SHEAR STRENGTH AND ACCELERATED DURABILITY TESTS ON GLUE JOINTS IN LAMINATED RED OAK BEAMS APPLICABLE TO SUCH USES AS TRUCK BODIES, WAGONS, AND IMPLEMENT PARTS

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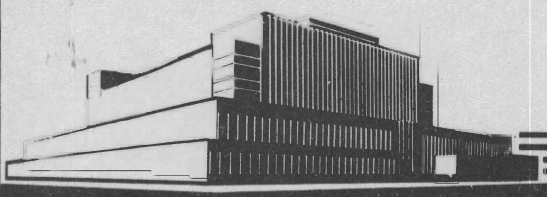

FOREST PRODUCTS LABORATORY
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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

SHEAR STRENGTH AND ACCELERATED DURABILITY TESTS ON GLUE JOINTS IN LAMINATED RED OAK BEAMS APPLICABLE TO SUCH USES AS TRUCK BODIES, WAGONS, AND IMPLEMENT PARTS [1]

By

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Summary

Laminated red oak beams of cross-sectional dimensions similar to truck body, wagon, and implement parts were fabricated with nine resorcinol and two urea-resin glues. Sections of the laminated beams were tested by soaking-drying cycles for resistance to delamination. All of the resorcinol glues produced bonds that appeared adequately durable for such parts when cured for 8 hours at 120° F., and four of them gave indications of being reasonably durable when cured for 16 hours at 80° F. The urea resins cured for 8 hours at 120° F. did not produce bonds that would appear adequate in extended service for laminated oak members under exterior conditions.

Introduction

During World War II wood bolsters and sills for truck bodies were produced to a large extent by laminating hardwood lumber, principally red oak, with urea-resin glues. Although these laminated members were protected by paint, the glue joints often developed delamination when exposed to the weather conditions encountered in service.

The development of resorcinol resins made available a type of glue that could provide joints of greater durability than the urea resins in such service. During 1945 when the merits of resorcinol glues had become known and the production of these resins had reached a sufficient quantity to make them available to laminators, the Forest Products Laboratory was

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

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consulted in the preparation of specifications for the procurement and application of resorcinol-resin glues. Insufficient data were available, however, to serve as a basis for specification tests.

The conventional dry block shear test, which is commonly included in most glue specifications, was not considered adequate to demonstrate glue-bond durability under severe service exposures.

An accelerated cyclic soaking-drying test developed at the Forest Products Laboratory had been found to give a reasonable indication of the durability that might be expected of glue joints in laminated construction in exterior service. This particular test had not been applied to specimens of red oak, nor to specimens directly comparable in size to members generally used for truck or wagon parts, however, and no data were available to establish directly the amount of delamination that might be acceptable in such sections when subjected to this test; nor were any data available from this test to show by direct comparison the performance of the several resorcinol glues offered on the market.

Based upon previous weathering tests on laminated white oak timbers, a heating period of 8 hours in a chamber maintained at 120° F. had been recommended for the fabrication of laminated red oak truck sills, of about 2-1/2 by 6 inches in cross section, with resorcinol resins.

Some manufacturers, however, had inquired whether gluing such members in multiple widths with resorcinols and curing them in clamps at room temperature overnight would be satisfactory if, subsequent to clamp removal, the members were ripped to about the sill size and then given the prescribed 120° F. curing treatment without the application of pressure. They inquired also whether a delayed heating treatment, possibly 1 to 2 weeks after the initial cure of the glue, would produce satisfactory joints.

It was desirable, therefore, to study the laminating of red oak for the following purposes: (1) to compare the qualities of the joints made with urea and resorcinol resins, (2) to devise a satisfactory procedure for laminating red oak lumber with resorcinol-resin glues, (3) to obtain test data that would permit the establishment of performance specifications, and (4) to compare various commercial resorcinol glues for laminating red oak.

Preparation of Test Specimens

Seventy-nine laminated beams, 2-1/2 by 6 by 12 inches, were made by gluing together 3/4-inch red oak boards selected for freedom from knots and defects. The boards had been previously conditioned to approximately 10 percent moisture content. Each assembly was made of eight laminations ranging in density from about 0.56 to 0.67 upon basis of weight when oven

dry and volume at 12 percent moisture content. The average density of the wood in each assembly was about 0.60, and the lumber was selected so that both the range in density and the average density were approximately the same for all beams.

In this work glued assemblies were cured under the following procedures:

I. In clamps for 8 hours in a chamber at 120° F.

II. In clamps for 16 hours in a room at 80° F.; then without pressure for 8 hours in a chamber at 120° F.

III. In clamps for 16 hours in a room at 80° F.; then without pressure in a room at 80° F. for 10 days; and then without pressure for 8 hours in a chamber at 120° F.

IV. In clamps for 16 hours in a room at 80° F.

Tests for dry shear strength and for resistance to delamination under accelerated cycles of soaking and drying were made on sections cut from the glued beams.

Nine resorcinol glues and two urea-resin glues were included in this study. The number of beams made with each glue by each of the four procedures is given in table 1.

The glues were mixed according to the manufacturers' instructions. Glue was spread on each mating surface for a total glue spread of about 60 pounds per 1,000 square feet of joint area. A closed-assembly time of 30 minutes was allowed for the resorcinol glues and of 15 minutes for the urea resins. The open-assembly time was negligible. A clamping pressure of about 150 pounds per square inch was applied by means of retaining clamps.

In procedure I the clamped beams were moved to a curing chamber shortly after the clamps were tightened. The temperature of the chamber was maintained at 120° F. and the relative humidity at about 65 percent (equilibrium moisture content about 11 percent). After 8 hours, the beams were removed from the chamber and unclamped while hot.

In procedure II the beams were held under pressure in clamps for 16 hours in a room kept at 80° F. and 65 percent relative humidity, after which they were unclamped and moved to a chamber at 120° F. and 65 percent relative humidity, where they were held for 8 hours without pressure.

In procedure III the beams were cured in the same manner as in procedure II, except that there was a lay-over period of 10 days between unclamping and the final curing at 120° F. During the 10 days the beams were kept in a room at 80° F. and 65 percent relative humidity.

In procedure IV the beams were held in clamps in a room kept at 80° F. and 65 percent relative humidity for 16 hours.

All beams were allowed to condition for at least 1 week in air at 80° F. and 65 percent relative humidity before they were cut into specimens and tested.

Testing

After conditioning, all beams were surfaced to 2-1/4 inches in width, and specimens were cut for testing as follows:

1. Dry Block Shear Test

At least 2 inches were removed from one end of each beam and discarded (fig. 1). A conventional "stairstep-type" shear block specimen was cut from the adjoining section to furnish one test on each of the seven glue joints. The joints were tested dry on a universal testing machine with the shearing tool moving at approximately 0.015 inch per minute. A summary of the results is shown in table 2.

2. Accelerated Vacuum-pressure Soaking-drying Delamination Test

Two 3-inch sections were cut from each beam, one (marked section 1) cut with its center about 4-3/4 inches from the end of the beam and the other (marked section 2) taken next to the end of the beam with merely 1/8 to 1/4 inch allowed for end trimming. The location of test sections in the beam is shown in figure 1. It was thought that a comparison of the performances of the two sections might furnish some information as to the amount of end trimming that would be required for laminated material.

The 3-inch sections were subjected to three cycles of soaking and drying, according to the following procedure:

The test specimens were placed in an autoclave and weighted down, and a vacuum of from 20 to 25 inches of mercury was drawn for 2 hours. Then, without breaking the vacuum, water at room temperature was admitted to the autoclave in sufficient quantity to cover the specimens. The vacuum was broken, and air pressure of 75 pounds per square inch was applied to the submerged samples and held for 2 hours. The vacuum-pressure cycle was repeated once with the specimens remaining submerged. The soaking was continued for an additional 16 hours at atmospheric pressure, after which the specimens were dried for 6 days in a room at 80° F. and 30 percent relative humidity with good circulation of air. The delamination of glue

joints was measured during the fourth day of drying in the third cycle. A summary of the results of these tests is shown in table 3. The percentage of delamination shown for the specimens is the length of open glue joints based upon the total length of joints exposed on the end-grain surfaces of the sections. The depth of separation in the open glue joints was not considered in the evaluation of results.

