BUILT-UP BEAMS FOR LIGHT FRAME AND POLE CONSTRUCTION

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In Cooperation with the University of Wisconsin
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By

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Summary

The strength and rigidity of simple and continuous built-up beams were evaluated by subjecting full-size members to a static load test. The test beams were representative of a framing member formed by nailing a cover plate to the narrow edge of the nailing members or girts in post or pole frame construction. The test results show that for center deflections equivalent to 1/240 of the span the built-up beams which were constructed by nailing plywood to 2-by-4 flanges sustained about 4-1/4 times and the glued built-up beams about 6-1/4 times more load than a single 2 by 4. Nailed beams, continuous over two and three spans, sustained about 1-1/4 to 1-1/2 times more load at center deflections of 1/240 of the span than the single span nailed beams.

Introduction

This report presents the results of a study conducted at the Forest Products Laboratory in cooperation with the Livestock Engineering and Farm Structures Research Branch, Agricultural Engineering Research Division, Agricultural Research Service, U.S. Department of Agriculture, on simply constructed built-up beams. In most pole frame buildings, such as machine sheds, the girts are nailed to the outer edges of the poles to provide for the attachment of the exterior covering material. In pole frame buildings used as grain bins and the like, additional girts are nailed to the interior edges of the poles to provide for the attachment of the interior lining material. The girts are generally nominal 2-inch-thick lumber applied flatwise to the poles. For the conventional span lengths, they do not provide sufficient support to resist the pressure of the grain. A means of increasing the strength and stiffness of the horizontal interior and exterior nailing members or girts in conventional post and pole frame construction was studied in this investigation. The function of the beam is illustrated in figure 1.

1 Presented at the Winter Meeting of the American Society of Agricultural Engineers at Chicago, Ill., December 1961.

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

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Such factors as thickness of plywood, size and type of nails, and gluing were studied in the built-up beams. The beams were tested as simple beams and as continuous beams of two and three spans.

Description of Material

The material used in the construction of the beams consisted of nominal 2-by-4 Standard or Better grade coast-type Douglas-fir lumber and 1/4- and 3/8-inch A-C grade, three-ply, exterior-type Douglas-fir plywood. The modulus of elasticity of the 2-by-4 pieces ranged from about 1,800,000 to 2,500,000 pounds per square inch with an average of 2,160,000 pounds per square inch. The moisture content of the pieces ranged from 6.8 to 8.6 percent and the specific gravity based on ovendry weight and volume ranged from 0.45 to 0.56.

The nails were sixpenny and eightpenny common wire nails and eightpenny screw shank nails.

The glue was polyvinyl emulsion-type adhesive. The performance of this glue is adequate under the conditions of this study. However, a resorcinol resin glue is recommended for beams used in buildings of a permanent nature.

Description of Built-Up Beams

The built-up beams consisted of two flanges of 2-by-4 Dimension lumber with a plywood cover plate or web fastened to one narrow face of each flange as illustrated in figure 2. The beams were of single 60-inch span, continuous two-span with each span 90 inches in length, and continuous three-span with each span 60 inches long. The plywood, with the face grain parallel with the flanges, was nailed to the flanges in accordance with the nailing pattern shown in figure 3. The construction details, along with the type and number of test specimens, are listed in table 1.

The effect of plywood web thickness was studied in the tests of the single-span built-up beam. Two groups of three specimens each were constructed in which the 2-by-4 flanges of one group were end matched to the corresponding flanges of the other group. A 1/4-inch-thick plywood web was applied to the flanges in one group, and a 3/8-inch-thick plywood web was applied to the flanges of the other group. The plywood for the beams in each group was obtained from a different sheet of plywood. The plywood was nailed to the flanges with sixpenny common nails. One specimen in each group was tested to failure and the remaining specimens were test loaded only to 1,000 pounds.

Following these tests, the two unbroken beams in each group were disassembled and the flanges reused for additional tests. In these tests, 3/8-inch-thick plywood was nailed to one group of flanges with eightpenny common nails and to the other group with eightpenny screw shank nails. The cover plates were cut from the plywood sheets that remained from the previous beams. Again, one
beam in each group was loaded to failure and the remaining beams test loaded to 1,000 pounds.

The flanges of the unbroken beams were used once more for additional tests in which 3/8-inch-thick plywood was glued to the flanges with a polyvinyl glue and nailed with sixpenny common nails. The plywood was applied with the face grain parallel to the length of the beam in one test and perpendicular to the length of the beam in the other test. The beams were loaded to failure.

Two double-span and two triple-span beams of a kind were also constructed and tested (fig. 2). The beams consisted of continuous 2-by-4 flanges with 3/8-inch-thick plywood cover plates between supports. Plywood with the face grain parallel to the length of the beam was nailed to the flanges with sixpenny common nails (fig. 3). All beams were tested to failure.

