moisture content	Load at slip of 0.01 inch	0.02 inch	0.03 inch	0.04 inch	0.05 inch	0.06 inch	0.08 inch	0.10 inch	0.20 inch	0.30 inch	Proportional limit: Load	Proportional limit: Slip	Maximum Load	Maximum Slip	Initial non-elastic slip	Slip when curve is straight	Bearing stress at proportional limit	Bearing stress at Maximum	Properties of material[2]: Specific gravity[3]	Moisture content	Stress at proportional limit	Maximum crushing strength	Modulus of elasticity
(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)
		Percent	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	In.	Lb.	In.	In.	In.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	1,000 p.s.i.
JOINTS WITH ONE BOLT[4]																									
e2-1	0.458	13.6	3,300	6,500	8,800	10,000	10,600	10,900	11,100	11,300	11,600	10,500	6,200	0.018	11,820	0.277	0	0	2,540	4,840	0.445	11.9	5,180	6,400	1,938
e4-1	.421	13.6	3,000	5,800	8,000	9,400	10,400	11,100	11,500	11,600	11,900	12,300	6,000	.021	12,300	.300	0	0	2,450	5,030	.383	13.2	3,460	5,530	1,460
Av.	.440	13.6	3,150	6,150	8,400	9,700	10,500	11,000	11,300	11,450	11,750	11,400	6,100	.020	12,060	.288	0	0	2,500	4,940	.414	12.6	4,320	5,960	1,699
e2-2	.502	13.0	3,000	6,600	9,000	10,400	11,200	11,800	12,200	12,300	13,000	13,400	6,800	.019	13,560	.280	.002	.003	2,780	5,550	.435	12.7	4,420	7,120	2,065
e4-2	.558	12.9	3,600	7,300	10,000	11,400	12,100	12,400	12,600	12,800	13,300	.....	7,000	.019	13,300	.230	0	0	2,870	5,460	.537	12.5	4,190	8,160	2,791
Av.	.530	13.0	3,300	6,950	9,500	10,900	11,650	12,100	12,400	12,550	13,150	13,400	6,900	.019	13,430	.255	.001	.002	2,820	5,500	.486	12.6	4,300	7,640	2,428
e2-3	.508	12.6	3,300	7,000	9,500	11,100	12,100	12,700	13,300	13,400	13,700	.....	7,000	.019	13,740	.160	.001	.002	2,860	5,600	.496	12.6	6,160	7,370	2,440
e4-3	.479	12.7	3,300	7,100	9,800	11,300	12,400	13,200	14,300	14,200	.....	.....	6,600	.017	14,360	.085	.002	.004	2,690	5,860	.459	11.8	4,150	7,080	2,077
Av.	.494	12.6	3,300	7,050	9,650	11,200	12,250	12,950	13,800	13,800	13,700	.....	6,800	.018	14,050	.122	.001	.003	2,780	5,730	.478	12.2	5,160	7,220	2,258
Average:	.488	13.1	3,250	6,720	9,180	10,600	11,470	12,020	12,500	12,600	12,870	12,400	6,600	.019	13,180	.222	.001	.002	2,700	5,390	.459	12.5	4,590	6,940	2,128
JOINTS WITH EIGHT BOLTS[5]																									
E1	.449	13.1	963	2,310	3,840	5,420	6,880	7,860	7,060	7,160	.....	.....	5,750	.035	8,090	.071	.006	.015	2,360	3,310	.....	.....	.....	.....	.....
E2	.475	12.9	913	1,850	2,940	4,380	5,920	7,380	.....	.....	.....	.....	6,620	.043	8,300	.069	.011	.034	2,710	3,410	.....	.....	.....	.....	.....
E3	.473	13.1	638	1,280	1,880	2,650	3,620	4,900	7,200	.....	.....	.....	6,250	.050	8,480	.098	.019	.044	2,560	3,470	.....	.....	.....	.....	.....
Average:	.466	13.0	840	1,810	2,890	4,150	5,470	6,710	7,130	7,160	.....	.....	6,210	.043	8,290	.079	.012	.031	2,540	3,400	.....	.....	.....	.....	.....

[1] Specific gravity based on ovendry weight and volume. Values listed for single-bolt joints are for the laminations containing the individual bolts. Values for the multiple-bolted specimens are the average of the five laminations comprising the specimens.

[2] Data from 1- by 1- by 4-inch specimens tested with compression parallel to the grain. Specimens were cut from the laminations containing the bolts.

[3] Specific gravity based on ovendry weight and volume at test.

