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In Cooperation with the University of Wisconsin

EFFECT OF MIXING FLAT AND VERTICAL GRAIN

IN LAMINATED WHITE OAK BEAMS¹

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Summary

Laminated white oak beams were fabricated with all vertical-grained laminations or with vertical- and flat-grained boards alternated, and were subjected to longterm soaking and weathering exposures. The results indicated that adequate and durable glue bonds can be obtained in both types of construction, but that vertical-grained oak laminations have a tendency to develop cleavage parallel to the glue lines when subjected to severe exposures and therefore may be less desirable than flat-sawn oak material for use in members intended for exterior service.

Introduction

Studies made on the durability of glue bonds in laminated beams, glued with highly water-resistant synthetic-resin glues at the Forest Products Laboratory, have dealt chiefly with clear, flat-grained lumber. While occasional vertical-grained boards were used, no attempt had been made to study systematically the effect of mixed grain on the quality of the glue bonds. Since segregation of lumber according to grain involves extra labor and expense to a commercial laminator, it seemed advisable to study the relative quality of glue bonds between vertical-grained boards and between vertical- and flat-grained boards, and to compare the results with those previously obtained from beams laminated from all flat-grained lumber.

¹The work here reported was conducted in cooperation with the Bureau of Ships, U.S. Navy. Original report dated June 1948.

²This study was started by the late R. O. Rosendahl, Technologist.

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

Preparation of Test Beams

Four white oak beams, each consisting of 13 laminations $\frac{3}{4}$ by $9\text{-}\frac{3}{4}$ by 48 inches, were glued. The lumber was selected for freedom of knots and other defects and was conditioned to approximately 12 percent moisture content before it was surfaced for gluing. In two of the beams all laminations were vertical-grained material, and in the other two vertical- and flat-grained boards were alternated. An intermediate-temperature-setting phenol-resin glue was used, and the curing was carried out in a chamber maintained at a temperature of 210° F. and at about 85 percent relative humidity for 24 hours. The glue was applied at a rate of 60 pounds per 1,000 square feet of joint area, and clamp pressure of 150 pounds per square inch was applied after a closed-assembly period of 60 minutes. The beams were conditioned about 2 weeks at a temperature of 80° F. and 65 percent relative humidity after gluing and before testing.

Testing

The following tests were made on each beam:

1. Dry shear tests.--A short section was cut from the end of each beam, and from this section 24 shear block specimens were prepared. The specimens were conditioned for about a week at 65 percent relative humidity and 80° F. temperature before they were tested.
2. Cyclic soaking-drying test.--A 2-inch section was cut off each beam and subjected to a repeating cycle of soaking in 4 percent salt solution for 30 days, followed by drying at 30 percent relative humidity for 30 days. The sections were inspected for delamination during the drying period of the cycle.
3. Soaking and weathering test.--Two of the beams, one made of all flat-sawn boards and the other of alternate flat- and quarter-sawn boards, were placed on outdoor exposure racks. One end of each beam was coated with asphalt paint prior to exposure. The beams were placed with the unpainted ends facing south. The two remaining beams were immersed in 4 percent salt solution for continuous soaking. The beams that were exposed to the weather and those that were soaked in salt-water were inspected at regular intervals for delamination, and after 4, 8, 12, and 48 months of exposure a section was cut from the painted end of each beam, from which shear block specimens were prepared. The specimens were conditioned to about 12 percent moisture content before testing. The end from which the section was cut was repainted before the exposure was continued. After completion of the 48 months of soaking, the beams immersed in salt water were allowed to dry for several months at ordinary outdoor conditions before sections for shear tests were cut and the beams examined for delaminations.

Results

Original joint strengths and percentages of wood failure, and similar values after 4, 8, 12, and 48 months of exposure, are shown in table 1. Delamination values for the cyclic test and for the beams at the completion of exposure are given in table 2. Photographs of the beams taken after completion of the exposures are shown in figure 1. A photograph of four beams similarly glued, cured, and exposed, but made of flat-grained material, is shown in figure 2 for comparison.

The wood-failure values shown in table 1 indicate that the original bond quality was high and that it was maintained without appreciable deterioration throughout the 4 years of exposure. The shear strength of the soaked beams was lower in the final than in the original test, but this decrease was probably due to weakening of the wood caused by development of a great deal of checking during the final drying of the beams. (After removal from soaking, the beams were dried for several months at ordinary outdoor conditions before sections for shear specimens were cut from them.) There was no consistent difference between the initial and final shear test values of the beams exposed to the weather.