Method of Test

The single-span beams were tested over a 60-inch span. Five equal loads spaced 12 inches apart were applied through 4-inch-long wood blocks to the upper flange of the beam as shown in figure 4. The load at each end reaction was measured with a hydraulic capsule.

The double-span beams were continuous over two 90-inch spans, and the triple-span beams were continuous over three 60-inch spans. The beams were loaded on the flanges at the quarter points of each span. The load was measured with a hydraulic capsule at the center and at one end reaction of the double-span beams and at one center reaction and the adjacent end reaction of the triple-span beams as shown in figure 5. The deflection was measured at the midpoint of each span with a dial gage supported on a metal yoke.

In the single-span tests, a load-deflection curve was obtained by reading the deflection at the center of the span at uniform intervals of increasing load to 1,000 pounds. The load was then removed and the residual deflection of the beam was obtained. The beams were then loaded to failure except for the beams in which the flanges were scheduled for reuse in subsequent tests. The continuous beams were tested in a similar manner except that the initial load applied to the beams varied from 860 to 1,460 pounds and the beams were all loaded to failure in the second test loading.

Discussion of Results

The results of the tests are presented in table 1, and by load-deflection curves for the single-span beams in figure 6, and the double- and triple-span beams in figure 7. The relationships of the various beams at a deflection of 1/240 of the span are shown in figures 6 and 7, and the relationships between single-span beams and a single 2 by 4 are shown in figure 6.
The results in table 1 and figure 6 show that the beams with 1/4- and 3/8-inch plywood webs as well as those nailed with sixpenny, eightpenny, and eightpenny screw shank nails were comparable in strength and stiffness. The beam failures, however, show that the heads of the sixpenny nails had a greater tendency to pull into the plywood throughout the central portion of the span than the eightpenny nails (fig. 8).

The beams with the web glued to the flanges failed in rolling shear in the plywood and shearing out of the nails near the outer ends of the web (fig. 8). The glued beams with the face grain of the plywood applied parallel to the flanges were comparable in strength and stiffness to the beams with the plywood perpendicular to the flanges. The glued beams sustained about 50 percent greater load at a deflection equal to 1/240 of the span than the unglued beams of similar construction.

A load-deflection curve computed for a nominal 2 by 4 with a modulus of elasticity of 2,160,000 pounds per square inch uniformly loaded flatwise over a 5-foot span is shown on figure 6. The figure shows that, for center deflections of 1/240 of the span, the nailed built-up beams sustained about 4-1/4 times, and the glued built-up beams about 6-1/4 times, more load than the single 2 by 4.

A comparison based on the ultimate test loads, which ranged from 1,980 to 3,030 pounds for the nailed built-up beams and the computed ultimate load of 1,170 pounds for a 2 by 4 uniformly loaded flatwise over a 5-foot span, shows that the built-up beams were approximately twice as strong as the single 2 by 4. The computed strength of the 2 by 4 was based on a fiber stress of 5,500 pounds per square inch. This value was obtained by applying the strength ratio factor for the bottom range of the Construction grade of 58 percent and a factor of 125 percent for drying to the average ultimate flexure stress of 7,600 pounds per square inch for green coast-type Douglas-fir.

The continuous beams with two 90-inch spans sustained maximum loads of 2,520 and 2,730 pounds per span, and the continuous beams with three 60-inch spans sustained maximum loads of 2,600 and 3,910 pounds per span. In general, the continuous beams failed at a knot in the upper flange after some nail slip had taken place in the plywood webs. Figure 9 shows a double-span beam under test at a point near maximum load. The results show that at a deflection of 1/240 of the span, the double- and triple-span beams sustained about 1-1/4 to 1-1/2 times more load than the single-span nailed beams.

As in most nailed structural elements, the nailed built-up beams showed a residual set after the initial load was removed and exhibited a steeper load-deflection curve in the second test loading of the beam. The set remaining at the center of the single-span beams after having been loaded to 1,000 pounds was from 0.02 to 0.05 inch.

In continuous triple-span beams of uniform cross section, the maximum deflection in the outer spans is 28.56 times the deflection at the midpoint of the center span. In the tests, however, the deflection at the center of the outer spans was about 2-1/2 times the deflection of the center span. This difference...
in deflection between the test beams and beams of uniform section is presumably due to lack of continuity in the webs or cover plates, the nonelastic deformation between the web and flange, and because deflection measurements were taken at the centers of the outer spans rather than at the points of maximum deflection.

Digest of Test Results

The following statements are based on the results of tests conducted on one to three built-up beams of each kind. The beams were of 60-inch single-span, continuous two-span with each span 90 inches in length, and continuous three-span with each span 60 inches in length.