Discussion of Results

Curing Procedure I

A summary of the results of dry block shear tests made on beams fabricated according to procedure I is given in table 2, and a graphical presentation of shear-test results and of results of the soaking-drying delamination test is shown in figure 2. The shear values shown (table 2 and fig. 2) are averages of 21 tests, for which seven specimens were taken from each of three beams made with each glue. Six of the resorcinol glues gave average wood failures of 75 percent or more, two gave values of 50 to 70 percent, and only one glue (G) gave less than 50 percent wood failure. Average shear strength values for resorcinol glues ranged from 2,179 to 2,543 pounds per square inch. All beams glued with urea resins showed high shear strengths, and the average wood-failure values were 75 percent or more.

The results of the dry shear tests furnished no basis for differentiating between durability of the resorcinol and urea-resin glue joints, as the test values for the urea joints compared favorably with those for the resorcinols.

A summary of results of the delamination tests on sections of the beams made in accordance with procedure I is given in table 3. The percentage delamination of the glue joints (for procedure I) is the average for six sections (two from each of three beams) made with the same glue. For most of the resorcinol glues the amount of delamination was low and reasonably uniform, with very little variation between specimens. With a few, the test values were somewhat erratic, but the averages for all resorcinol glues came within a rather narrow range. In general, the percentage delamination was somewhat less in these tests on 2- by 6-inch red oak beam sections than in similar tests at the Forest Products Laboratory on 6- by 6-inch white oak beam sections made with durable, well-cured glues.

In general, there was slightly more delamination in sections taken at the immediate ends of the beams than in sections taken a few inches away from the ends. With the possible exception of glue A, however, the delamination in sections taken at the ends was not significantly more serious than the delamination in sections taken away from the ends. It would appear,

therefore, that not much end trimming is necessary when uniform pressure is applied throughout the entire length of a laminated beam when curing temperatures are not high and the curing is completed before the pressure is removed. This, however, precludes any defects in planing that sometimes occur near the ends of boards; if such are present they must be removed by adequate end trimming.

In the cyclic test, the urea-resin glues showed definitely poorer performance than the resorcinols. Both urea-resin glues developed much more delamination than any of the resorcinol-resin glues. The highest average delamination for any of the resorcinol glues tested was about 5 percent; whereas sections glued with one urea resin had an average delamination of approximately 10 percent, and with the other about 26 percent.

Curing Procedure II

A summary of results of block shear tests on the beams cured in accordance with procedure II is shown in table 2, and average results of the delamination test are given in table 3. A graphical presentation of the results for procedure II is shown in figure 3. With this method of curing there was a wide variation in the performance of the various resorcinol glues. No urea resins were included in this test.

Glues B, E, and H gave results by this method of cure fairly comparable to those obtained in procedure I. Glues F and I showed appreciably poorer performance in procedure II than in procedure I, and results with glues A, C, D, and G indicated that these glues do not produce durable joints when cured in accordance with procedure II. In general, there was good agreement between results of the block shear test and the delamination test. Low wood failures invariably reflected poor performance in the delamination test; and where the wood failures were high, the delamination values were low, which indicated durable glue bonds.

Curing Procedure III

Results of block shear and delamination tests for beams cured according to procedure III are summarized in tables 2 and 3, and a graphical presentation of the results for procedure III is shown in figure 4. With one exception (glue F), every glue showed better resistance to delamination by this method of curing than by procedure II. The cause of the poorer performance in procedure II may have been that stresses due to expansion of the wood were exerted on the glue bonds when the beams were heated to 120° F. without clamping pressure before the glue was adequately cured. In procedure III, where secondary heating was delayed for 10 days, the glues had had the opportunity to set more firmly before the final heating was applied and were in a better position to resist stresses induced by heating.

By this method of curing (procedure III), glues B, D, E, H, and I in general developed high wood failures in the dry shear tests and showed high resistance to delamination, glue F gave somewhat erratic results, and glues A, C, and G showed decidedly unsatisfactory performance in both shear tests and cyclic tests.

The sections taken near the ends of the beams, cured according to procedures II and III, usually developed more delamination than those taken a few inches away from the ends for several of the glues used. This result appears to conform to the theory that the partially cured glue bonds are stressed and possibly ruptured by expansion of the wood when additional heat is applied without the benefit of clamps. Stresses due to expansion would be greater near the ends of the beams and would be likely to result in larger amounts of delamination in test sections taken adjacent to the ends.

Curing Procedure IV

Results of block shear test and delamination tests on beams cured at 80° F. without further heating at higher temperatures (procedure IV) are summarized in tables 2 and 3, and a graphical presentation of these results is shown in figure 5. Only the five glues that had shown the more promising results by curing methods I, II, and III were included in this procedure. Four of the glues, B, E, H, and I, developed reasonably high shear strengths and wood failures in the block shear test, and their delamination values were also of a satisfactorily low order. Joints made with glue F, however, gave low wood failures in the shear test and developed considerable delamination in the cyclic test, which indicated that this cure was inadequate for this glue.

Comparison of Performance of Various Glues Cured by the Four Different Procedures

In tables 2 and 3 it may be noted that certain of the resorcinol glues (B, E, H, and I) gave high wood failures and low delamination values rather consistently, regardless of curing method, while the others, in general, did not develop high wood failures or satisfactorily resist delamination except where the curing was carried out under pressure at 120° F. (procedure I).

Of the urea glues cured at 120° F., glue K performed poorly in the delamination test, and glue J, although it performed much better, was not entirely satisfactory. (The urea glues were not included in procedures II, III, and IV.)

In figures 6 to 9 are shown photographs of 3-inch beam sections glued with various resorcinol and urea resins and cured in accordance with procedure

I. The photographs were taken after the sections had been subjected to three cycles of the accelerated soaking-drying (vacuum-pressure) delamination test. As may be noted, the glue joints are practically free from delamination in all sections made with resorcinol glues (A to I inclusive), while the sections made with urea resins (J and K) are considerably delaminated.

In figures 10 and 11 are pictures of beam sections made with resorcinol glues and cured according to procedure IV (16 hours under pressure at 80° F.). These sections show only slight delamination, with the exception of the one made with glue F, which delaminated appreciably.

Conclusions

The results showed that the dry block shear test is not capable of differentiating between glues that are durable or nondurable under exposure to severe moisture conditions, but that with types of glues known to be durable, when used with the proper technique, the wood failures developed in the dry shear test give a good indication of the quality of the joints. The accelerated soaking-drying cyclic test, however, is very helpful in differentiating between joints of variable durability under exterior use.

From the results of these tests it is concluded that resorcinol glues, when adequately cured, produce much more durable glue bonds in laminated red oak than urea glues.

These investigations further indicated that all the resorcinol glues tested would produce glue bonds in red oak that would be adequate for truck bodies, wagons, implement parts, and the like, if the glues were cured under pressure for a period of 8 hours at 120° F. Curing at 80° F. did not produce joints so resistant to delamination as curing at 120° F., although with some glues a temperature of 80° F. appeared to be sufficient. A precure under pressure at 80° F. with subsequent additonal cure at 120° F. without clamping pressure was not so satisfactory as initial curing at 120° F., and it did not produce durable bonds for several of the glues tested. Heating the beams at 120° F. after 10 days' curing at 80° F. effected some improvement in the quality of the joints, but was not so satisfactory as initial curing at 120° F.