[4] Specimens were 3-1/4 by 3-1/4 by 12 inches with the bolt at an end distance of 5-1/4 inches, and located in the same laminations that contained a row of bolts in multi-bolted joints.

[5] Specimens were 3-1/4 by 7-1/2 by 82-1/4 inches with two rows of four bolts at a minimum end distance of 5-1/4 inches and a spacing of 3 inches between bolts. The laminated members were trimmed at their joint ends by cutting across their wide faces at a 30° angle.

Table 8.--Series F results with 1/2-inch bolts bearing parallel to the grain in laminated Douglas-fir members

Specimen No.	Specific gravity[1]	Moisture content	Load at slip of 0.01 inch	0.02 inch	0.03 inch	0.04 inch	0.05 inch	0.06 inch	0.08 inch	0.10 inch	0.20 inch	0.30 inch	Proportional limit Load	Proportional limit Slip	Maximum Load	Maximum Load Slip	Initial non-elastic slip	Slip when curve is straight	Bearing stress Proportional limit	Bearing stress Maximum crushing strength	Properties of material[2] Specific gravity[3]	Moisture content	Stress at proportional limit	Maximum crushing strength	Modulus of elasticity
(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)
		Percent	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	In.	Lb.	In.	In.	In.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	1,000 p.s.i.
JOINTS WITH ONE BOLT[4]																									
f2-1	0.423	14.0	1,900	3,280	4,100	4,700	5,180	5,630	6,390	7,020	8,010	8,180	2,600	0.014	8,180	0.430	0	0	1,600	5,020	0.399	12.9	3,480	5,780	1,971
f4-1	.434	13.6	1,500	3,000	3,800	4,440	4,820	5,190	5,910	6,550	7,940	8,290	3,000	.019	8,600	.....	.001	.002	1,850	5,290	.398	12.9	4,220	5,520	1,921
Av.	.428	13.8	1,700	3,140	3,950	4,570	5,000	5,410	6,150	6,780	7,980	8,240	2,800	.016	8,390	.430	.....	.....	1,720	5,160	.398	12.9	3,850	5,650	1,946
f2-2	.421	13.4	2,700	3,900	4,650	5,250	5,700	6,170	6,940	7,490	7,800	8,300	2,700	.010	8,480	.440	0	0	1,660	5,200	.389	12.5	4,220	5,860	1,975
f4-2	.446	13.3	2,200	3,300	4,150	4,800	5,350	5,850	6,850	7,620	9,300	9,900	2,500	.013	10,600	.505	.....	.....	1,530	6,500	.408	12.5	3,450	5,370	1,715
Av.	.434	13.4	2,450	3,600	4,400	5,020	5,520	6,010	6,900	7,560	8,550	9,100	2,600	.012	9,540	.472	.....	.....	1,600	5,850	.398	12.5	3,840	5,620	1,845
f2-3	.593	13.1	2,580	4,200	5,300	6,050	6,680	7,150	8,000	8,710	10,180	10,900	3,100	.014	12,500	.600	.....	.....	1,900	7,640	.503	12.7	4,170	6,940	2,290
f4-3	.561	13.1	2,150	3,600	4,500	5,200	5,700	6,110	6,830	7,500	9,450	10,100	3,100	.016	10,440	.455	.....	.....	1,900	6,390	.498	12.5	3,920	7,570	2,182
Av.	.577	13.1	2,360	3,900	4,900	5,620	6,190	6,630	7,420	8,100	9,820	10,500	3,100	.015	11,470	.528	.....	.....	1,900	7,020	.500	12.6	4,040	7,260	2,236
Average:	.480	13.4	2,170	3,550	4,420	5,070	5,570	6,020	6,820	7,480	8,780	9,280	2,830	.014	9,800	.477	.....	.....	1,740	6,010	.432	12.7	3,910	6,180	2,009
JOINTS WITH EIGHT BOLTS[5]																									
F1	.477	13.5	938	1,790	.....	3,360	.....	4,480	5,250	5,840	.....	.....	3,000	.035	7,160	.182	0	.002	1,850	4,400	.....	.....	.....	.....	.....
F2	.507	13.3	550	1,120	.....	2,580	.....	3,650	4,850	5,530	6,840	.....	3,250	.044	6,860	.220	.004	.018	2,000	4,210	.....	.....	.....	.....	.....
F3	.496	13.0	588	1,280	.....	2,400	.....	3,780	4,930	5,790	8,660	.....	4,250	.067	9,160	.234	0	.012	2,610	5,620	.....	.....	.....	.....	.....
Average:	.493	13.3	690	1,400	.....	2,780	.....	3,970	5,010	5,720	7,750	.....	3,500	.049	7,730	.212	.001	.011	2,150	4,740	.....	.....	.....	.....	.....

