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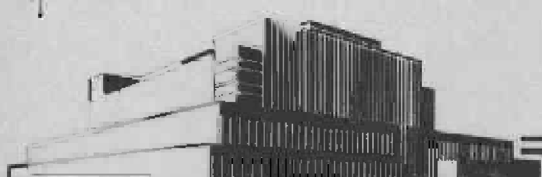
Information Reviewed and Reaffirmed

July 1959

INFORMATION REVIEWED
AND REAFFIRMED
1965

No. 1930



FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

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

RESEARCH IN WIND-RESISTANT FARM BUILDING CONSTRUCTION[1, 2]

By

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Wood, because it is light in weight and easy to shape, form, and fasten, has been used extensively throughout the years in the construction of rural buildings. While it is a complex material in its physical structure and chemical composition, craftsmen long have been able through rule-of-thumb experience, and cut-and-try methods, to construct buildings that serve effectively. In many instances, however, builders and designers have lacked essential knowledge of the properties of lumber on which sound construction depends, and, as a result, buildings considered substantially built are sometimes severely damaged by winds of moderate intensity.

In order to provide positive design information to the builder and designer of farm structures, the U. S. Forest Products Laboratory in cooperation with the Division of Farm Buildings and Rural Housing, Bureau of Plant Industry, Soils, and Agricultural Engineering, has during recent years conducted research covering the strength and rigidity of various anchorages, bracing methods, and diaphragms of the type and size commonly used in farm buildings. The findings of this research are believed to provide information leading to more wind-resistant and serviceable farm buildings.

Over the years since 1910, engineers, chemists, physicists, foresters, pathologists and even mathematicians at the Forest Products Laboratory have been conducting basic and applied research aimed toward better and wiser use of wood (11).[4] The basic findings of these scientists have provided a basis for

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[1] To be presented at the meeting of the North Atlantic Section of the American Society of Agricultural Engineers, Orono, Maine, Aug. 27, 1952.

[2] Acknowledgement is made to E. G. Molander, Senior Agricultural Engineer, Division of Farm Buildings and Rural Housing, Bureau of Plant Industry, Soils, and Agricultural Engineering, under whose supervision these investigations were conducted.

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

[4] Underlined numbers in parentheses refer to literature cited at the end of the paper.

the development of allowable unit stresses for lumber; of design-load formulas; of allowable loads for timber connectors (7), nails, bolts (6), screws, lag screws, etc.; and of design stresses and specifications for glued laminated structural members, as well as providing information on many wood products.

In order to correlate the basic information with the design of full-scale structural units used in farm building construction, specimens of conventional joint, bracing, and floor construction were subjected to simulated static wind loading tests. Specimens were also tested to provide comparative data of the strength and stiffness of similar assemblies reinforced by simple, practical, and economic methods.

Frame-wall Joints

Since in any structure the weakest points are likely to be the joints, a fundamental study was made of the strength and stiffness of conventional stud-to-sill (8) and rafter-to-plate joints in frame walls, which gives engineering guidance as to the comparative merits of toenailing and end-nailing, as well as to various types of simply fabricated metal tie-downs.

Four types of stud-to-sill specimens and rafter-to-plate specimens were subjected to both lateral and vertical loading to simulate thrust and uplift loads imposed on a building, principally by wind. Figures 1 and 2 illustrate the various types of joint construction and presents a comparison of the strength and rigidity of toenailed to other types of joints.

The test specimens, consisting of both green and dry Douglas-fir lumber, were assembled with common wire nails and 24-gage galvanized-sheet-metal tie-downs. The joints made of dry material were tested soon after fabrication, while half of those made of green material were tested immediately after fabrication and the remaining half after seasoning to a dry condition.

The results of the tests show that, for all conditions of seasoning, the toenailed joints provided a stronger and more rigid connection than the other types of joints up to the proportional limit load, which was arbitrarily chosen at 0.015 inch of joint slip. The U-strapped stud-to-sill joint and the diagonal metal tie-down of the rafter-to-plate joints, however, gave the highest maximum loads, but the slip accompanying the maximum loads was likewise relatively high. A well-designed toenailed joint supplemented with a simple metal tie-down provides an adequate connection under ordinary loading conditions with an additional safeguard against total destruction under loads of higher intensity. Good rules to follow in the fabrication of toenailed joints are: (1) start the nail at one-third the length of the nail from the end of the piece; (2)

drive the nail at a 30° angle; (3) bury the nail shank but avoid excessive mutilation of the wood around the nail head; and (4) avoid excessive splitting but use the largest nail possible, normally a tenpenny nail in nominal 2-inch lumber.