The percentages of delamination that developed in the sections subjected to cyclic test (table 2) were in general small and indicated durable glue bonds. These results were substantiated by results of the long-term exposures. Only one beam developed as much as 10 percent delamination on the end surface facing south. A section cut from this beam also developed the largest amount of delamination (5 percent) in the cyclic test.

There was no significant difference in glue-bond quality between beams having all vertical-grained laminations and those having alternate vertical-grained and flat-grained laminations, and inclusion of vertical-grained boards in beams subjected to severe exposures did not result in delamination of the glue joints. Vertical-grained oak in beams, however, showed a greater tendency to check than flat-grained oak (figs. 1 and 2). Beams exposed to soaking and then dried checked especially severely when vertical-grained material was used (figs. 1 and 3). In vertical-grained boards the weaker planes along the medullary rays often are continuous throughout the entire width of the boards, whereas in flat-sawn boards the rays are, in general, normal to the plane of the boards. Consequently, when splits or checks occur in flat-sawn boards, they are usually not of large dimensions, since the rays in one board seldom coincide with rays of adjacent boards. Furthermore, a beam made of vertical-grained material will shrink and swell more in the dimension, perpendicular to the glue joints than one made of flat-sawn laminations. Consequently, the tension stresses normal to the plane of the glue lines are more severe, and cleavage parallel to the glue lines is more apt to develop in a vertical-grained beam than in a flat-grained beam. For this reason, vertical-grained material in laminated oak beams intended for severe exposures may be less

desirable than flat-grained material. As far as glue bond quality is concerned, the results would indicate that adequate bonds can be made regardless of type of grain.

Conclusions

The results of this study showed that glue joints that are highly durable under severe exposures can be made in laminated white oak beams made of all vertical-grained or alternate vertical- and flat-grained laminations. Checking of the wood in vertical-grained laminations was more serious than in flat-grained laminations, and the checks had a tendency to attain great magnitude and often lay in the plane of shear. Consequently, vertical-grained oak may be less satisfactory for use in laminated beams intended for severe exposures than flat-grained oak. Beams of alternate flat- and vertical-grained laminations performed as well as, if not better than, those made of all vertical-grained laminations.

Table 1.--Joint strengths and percentages of wood failure of laminated white oak beams after various periods of exposure to outdoor weather or salt-water soaking

| Beam No. | Type of grain | Exposure: | Shear strength and wood failure |
|----------|---------------------------|-------------------|---|
| : | : | : | : |
| : | : | Original : | Exposure period |
| : | : | : | : |
| : | : | : | 4 months : 8 months : 12 months : 48 months |
| VG-1 | :Alternate flat-vertical: | Outdoor: 2,118-98 | : 2,554-91 : 2,259-89 : 2,310-97 |
| VG-2 | :Alternate flat-vertical: | Soaking: 2,258-92 | : 2,248-95 : 2,467-95 : 2,369-95 : 1,984-95 |
| VG-3 | :All vertical | Outdoor: 2,241-99 | : 2,184-96 : 2,525-94 : 2,305-97 : 2,084-85 |
| VG-4 | :All vertical | Soaking: 2,187-96 | : 2,149-88 : 2,268-91 : 2,168-85 : 1,877-87 |

The figure before the dash in each column is shear strength in pounds per square inch, and the figure after the dash is percentage estimated wood failure. Each value is the average result of 24 tests.

Table 2.--Delamination of glue joints in 2-inch sections of laminated white oak beams subjected to cyclic soaking-drying tests and delamination on end surface of beams subjected to weathering or soaking

| Beam No. | Type of grain | Delamination ¹ | | |
|----------|-----------------------------|--|--------------------------------|--|
| | | In sections exposed to soaking-drying cycles | In beams exposed to weathering | In beams exposed to soaking ² |
| | | Percent | Percent | Percent |
| VG-1 | :Alternate : flat-vertical: | 0.9 | 1.5 | |
| VG-2 | :Alternate : flat-vertical: | 1.9 | | 1.0 |
| VG-3 | :All vertical : | 5.0 | 10.0 | |
| VG-4 | :All vertical : | 3.0 | | 1.4 |

¹Length of open glue joints on end-grain surfaces of beam sections subjected to cyclic test or on unpainted ends of beams exposed to weathering or soaking expressed as a percentage of the total length of glue joints exposed on these surfaces.