It appeared from the results of these studies that a value of 10 percent might reasonably be set as the maximum delamination allowable in specifications for laminated red oak beams for uses such as truck bodies and wagon parts, when tested by the accelerated soaking-drying cyclic test.

Table 1.--Experimental beams

Procedure	Number of resorcinol-formaldehyde glues	Number of urea-formaldehyde glues	Number of beams with each glue	Number of beams by each procedure
I	9	2	3	33
II	9	0	2	18
III	9	0	2	18
IV	5	0	2	10

Table 2.--Summary of results of dry[1] block shear tests on glue joints in laminated red oak beams glued with resorcinol and urea-resin glues

Curing procedure[2]	Type of glue										
	Resorcinol-resin									Urea-resin	
	A	B	C	D	E	F	G	H	I	J	K
I	[3]2,377-83	2,543-88	2,389-56	2,222-67	2,499-75	2,441-76	2,179-42	2,443-81	2,479-84	2,577-96	2,401-75
II	1,673-7	2,325-70	2,106-12	1,582-23	2,354-82	1,996-36	1,686-10	2,500-73	2,235-56	.....	.....
III	2,183-23	2,322-69	2,087-11	2,337-48	2,146-87	1,947-24	1,658-8	2,396-82	2,130-64	.....	.....
IV	.....	2,310-69	.....	.....	2,412-73	2,115-35	.....	2,099-59	2,207-59	.....	.....

[1] Tested dry after being conditioned to 10 to 12 percent moisture content.

[2] I: The clamped assemblies were cured for 8 hours in a chamber held at 120° F.
II: The clamped assemblies were cured for 16 hours at 80° F. They were then unclamped and given an additional cure at 120° F. for 8 hours.
III: Identical with procedure II, with the exception that there was a 10-day lay-over period between unclamping and the final cure (during this time the beams were kept in a room held at 80° F. and 65 percent relative humidity).
IV: The clamped assemblies were cured for 16 hours at 80° F. They were then unclamped, but were not subjected to any further heating at higher temperatures.

[3] The first figure represents shear strengths in pounds per square inch; the second figure represents wood failure in percent. Each value given for procedure I is the average of 21 tests, and for the other procedures each value is the average of 14 tests.

Table 3.--Summary of results of glue-joint delamination tests on 3-inch sections of laminated red oak beams glued with resorcinol and urea-resin glues

Curing procedure[1]	Type of glue										
	Resorcinol-resin									Urea-resin	
	A	B	C	D	E	F	G	H	I	J	K
I	[2]4.7	0.0	1.0	4.5	0.2	2.7	2.5	0.3	0.3	10.5	26.4
II	41.1	5.3	22.4	43.3	5.3	9.2	33.0	.5	10.0	.....	.....
III	26.1	1.7	16.7	3.4	.0	10.0	26.5	.1	1.6	.....	.....
IV	.....	1.4	.....	.....	6.0	23.9	.....	6.3	3.0	.....	.....

[1] See table 2, footnote 2, for description of the various procedures.

[2] Average delamination of glue joints on the end-grain surfaces of the beam sections at completion of test, expressed as percentage of the total length of glue joints exposed on these surfaces.

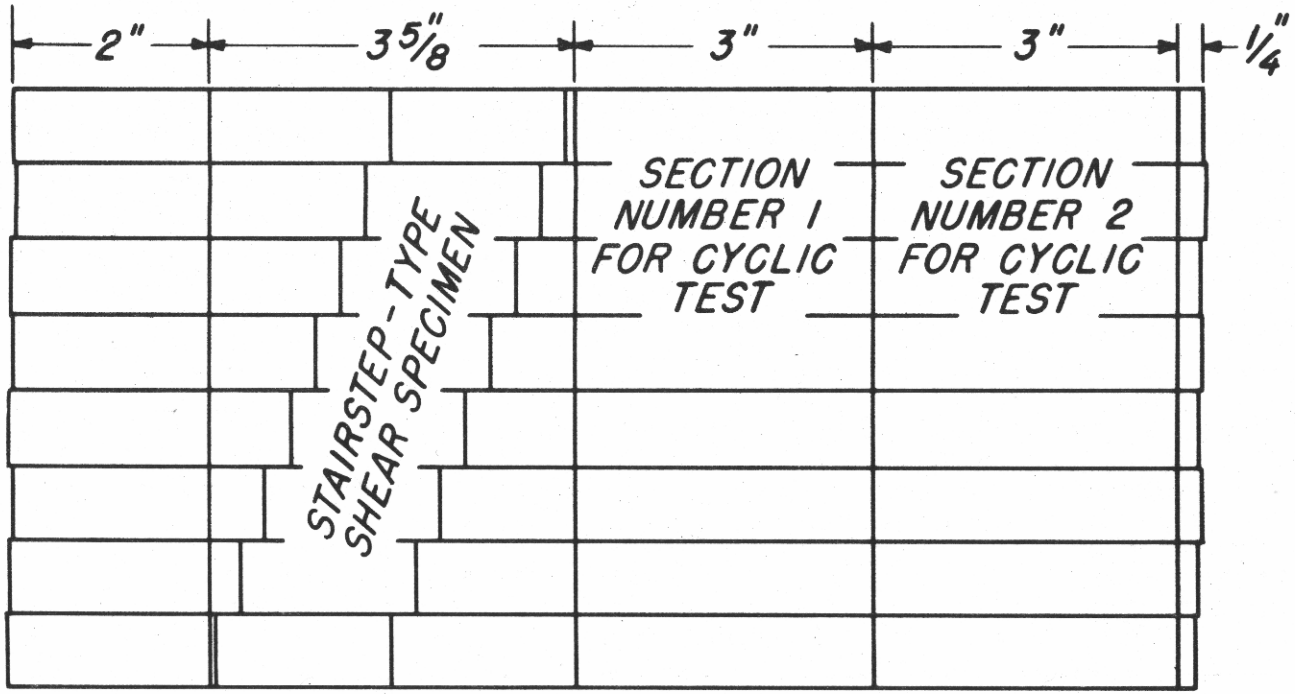

Figure 1.—Side view of laminated beam, showing method of cutting test specimens.