(1) Single-span beams with 1/4-inch plywood webs nailed with sixpenny common nails were comparable in strength and stiffness to similar beams with 3/8-inch plywood webs.

(2) Single-span beams with 3/8-inch plywood webs nailed with sixpenny common nails were comparable in strength and stiffness to similar beams nailed with an equal number of eightpenny common and with eightpenny screw shank nails.

(3) Single-span beams with the plywood web glued to the flanges sustained about 50 percent greater load at a center deflection of 1/240 of the span than the unglued beams of similar construction.

(4) Single-span beams of glued construction with the face grain of the plywood web parallel to the flanges were comparable in strength and stiffness to the beams with the face grain of the plywood perpendicular to the flanges. The glued beams failed in rolling shear of the plywood.

(5) The single-span beams with the plywood nailed to the flanges sustained about 4-1/4 times more load than a single 2 by 4 at center deflections of 1/240 of the span.

(6) Single-span beams with the plywood glue-nailed to the flanges sustained about 6-1/4 times more load than a single 2 by 4 at center deflections of 1/240 of the span.

(7) The double 90-inch span continuous beams sustained about the same maximum load per span as the single 60-inch span unglued beam, but showed somewhat greater stiffness.

(8) The triple 60-inch span continuous beams were about comparable in strength and stiffness to the single-span 60-inch beams of glue-nailed construction.

(9) At a center deflection of 1/240 of the span, the double- and triple-span continuous beams sustained a load about 1-1/4 to 1-1/2 times that of the single-span nailed beams.
(10) A nailing pattern with the nails grouped near the ends of the cover plates was found in preliminary tests to provide greater strength and stiffness in built-up beams than a pattern with an equal number of nails uniformly spaced.

(11) The splitting of the flanges, the bending of the nails, and the pulling of the nailheads into the plywood cover plates of the test beams demonstrated the effectiveness of grouping the nails near the ends of the cover plates.

(12) A beam with nailed plywood cover plates was found in preliminary tests to provide a higher maximum load than a beam with 1-inch-thick lumber cover plates. Splitting at the nails near the ends of the boards caused early failure of these beams.
Table 1.—Results of bending tests of built-up wood-plywood beams

<table>
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<tr>
<th>Specimen No.</th>
<th>Percent</th>
<th>Size</th>
<th>Maximum Center deflection at load per span</th>
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<tr>
<td>Average</td>
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SINGLE SPAN - 60-INCH

DOUBLE SPAN - 90-INCH

TRIPLE SPAN - 60-INCH

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1 Specific gravity based on oven-dry weight and volume.
2 Average center deflection of the 2 outer spans of the double- and triple-span beams.
3 Screw shank nails.
4 Plywood webs glued to flanges.
5 Face grain of plywood perpendicular to flanges.

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Figure 1. - Plywood cover plates attached to the top edges of the horizontal nailing members or girts in conventional post or pole frame construction increases their strength and stiffness.
Figure 2.--Construction and loading of test beams.
Figure 3. -- Nailing pattern used in fastening the plywood web or cover plate to the 2-by-4 flanges of the single-span beams. The same nailing pattern was used in the construction of the double- and triple-span beams.
Figure 4.—Single-span built-up beam setup ready for test. The load is applied at five points by means of the cables and sheaves. The load is measured near each reaction by hydraulic capsules.
Figure 5. -- Triple-span beam setup ready for test. The load was applied at the quarter points of each span and was measured at one center reaction and the adjacent end reaction. The deflection was measured at the midpoint of each span with a dial gage.

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Figure 6.--Load-deflection curves obtained for the single-span beams. The portion of each curve from 0 to 1,000 pounds for the nailed beams is a composite curve for two and three test specimens, and the portion above 1,000 pounds is a curve for a single test specimen. The curves for the nail-glued beams are from a single test specimen.
Figure 7. --Load-deflection curves for double- and triple-span beams. The beams consisted of 3/8-inch plywood cover plates nailed to the flanges with sixpenny nails.
Figure 8. --Single-span beams after testing to maximum load. The beams were constructed of 2-by-4 flanges with a plywood cover plate. The construction details of the beams beginning at the top are: (A) 1/4-inch plywood, sixpenny nails; (B) 3/8-inch plywood, sixpenny nails; (C) 3/8-inch plywood, eightpenny nails; (D) 3/8-inch plywood, eightpenny screw shank nails; (E) 3/8-inch plywood glued with the face grain parallel to flanges; and (F) 3/8-inch plywood glued with the face grain perpendicular to flanges.
Figure 9.- Double-span beam with the test approaching the point of maximum load. The load was applied at the quarter points of each span and was measured at the center and one end reaction with a hydraulic capsule. The dial gages used to measure the deflection at the midpoint of each span were removed prior to the taking of the photograph.