[1] Specific gravity based on ovendry weight and volume. Values listed for single-bolt joints are for the laminations containing the individual bolts. Values for the multiple-bolted specimens are the average of the five laminations comprising the specimens.

[2] Data from 1- by 1- by 4-inch specimens tested with compression parallel to the grain. Specimens were cut from the laminations containing the bolts.

[3] Specific gravity based on ovendry weight and volume at test.

[4] Specimens were 3-1/4 by 3-1/4 by 12 inches with the bolt at an end distance of 5-1/4 inches, and located in the same laminations that contained a row of bolts in multi-bolted joints.

[5] Specimens were 3-1/4 by 7-1/2 by 82-1/4 inches with two rows of four bolts at an end distance of 5-1/4 inches and a spacing of 3 inches between bolts.

Table 9.--Series G results with 1/2-inch bolts bearing parallel to the grain in laminated Douglas-fir members

Specimen No.	Specific gravity[1]	Moisture content	Load at slip of 0.01 inch	0.02 inch	0.03 inch	0.04 inch	0.05 inch	0.06 inch	0.08 inch	0.10 inch	0.20 inch	0.30 inch	Proportional limit Load	Proportional limit Slip	Maximum Load	Maximum Slip	Initial elastic non-slip	Slip when curve is straight	Bearing stress Proportional limit	Bearing stress Maximum	Properties of material[2] Specific gravity[3]	Moisture content	Stress at proportional limit	Maximum crushing strength	Modulus of elasticity
(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)
		Percent	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	In.	Lb.	In.	In.	In.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	1,000 p.s.i.
JOINTS WITH ONE BOLT[4]																									
g2-1	0.500	13.5	1,550	3,400	4,500	5,210	5,800	6,380	7,450	8,200	9,820	10,520	3,400	0.019	12,700		0.001	0.002	2,090	7,800	0.476	13.0	5,680	7,210	2,426
g4-1	.517	13.6	1,200	2,950	4,120	4,900	5,500	6,030	7,080	8,000	10,020	10,800	3,400	.019	12,500		.003	.007	2,080	7,640	.496	13.3	3,720	7,860	2,565
Av.	.508	13.6	1,380	3,180	4,310	5,060	5,650	6,200	7,260	8,100	9,920	10,660	3,400	.019	12,600		.002	.005	2,080	7,720	.486	13.2	4,700	7,540	2,496
g2-2	.573	13.3	1,900	3,700	5,000	5,800	6,500	7,200	8,100	8,900	10,400	11,200	2,800	.014	15,400		0	0	1,710	9,400	.540	12.5	7,940	9,570	3,062
g4-2	.551	13.2	1,800	3,400	4,300	5,100	5,600	6,100	6,900	7,700	9,600	10,000	4,000	.027	10,400				2,450	6,380	.578	12.6	7,360	10,100	2,916
Av.	.562	13.2	1,850	3,550	4,650	5,450	6,050	6,650	7,500	8,300	10,000	10,600	3,400	.020	12,900				2,080	7,890	.559	12.6	7,650	9,840	2,989
g2-3	.508	12.8	2,000	3,500	4,300	4,900	5,300	5,750	6,590	7,300	9,480	10,180	2,800	.015	11,160	0.560			1,720	6,870	.457	12.5	4,140	6,730	2,268
g4-3	.503	12.7	2,100	3,380	4,080	4,600	5,050	5,450	6,200	6,940	8,820	9,450	2,600	.015	10,600	.545			1,600	6,530	.482	12.5	3,210	6,910	2,484
Av.	.506	12.8	2,050	3,440	4,190	4,750	5,180	5,600	6,400	7,120	9,150	9,820	2,700	.015	10,880	.552			1,660	6,700	.470	12.5	3,680	6,820	2,376
Average:	.525	13.2	1,760	3,390	4,380	5,090	5,620	6,150	7,050	7,840	9,690	10,360	3,170	.018	12,130	.552			1,940	7,440	.505	12.8	5,340	8,070	2,620
JOINTS WITH EIGHT BOLTS[5]																									
G1	.506	13.3	610	1,220		2,180		3,620	4,800	5,820	8,340	9,420	3,500	.048	11,360	.526	0	.008	2,150	7,000					
G2	.538	12.7	775	1,380		2,960		4,530	5,600	6,360	8,540	9,530	3,750	.045	9,680	.356	.003	.018	2,300	5,940					
G3[6]	.478	12.7	1,250	2,870		4,620		6,500	7,930	8,910			3,000	.023	9,340	.127			1,850	5,750					
Average:	.507	12.9	690	1,300		2,570		4,080	5,200	6,090	8,440	9,480	3,630	.046	10,520	.441	.001	.013	2,230	6,470					

[1] Specific gravity based on ovendry weight and volume. Values listed for single-bolt joints are for the laminations containing the individual bolts. Values for the multiple-bolted specimens are the average of the five laminations comprising the specimens.