ZM 73049 F

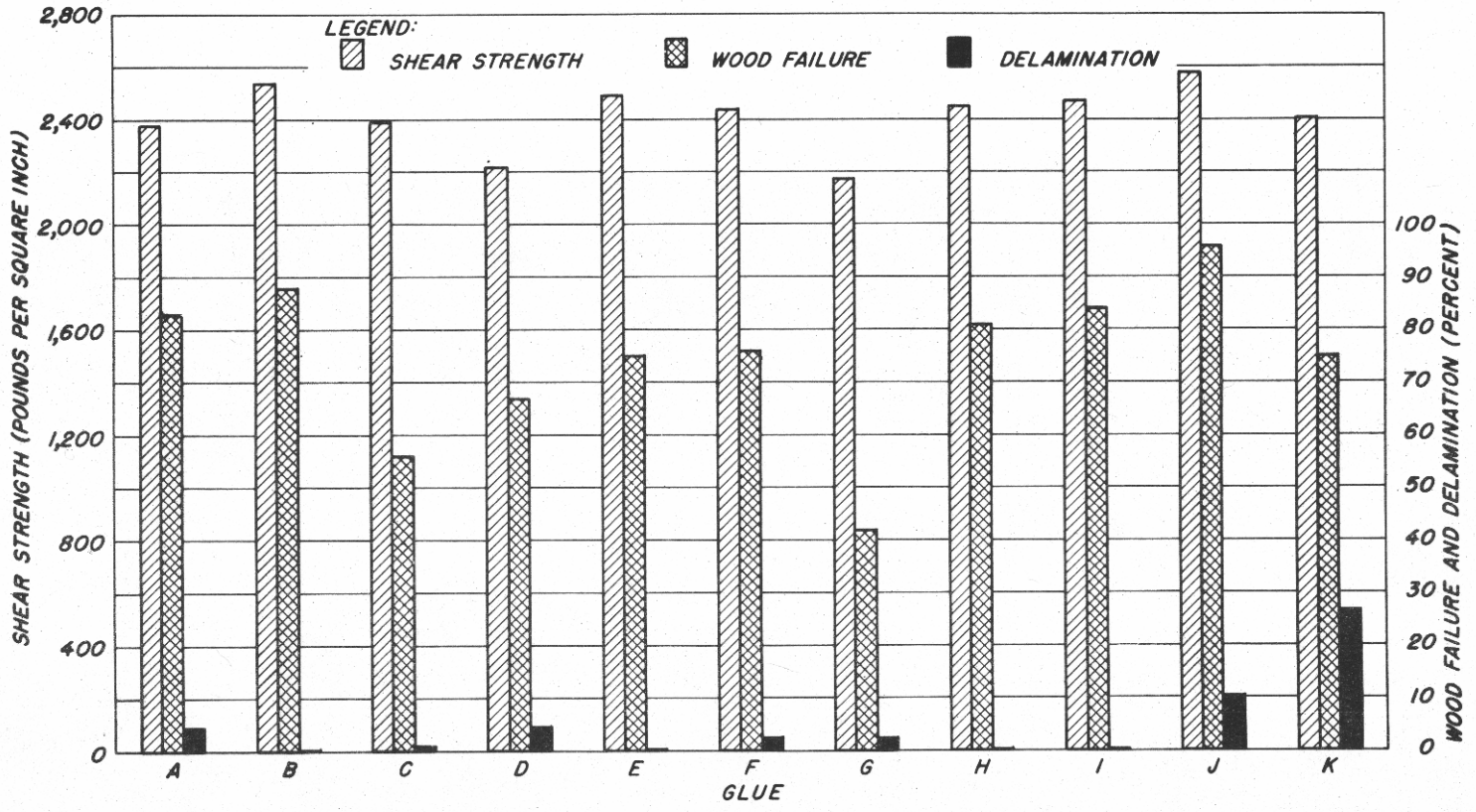

Figure 2.--Results of dry block shear tests (shear strength and wood failure) and accelerated soaking-drying delamination tests on glue joints in laminated red oak beams glued with nine resorcinol (A to I) and two urea (J and K) resin glues and cured 8 hours in a chamber maintained at 120° F. (procedure I).

Z M 74800 F

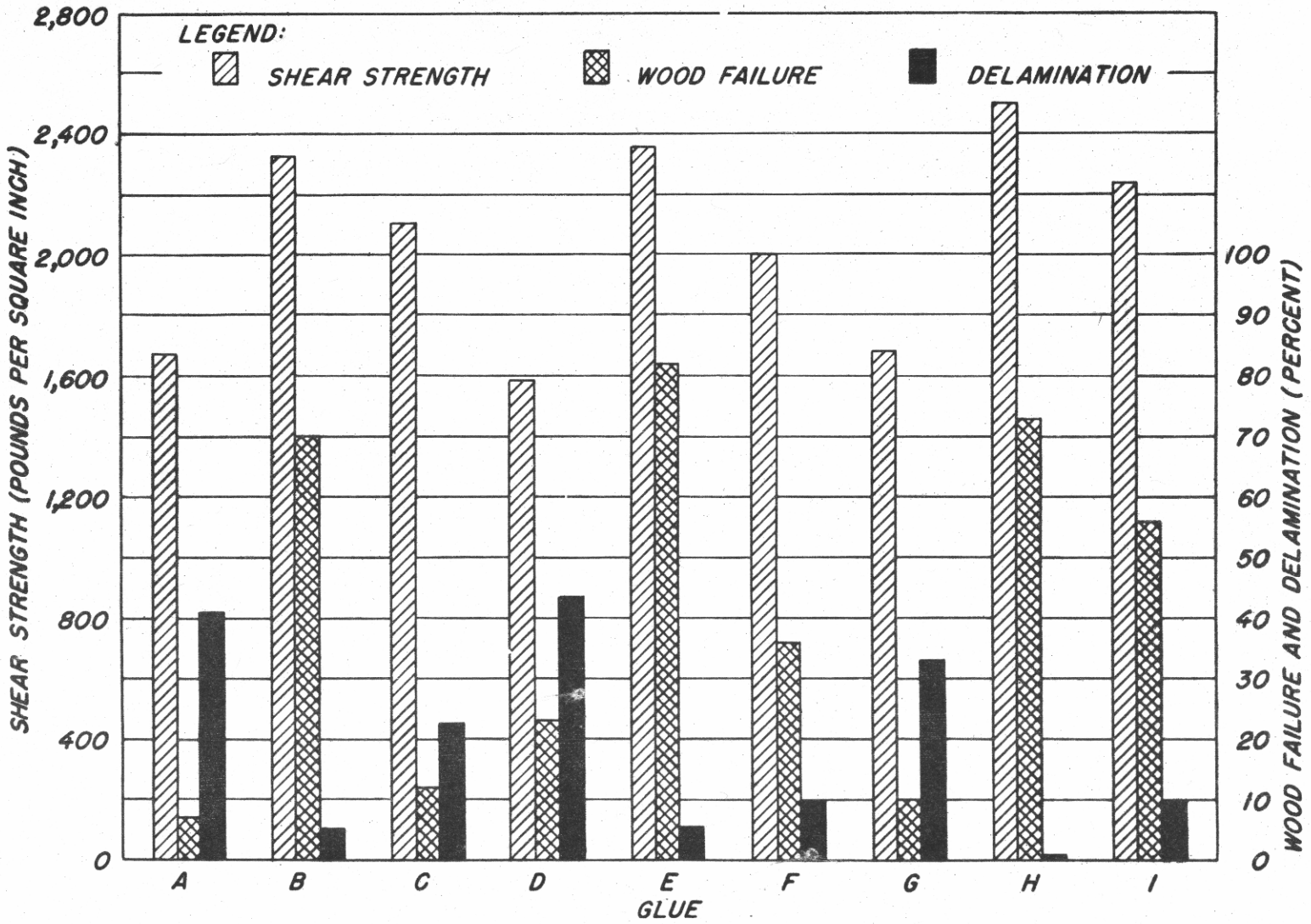

Figure 3.--Results of dry block shear tests and accelerated soaking-drying delamination tests on glue joints in laminated red oak beams glued with nine resorcinol-resin glues and cured 16 hours at 80° F. (in clamps), followed by 8 hours at a chamber temperature of 120° F. (without clamps) (procedure II).