²Delamination was measured subsequent to the several months of drying that followed the 4 years of soaking.

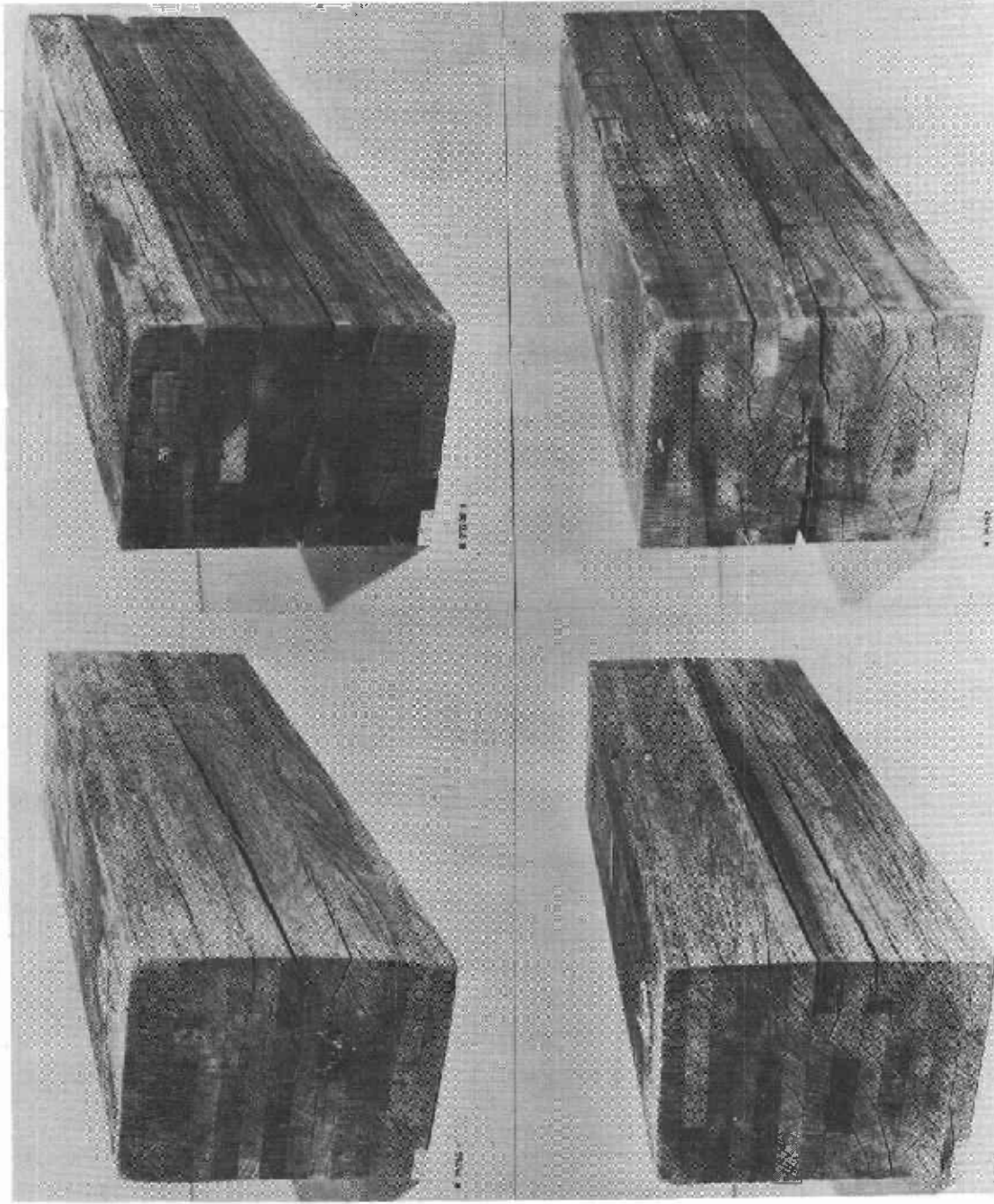


Figure 1.--Laminated white oak beams exposed about 4 years to weathering (VG-1 and VG-3) or continuous soaking followed by several months of drying (VG-2 and VG-4). Beams VG-1 and VG-2 were made of alternate flat- and vertical-grained laminations and beams VG-3 and VG-4 were made of all vertical-grained boards. The failures consisted almost entirely of checking in the wood, except in beam VG-3, which had slight openings in some glue joints. The large openings on the side of this beam, however, are practically all due to failure in the wood.