[2] Data from 1- by 1- by 4-inch specimens tested with compression parallel to the grain. Specimens were cut from the laminations containing the bolts.

[3] Specific gravity based on ovendry weight and volume at test.

[4] Specimens were 3-1/4 by 3-1/4 by 12 inches with the bolt at an end distance of 5-1/4 inches, and located in the same laminations that contained a row of bolts in multi-bolted joints.

[5] Specimens were 3-1/4 by 7-1/2 by 82-1/4 inches with two rows of four bolts at an end distance of 5-1/4 inches and a spacing of 4-1/2 inches between bolts.

[6] Test values were not included in the average of the series.

Table 10.--Series H results with 1/2-inch bolts bearing parallel to the grain in laminated Douglas-fir members

Specimen No.	Specific gravity[1]	Moisture content	Load at slip of 0.01 inch	0.02 inch	0.03 inch	0.04 inch	0.05 inch	0.06 inch	0.08 inch	0.10 inch	0.20 inch	0.30 inch	Proportional limit Load	Proportional limit Slip	Maximum Load	Maximum Slip	Initial non-elastic slip	Slip when curve is straight	Bearing stress Proportional limit	Bearing stress Maximum	Properties of material[2] Specific gravity[3]	Moisture content	Stress at proportional limit	Maximum crushing strength	Modulus of elasticity
(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)
		Percent	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	In.	Lb.	In.	In.	In.	P.s.i.	P.s.i.		Percent	P.s.i.	P.s.i.	1,000 p.s.i.
JOINTS WITH ONE BOLT[4]																									
h2-1	0.596	14.3	1,200	2,600	4,100	4,800	5,400	6,000	7,000	7,900	9,850	10,500	4,200	0.031	11,740	.....	0.010	0.012	2,580	7,220	0.577	14.2	3,470	7,420	2,315
h4-1	.424	13.0	1,300	2,600	3,550	4,250	4,800	5,250	5,960	6,600	7,400	7,360	2,900	.022	7,400	0.230	.002	.006	1,780	4,560	.386	13.2	2,020	5,160	2,020
Av.	.510	13.6	1,250	2,600	3,820	4,420	5,100	5,620	6,480	7,250	8,620	8,930	3,550	.026	9,570	.230	.006	.009	2,180	5,890	.482	13.7	2,740	6,290	2,168
h2-2	.592	13.8	960	1,860	2,830	3,740	4,320	4,850	5,580	6,160	8,350	9,360	3,840	.041	10,900	.....	.002	.004	2,360	6,680	.550	12.2	5,930	9,400	2,771
h4-2	.445	13.7	720	1,400	2,100	2,780	3,260	3,600	4,460	5,040	7,030	8,220	2,760	.040	8,860	.625	.003	.008	1,700	5,460	.423	13.6	4,170	6,840	1,624
Av.	.518	13.8	840	1,630	2,470	3,260	3,790	4,220	5,020	5,600	7,690	8,790	3,300	.040	9,880	.625	.002	.006	2,030	6,070	.486	12.9	5,050	8,120	2,198
h2-3	.588	13.7	1,300	2,700	3,750	4,500	5,080	5,600	6,500	7,260	9,100	9,320	3,200	.023	9,400	.340	.005	.010	1,960	5,760	.502	13.8	4,440	7,390	2,221
h4-3	.399	13.1	1,460	2,740	3,600	4,160	4,620	4,940	5,600	6,260	7,420	7,540	2,400	.017	700	.....	.005	.010	1,470	4,720	.432	12.6	2,460	4,630	1,162
Av.	.494	13.4	1,380	2,720	3,680	4,330	4,850	5,270	6,050	6,760	8,260	8,430	2,800	.020	8,550	.340	.005	.010	1,720	5,240	.467	13.2	3,450	6,010	1,692
Average	.507	13.6	1,160	2,320	3,320	4,000	4,580	5,040	5,850	6,540	8,190	8,720	3,220	.029	9,330	.398	.004	.008	1,980	5,730	.478	13.3	3,750	6,810	2,019
JOINTS WITH EIGHT BOLTS[5]																									
H1	.516	13.5	688	1,440	.....	3,000	.....	4,280	5,180	5,920	8,090	8,780	3,250	.042	9,240	.404	0	.006	2,000	5,680	.....	.....	.....	.....	.....
H2	.499	13.6	638	1,340	.....	2,690	.....	4,060	5,160	5,920	8,320	8,680	3,750	.054	8,880	.276	0	.009	2,300	5,480	.....	.....	.....	.....	.....
H3	.508	13.3	612	1,410	.....	3,250	.....	4,590	5,360	6,000	7,390	7,750	3,000	.033	7,760	.302	.004	.012	1,850	4,780	.....	.....	.....	.....	.....
Average	.508	13.5	650	1,400	.....	2,980	.....	4,300	5,230	5,950	7,930	8,400	3,330	.043	8,630	.327	.001	.009	2,050	5,310	.....	.....	.....	.....	.....