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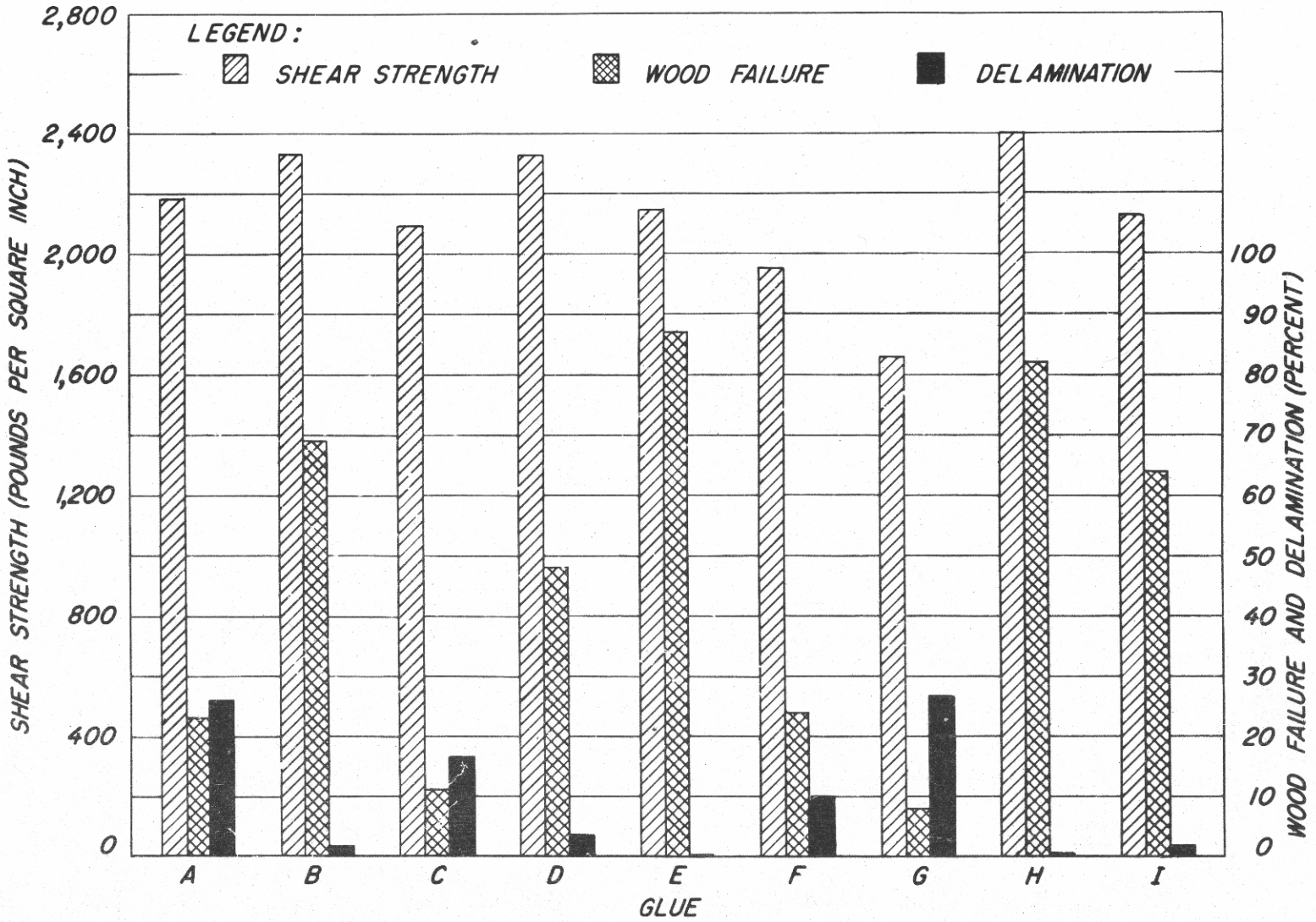

Figure 4.--Results of dry block shear tests and soaking-drying delamination tests on glue joints in laminated red oak beams glued with nine resorcinol-resin glues and cured as follows: 16 hours at 80° F. (in clamps), followed by 10 days at 80° F. (without clamps), followed by 8 hours at 120° F. (without clamps) (procedure III).

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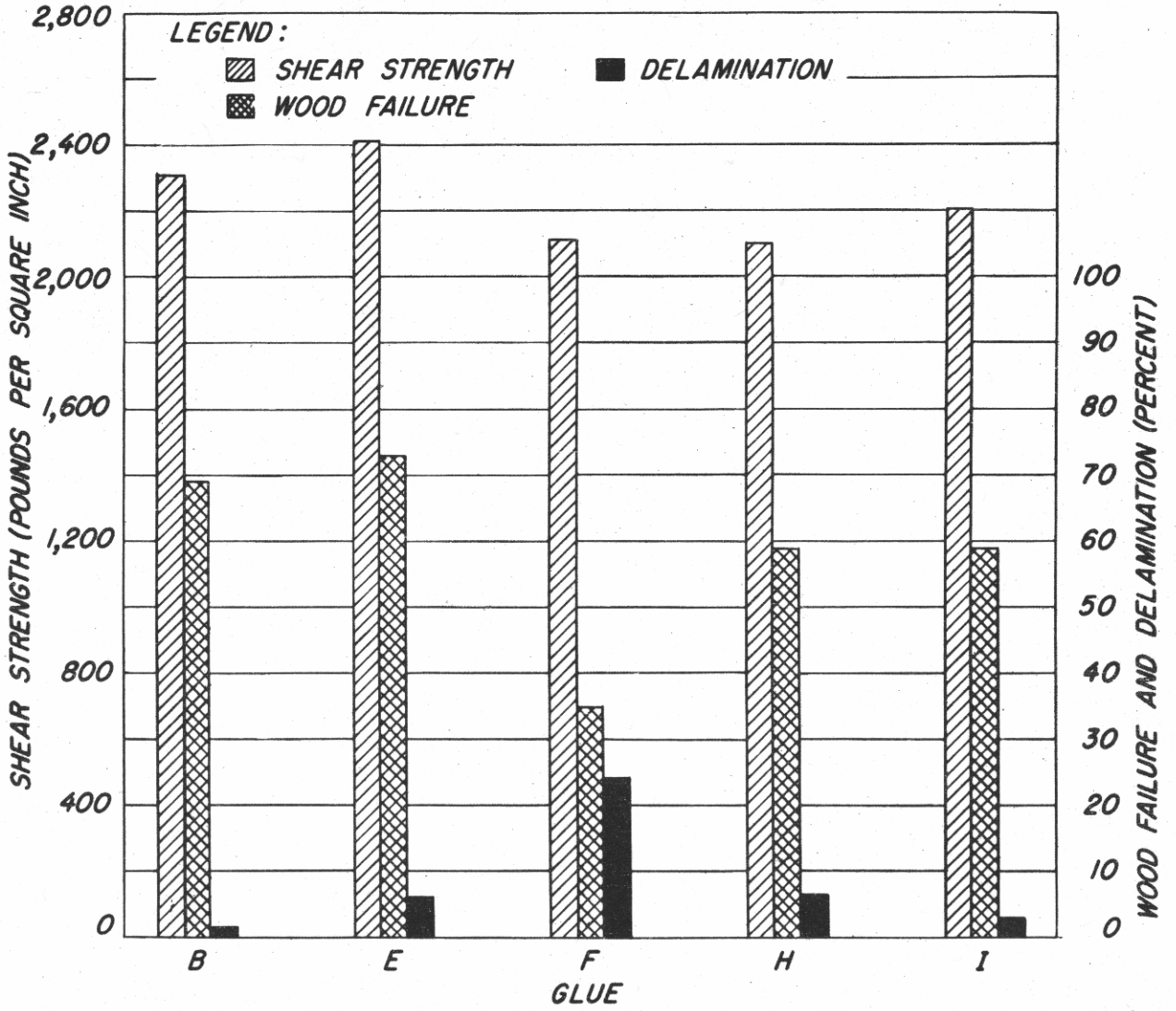

Figure 5.--Results of dry block shear tests and accelerated soaking-drying delamination tests on glue joints in laminated red oak beams glued with five resorcinol-resin glues and cured 16 hours at 80° F. (procedure IV).