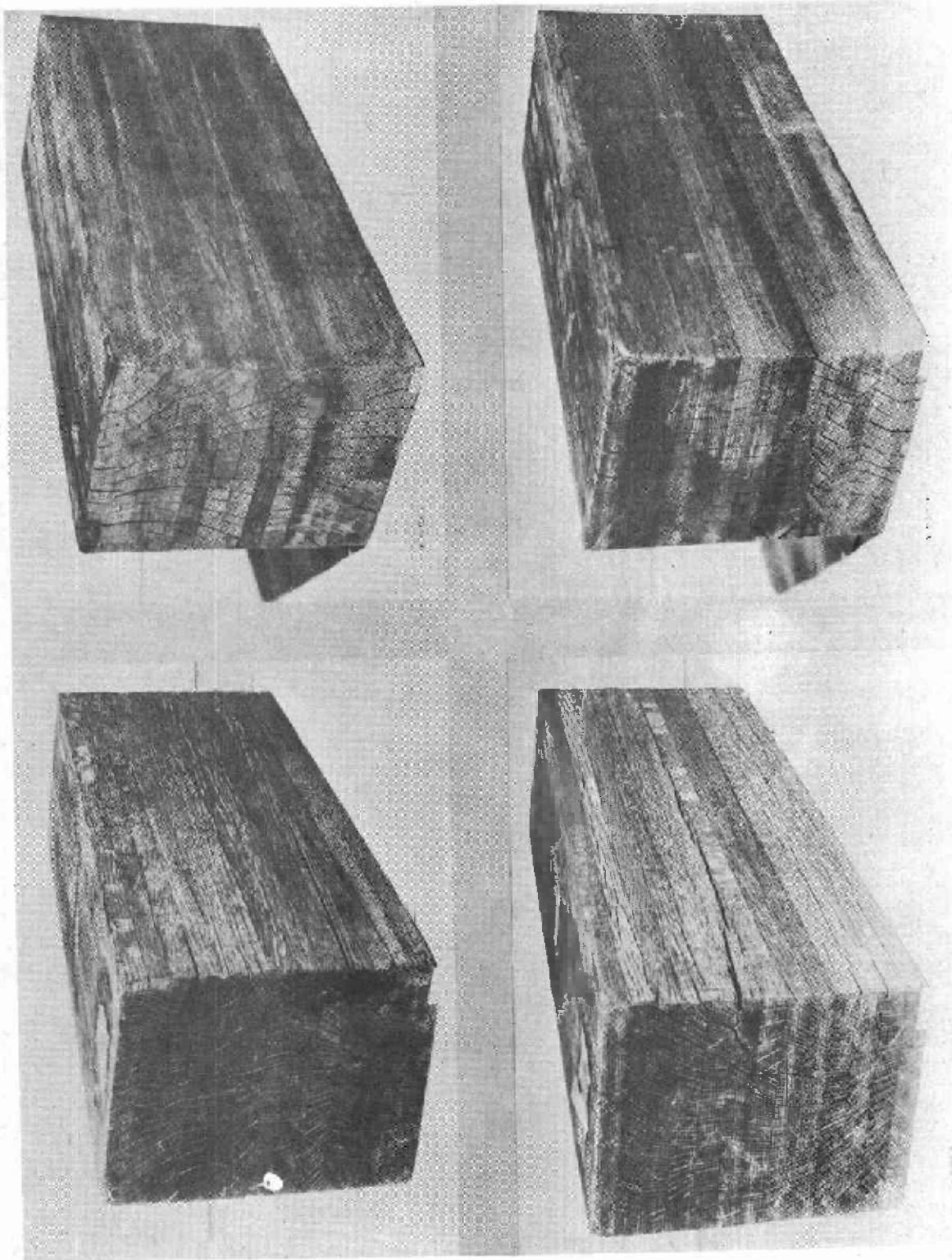


Figure 2.--Laminated white oak beams fabricated and exposed similarly to those shown in figure 1, but made of essentially flat-grained material. (The beams on the left were exposed to the weather and those on the right to soaking.) The checking was less severe in these beams than in those made with mixed- or vertical-grained material (shown in fig. 1).