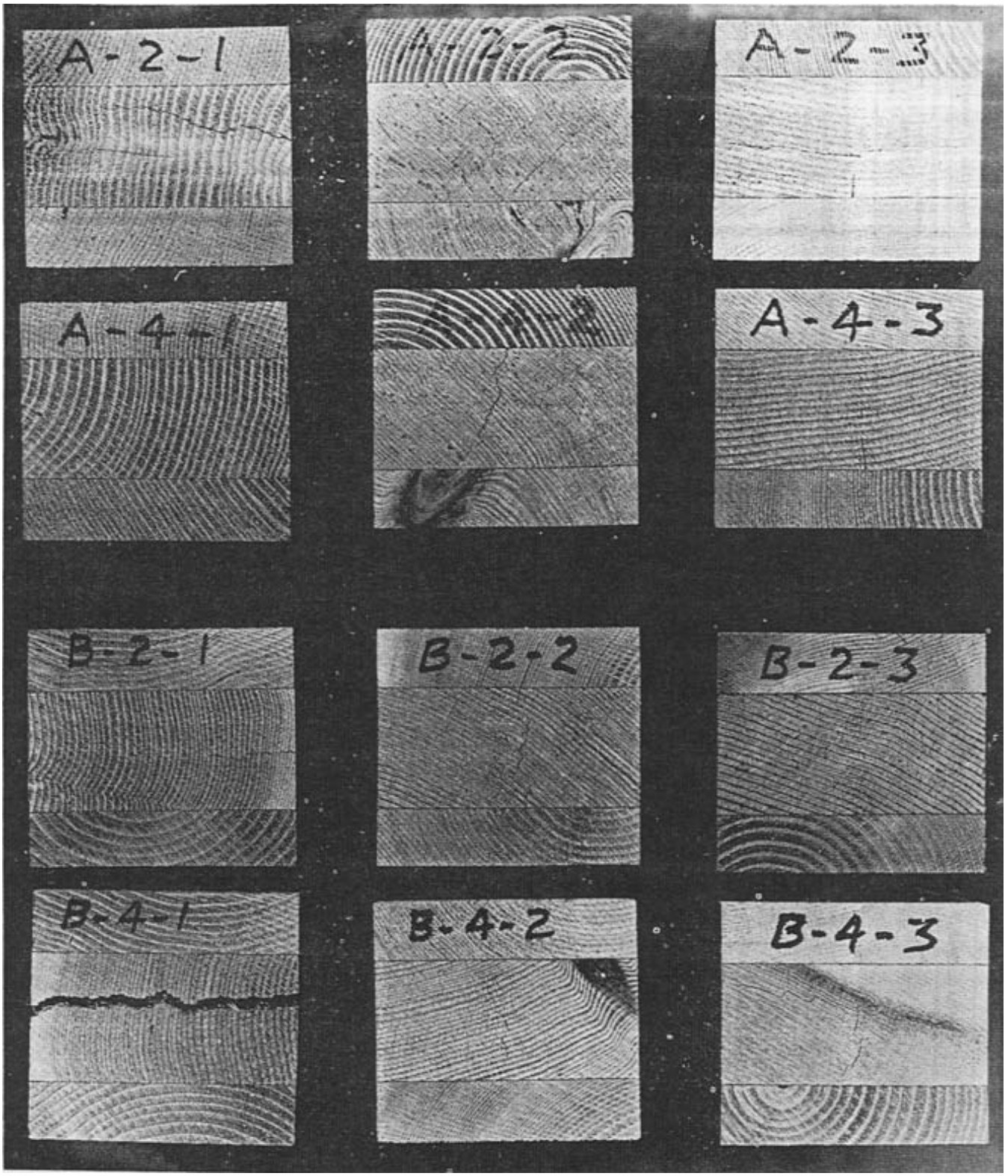
[1] Specific gravity based on ovendry weight and volume. Values listed for single-bolt joints are for the laminations containing the individual bolts. Values for the multiple-bolted specimens are the average of the five laminations comprising the specimens.