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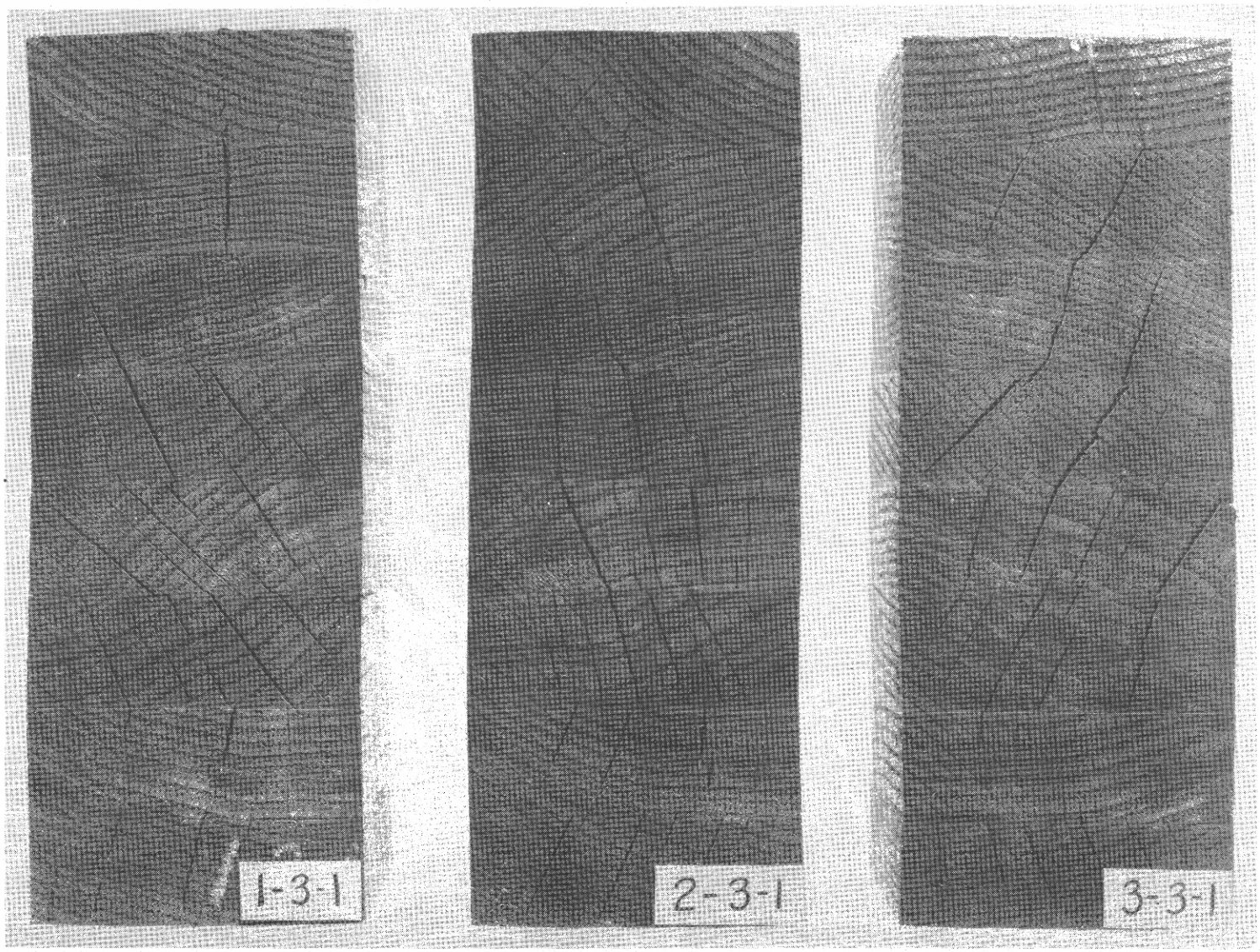

Figure 6.—Sections of laminated red oak beams glued with resorcinol resins cured under pressure for 8 hours at 120° F. (procedure I) and subjected to three cycles of accelerated soaking and drying. From left to right the sections were made with glues A, B, and C, in the order named. The wood has checked considerably, but the glue joints are practically free from delamination.

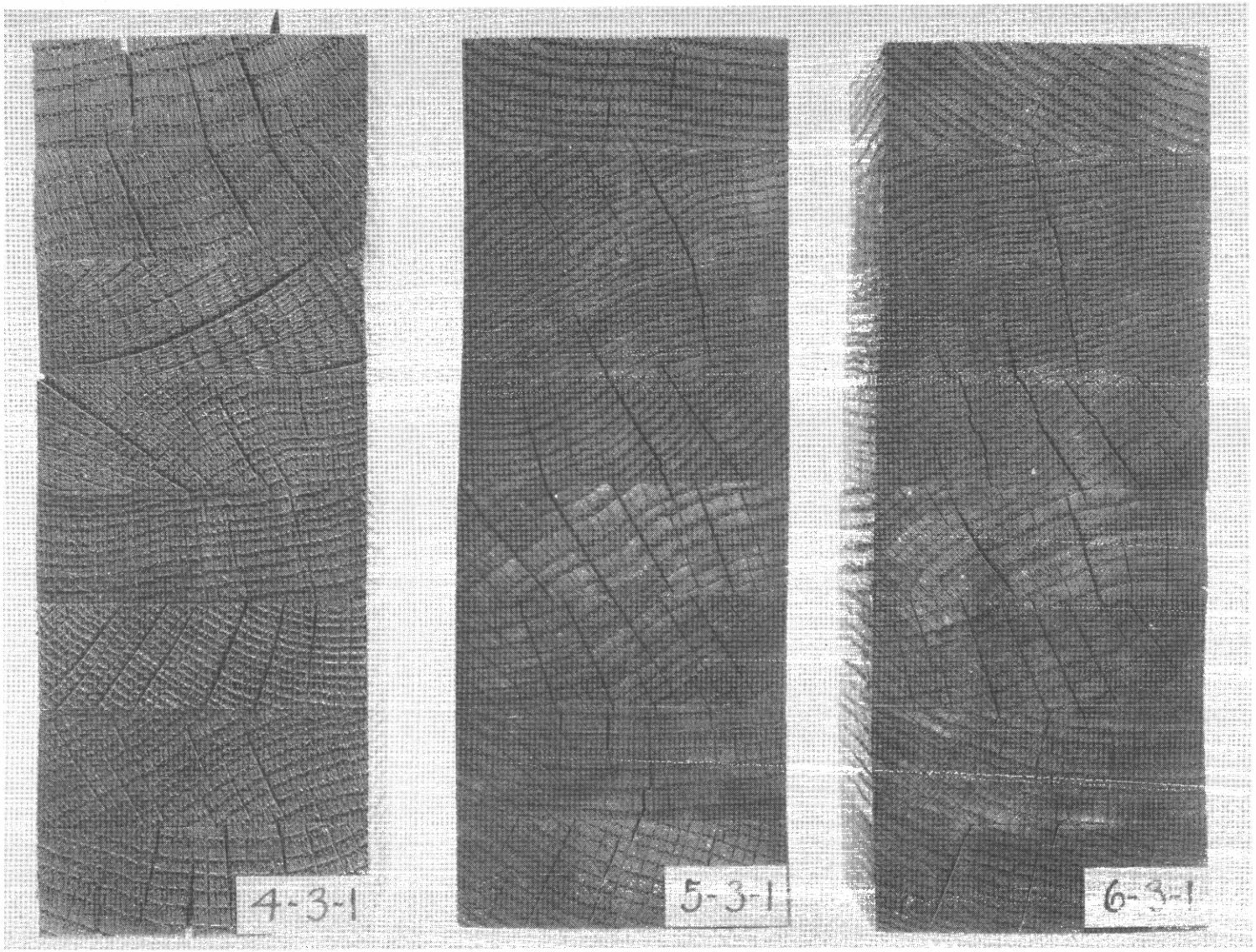

Figure 7.--Sections of laminated red oak beams glued with resorcinol resins cured under pressure for 8 hours at 120° F. (procedure I) and subjected to three cycles of accelerated soaking and drying. From left to right the sections were made with glues D, E, and F, in the order named. The wood has checked considerably, but the glue joints are practically free from delamination.