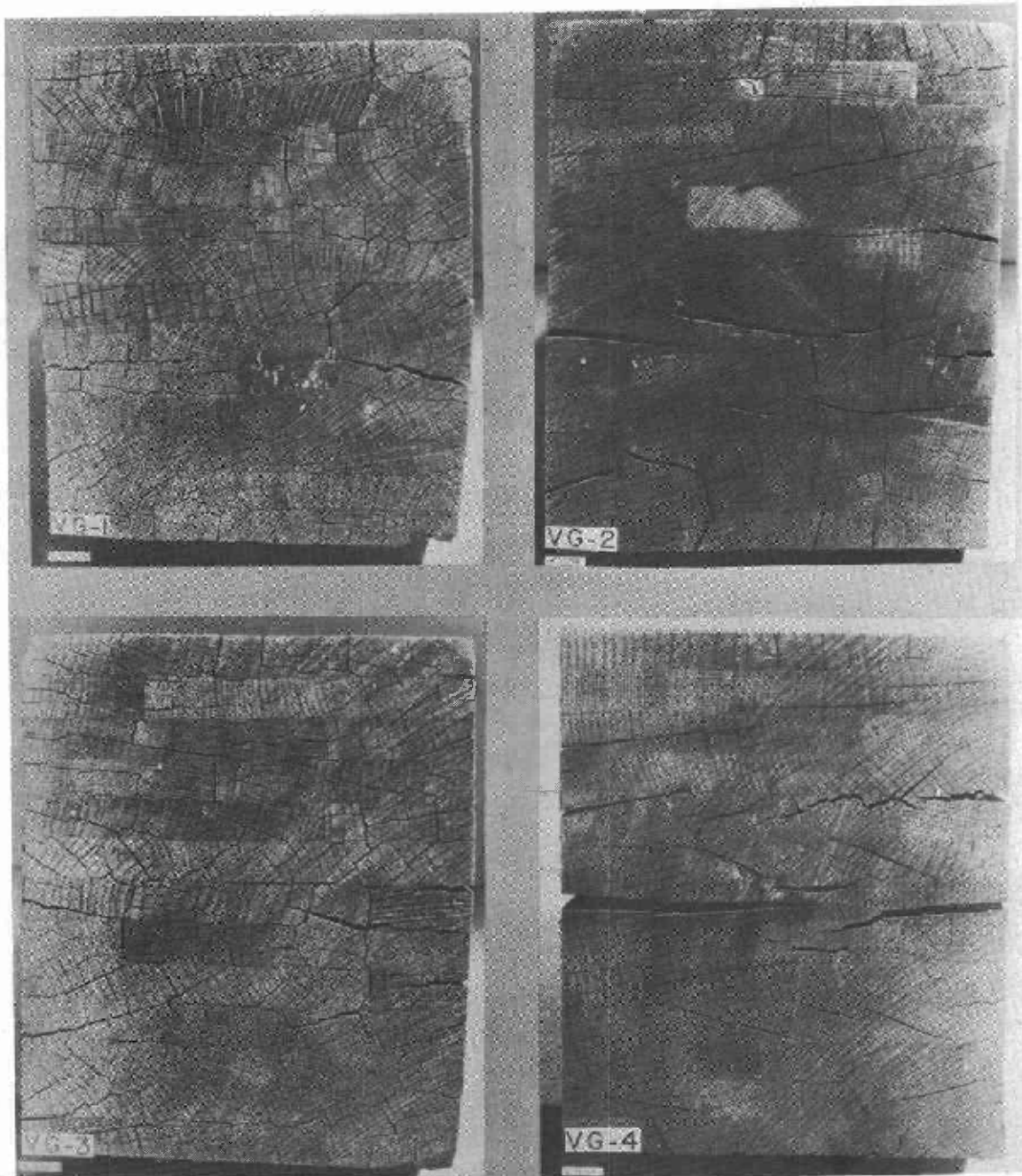


Figure 3.--Close-up of end sections of beams shown in figure 1. Note magnitude of checks in beams that were soaked for a long time and then dried (VG-2 and VG-4).

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