[2] Data from 1- by 1- by 4-inch specimens tested with compression parallel to the grain. Specimens were cut from the laminations containing the bolts.

[3] Specific gravity based on ovendry weight and volume at test.

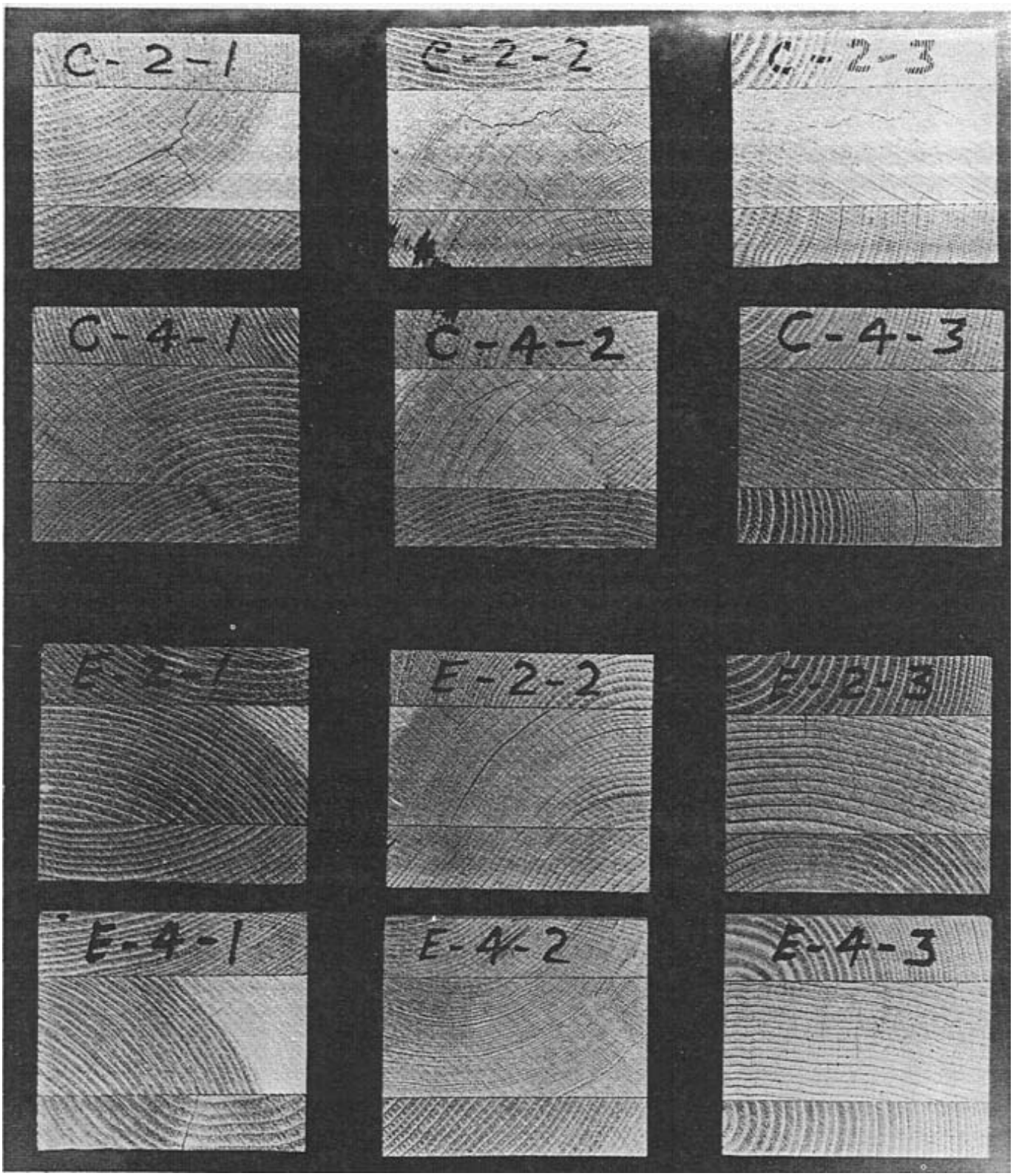
[4] Specimens were 3-1/4 by 3-1/4 by 12 inches with the bolt at an end distance of 5-1/4 inches, and located in the same laminations that contained a row of bolts in multi-bolted joints.