Z M 75144 F

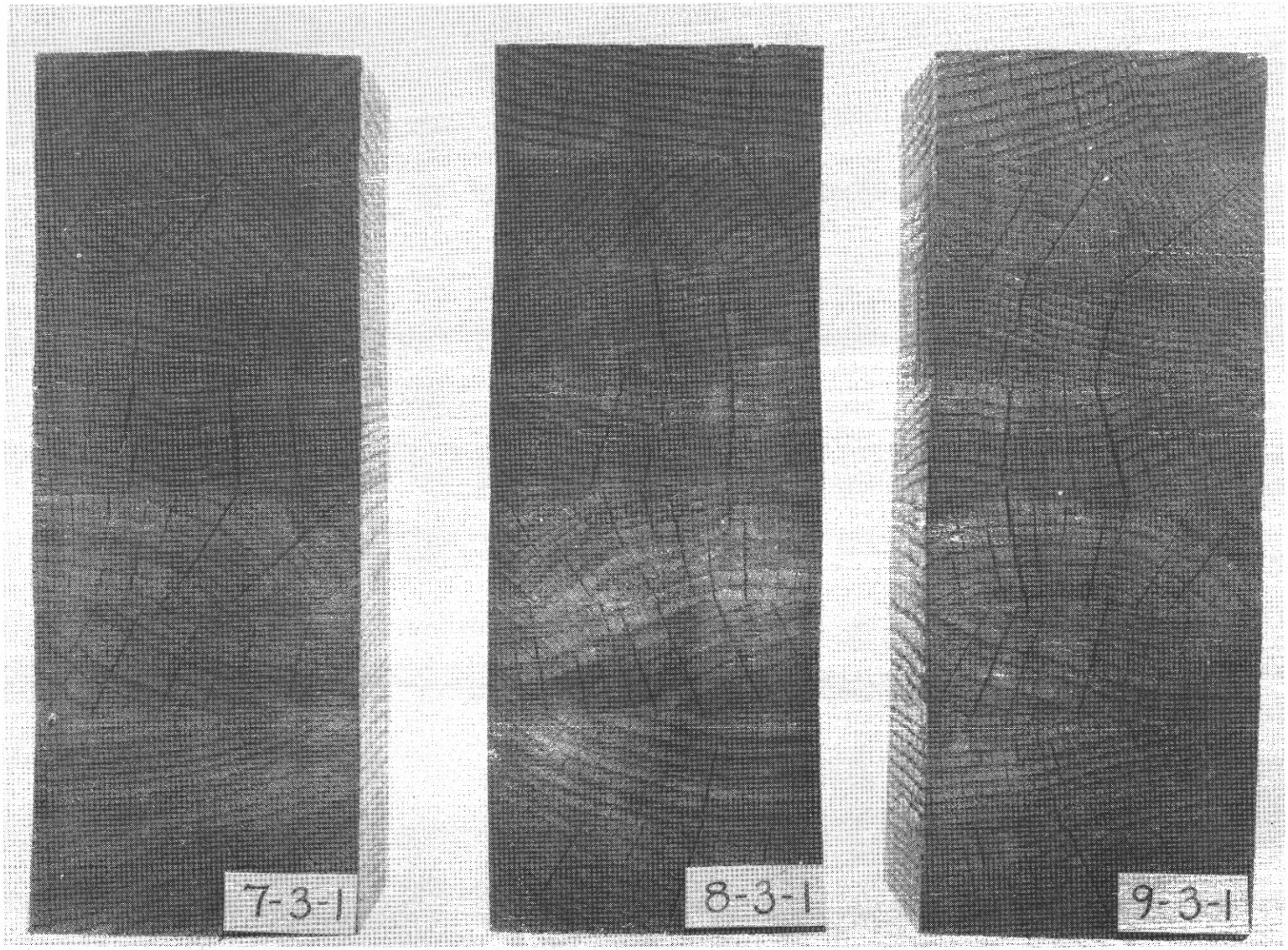

Figure 8.--Sections of laminated red oak beams glued with resorcinol resins cured under pressure for 8 hours at 120° F. (procedure I) and subjected to three cycles of accelerated soaking and drying. From left to right the sections were made with glues G, H, and I, in the order named. The wood has checked considerably, but the glue joints are practically free from delamination.

Z M 75145 F

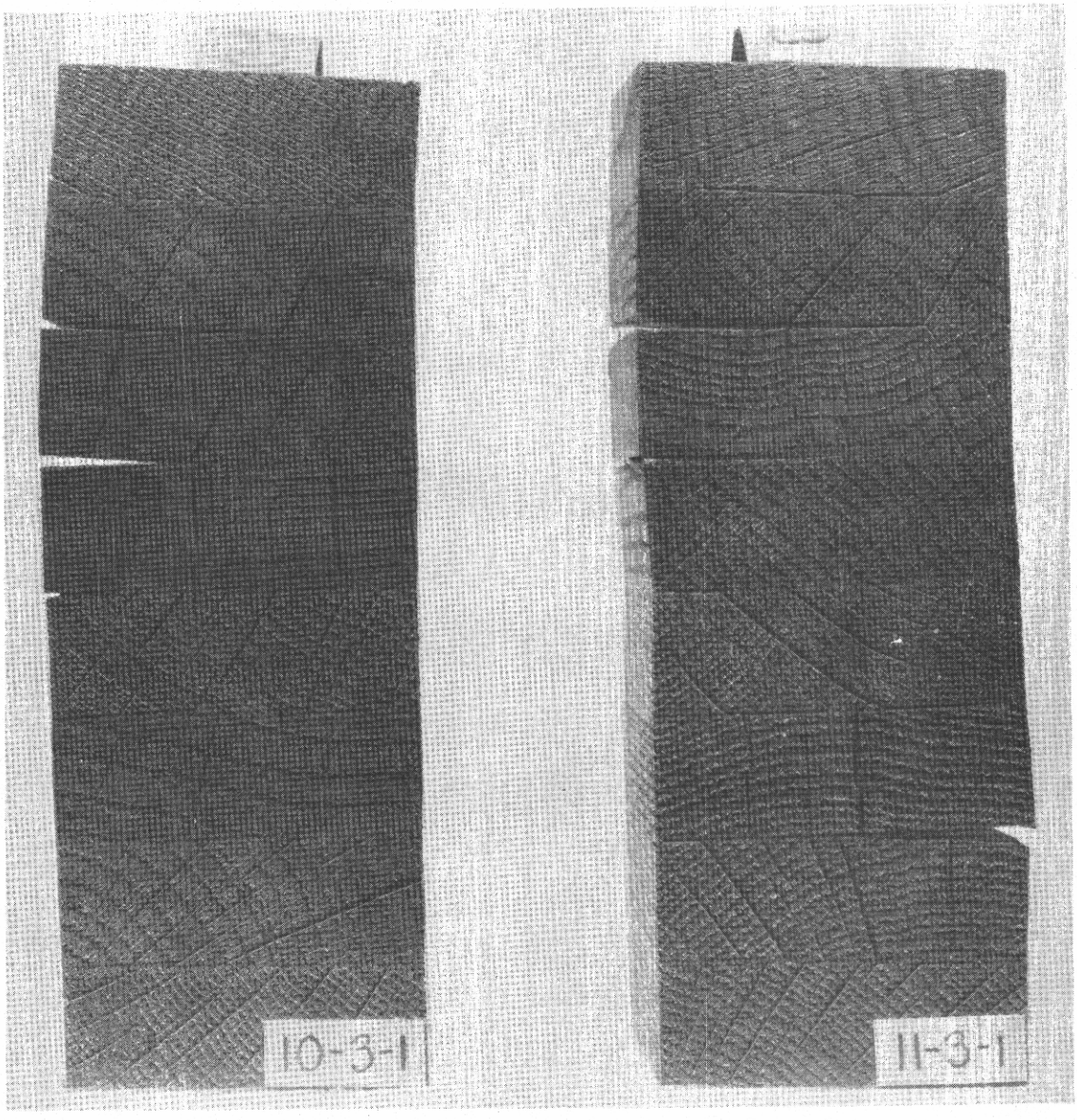

Figure 9.--Sections of laminated red oak beams glued with urea resins cured under pressure for 8 hours at 120° F. (procedure I) and subjected to three cycles of accelerated soaking and drying. Note large amount of delamination. Section on left made with glue J, the one on right with glue K.