[5] Specimens were 3-1/4 by 7-1/2 by 82-1/4 inches with two rows of four bolts at an end distance of 5-1/4 inches and a spacing of 3 inches between bolts. The laminated members were assembled with each row of bolts bearing in laminations of relatively high and low density respectively.



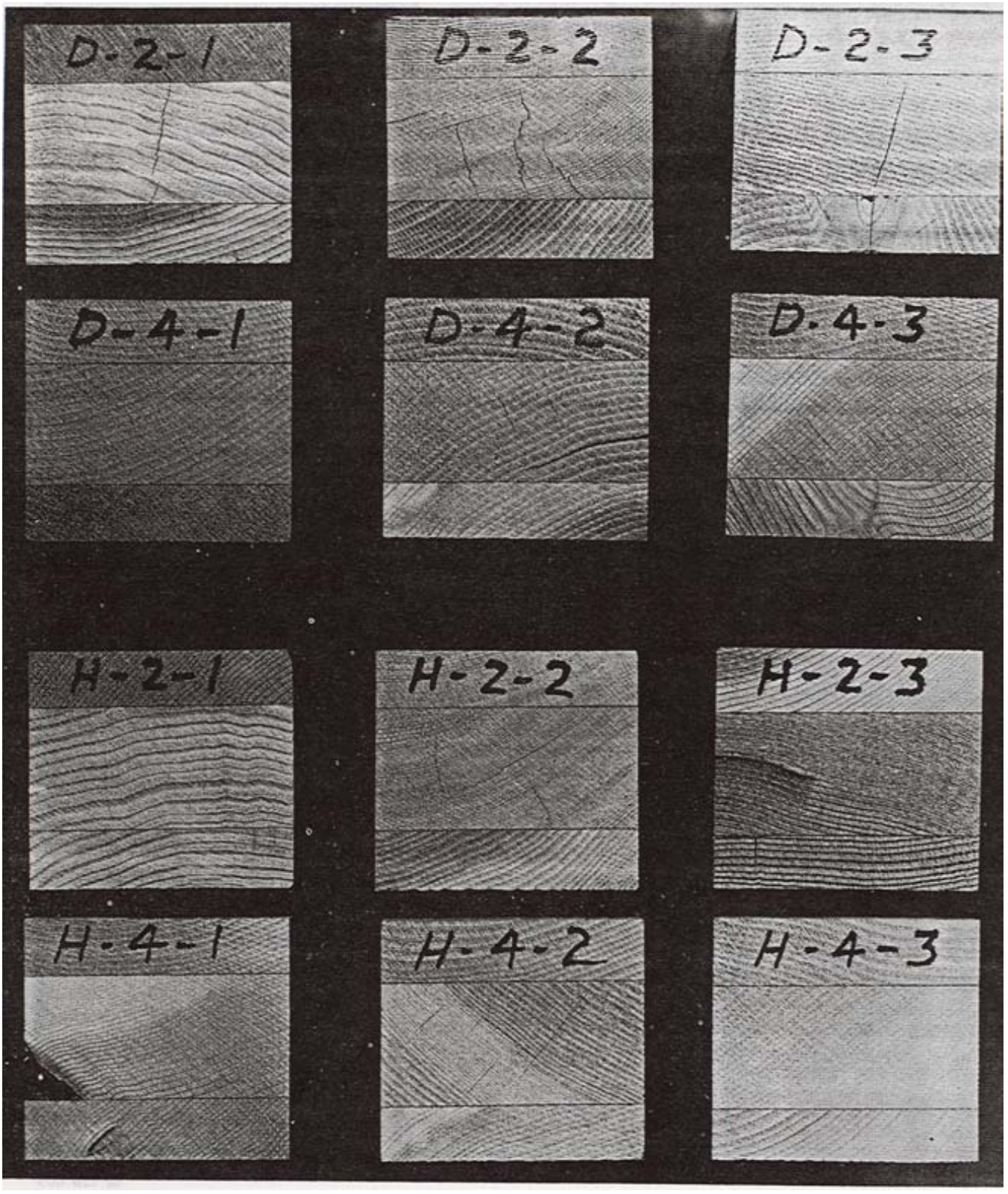
M 120 608

Figure 12.--End view of the single-bolt control specimens cut from the laminated members of series A and B. The failure in specimen B-4-1 resulted during testing of the specimen.



M 120 609

Figure 13.--End view of the single-bolt control specimens cut from the laminated members of series C and E.



M 120 610

Figure 14.--End view of the single-bolt control specimens cut from the laminated members of series D and H.

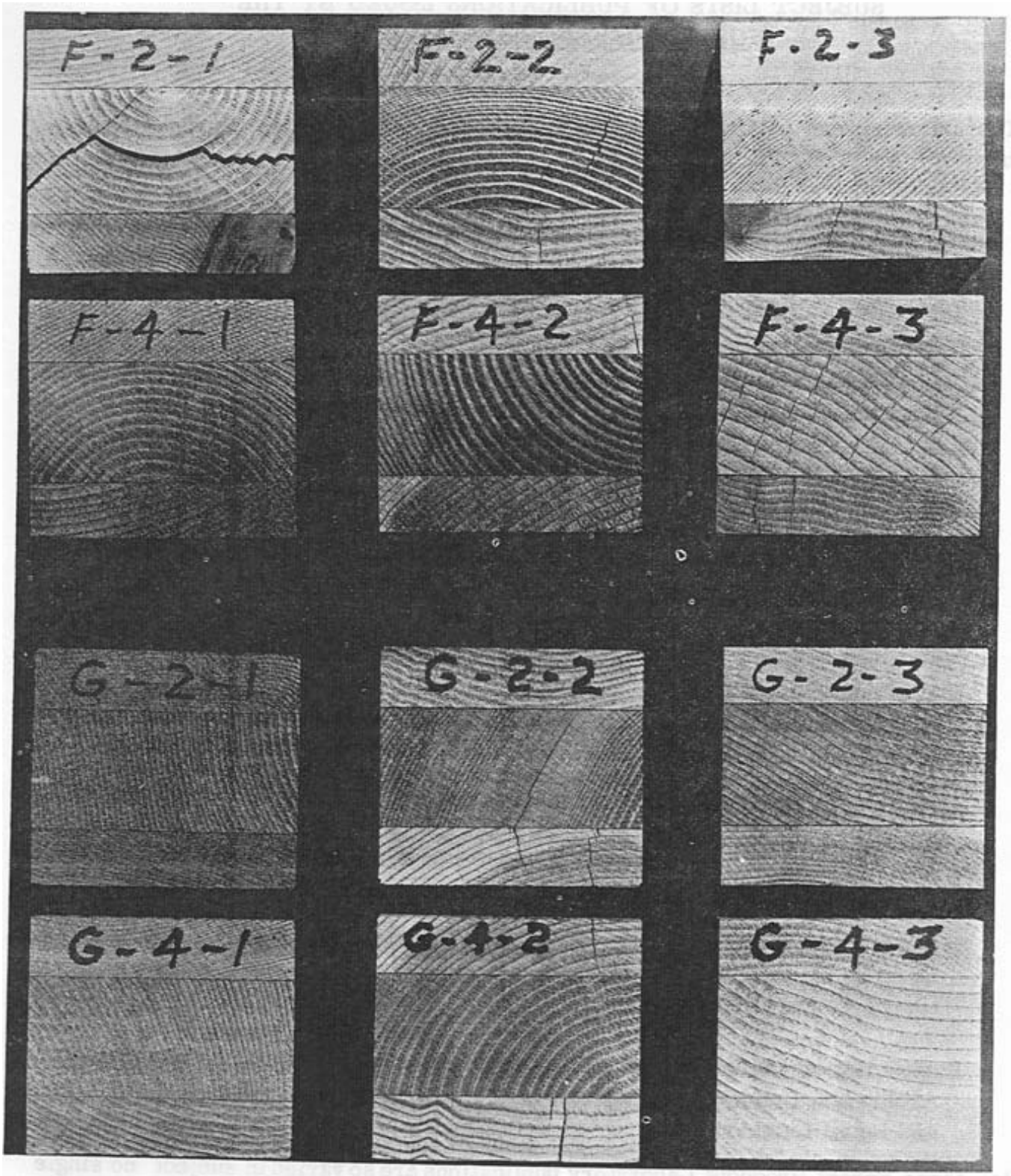


Figure 15.--End view of the single-bolt control specimens cut from the laminated members Of series F and G. The failure in specimen F-2-1 resulted during testing of the specimen.

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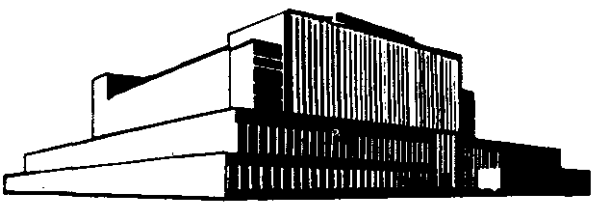

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