Z M 75146 F

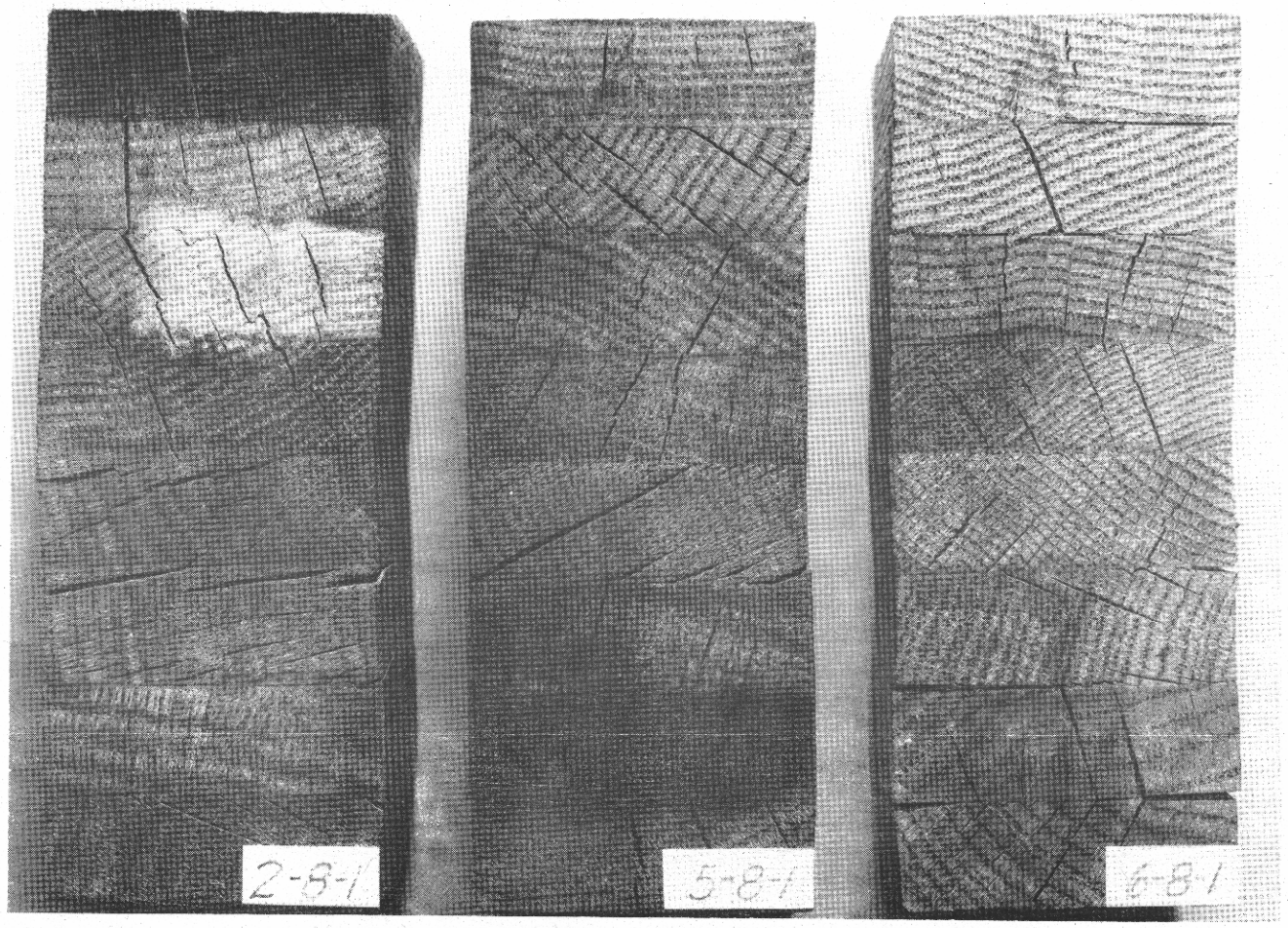

Figure 10.--Sections of laminated red oak beams glued with resorcinol resins cured under pressure for 16 hours at 80° F. (procedure IV) and subjected to three cycles of accelerated soaking and drying. From left to right the sections were made with glues B, E, and F, in the order named. The wood has checked considerably. The section made with glue F has developed a considerable amount of open glue joints.

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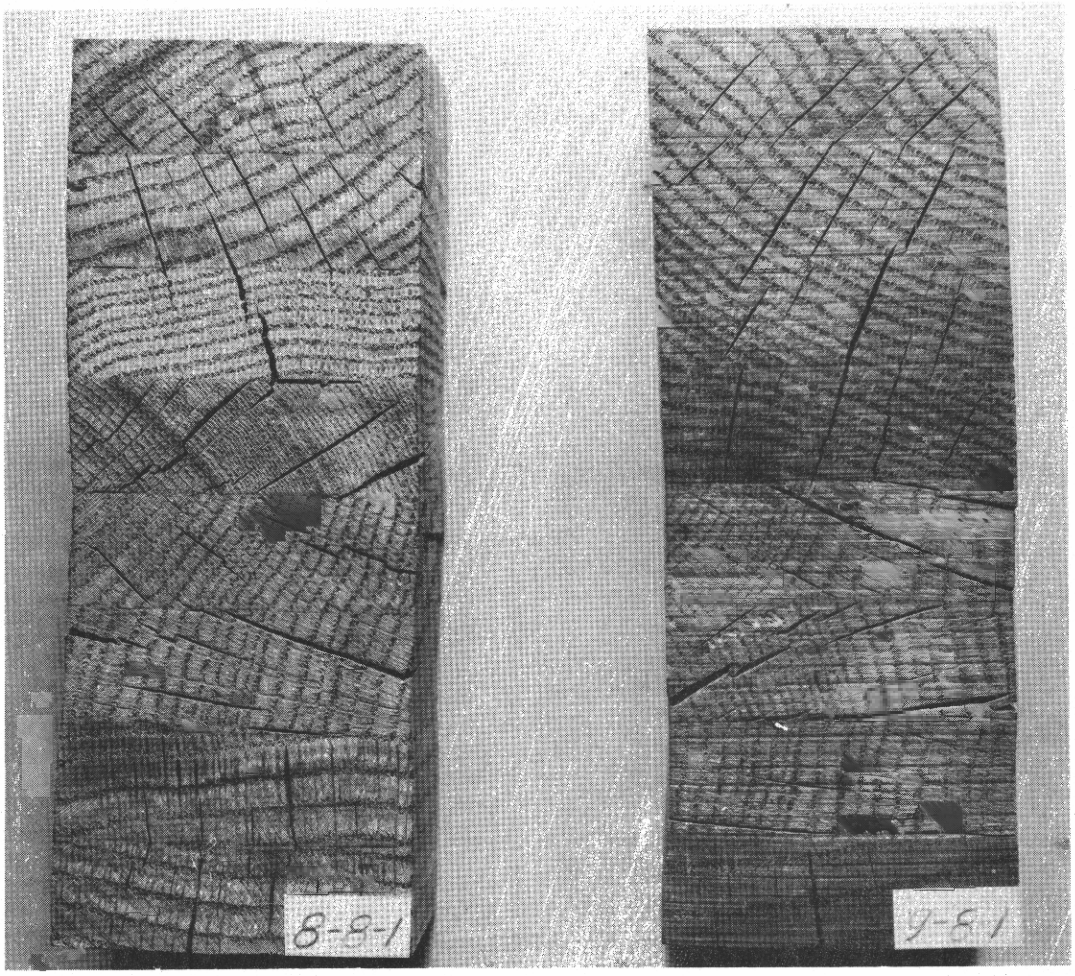

Figure 11.—Sections of laminated red oak beams glued with resorcinol resins cured under pressure for 16 hours at 80° F. (procedure IV) and subjected to three cycles of accelerated soaking and drying. Section on left made with glue H, the one on right with glue I. The wood has checked considerably, but the glue joints are practically free from delamination.

Z M 75148 F