Diaphragm Action of Haymow Floors

In the planning of barns, vertical partitions and bracing are often eliminated from the stable and loft areas where they tend to restrict the free movement of feed, animals, and caretakers. Without these supporting mediums, the lateral loads imposed on the side of a barn, mainly by direct wind pressure on the windward side plus negative pressure or suction on the leeward side (2, 4) must be transmitted through beam or diaphragm action of the loft floor and roof to the walls that are parallel to the direction of the force. These walls in turn must transmit the imposed loads to the foundation. It is therefore important that the loft floor and roof of two-story barns be designed with sufficient rigidity to transfer without excessive distortion the lateral load on the sides of a structure to the end walls and that the resisting end walls be sufficiently rigid to transmit the load to the foundation without excessive racking (5). It is also important that the connection between the mow floor and the end wall be sufficiently strong and rigid to transfer the lateral floor load to the end wall.

To provide information that will aid in the structural design for this type of loading, three series of tests were conducted on two sizes of test panels. The panels were built of nominal Douglas-fir lumber and, in general, represented the construction normally used in the loft-floor systems of two-story barns. The tests in series 1, which were more or less of an exploratory nature, and those of series 3, which were of a comparative nature, were conducted on 6- by 16-foot panels. These panels were placed on edge in a testing machine and loaded laterally in the direction of the joists. The tests in series 2 were made on 18- by 48-foot panels. These panels were constructed outdoors on a paved parking area (fig. 3) and loaded against the Laboratory building through a wire rope that passed about the panel, over a pair of sheaves, and was attached to the movable head of a testing machine.

In the three series of tests, the load was applied at the third points; and the deflection between supports, the deflection between load points, and the bending of the end joists were observed at various uniform intervals of load. Upon completion of the tests, an evaluation of the bending strength and lateral nail-holding properties, as well as of the moisture content and specific gravity, was made of the material.

In series 1, 12 tests were made on wood floor frames to which were added various types of sheathing, bracing, and stiffeners. In series 2, three of the floor constructions tested in series 1, namely, the plain longitudinally sheathed, the longitudinally sheathed with diagonal bracing, and the spaced diagonally sheathed overlain with longitudinal sheathing, were reconstructed and tested in the full-scale panels as shown in figure 4. In addition to the tests of the sheathed panels, three independent applications of load were made on the unsheathed frame, which was braced from the load points to the reactions with single, double and triple members, respectively. In series 3, an evaluation of stiffness was made of panels with various spacings of the diagonal sheathing.

The longitudinally sheathed panel consisting of nominal 1-inch boards nailed normal to 2- by 10-inch joists represents the simplest and perhaps the most common type of haymow floor construction. This type of panel was tested in each series and taken as the standard for comparing the test results of panels representing other types of construction. In making the comparisons, the panels are assumed to resist lateral bending forces in a manner similar to that of a simple beam under third-point loading insofar as stiffness is concerned. Table 1 presents the load and center deflection at the termination of the tests, along with the stiffness factors at various intervals of load for the full scale panels. The stiffness factors are the ratios of the computed stiffness of the panel in question to the stiffness of the standard panel.

In all tests the longitudinally sheathed or standard panel was less rigid and the panel with spaced diagonal sheathing overlain with longitudinal sheathing was more rigid than the other test panels, which represented other methods of construction. In the full-scale tests, the standard panel deflected 6-1/2 inches under a load of 4,000 pounds, while the spaced diagonal longitudinally sheathed panel deflected only 1-2/3 inches under a load of 30,000 pounds. With diagonal braces nailed to the under side of the joists, the longitudinally sheathed panel carried nearly 6,000 pounds at 6-1/2 inches center deflection. The braced panel without sheathing was more rigid than the standard panel until the lateral resistance was exceeded for the nails securing the ends of the braces.

The results of these tests tend to show that (1) friction resulting from nailing boards tightly to the joists increases the initial stiffness of a panel about 10 percent over a panel with a 1/32-inch separation between boards and joists; (2) cement-asbestos board sheets nailed to the under side of the joists of a longitudinally sheathed panel increase the initial stiffness by about 11 times that of the standard panel; (3) diagonal sheathing provides considerable rigidity to a panel, but, under lateral load, the frame is subjected to racking forces; (4) diagonal sheathing performs more effectively when longitudinal members, such as stiffeners, longitudinal sheathing, or cross-diagonal sheathing, are applied over the diagonal members; (5) the strength of a longitudinally sheathed panel can be closely estimated for a given deflection by a theoretical analysis resulting from the common bending formulas and the lateral resistance of the nailed joints; (6) the diagonal sheathing members that intersect opposite corners of the panel are most effective during the initial loading of the panel, with the adjacent boards becoming more effective as the loading progresses; (7) the strength afforded by diagonal members is closely related to the lateral resistance of the nails securing the ends of the members; and (8) the stiffness of a spaced diagonal longitudinally sheathed panel varies inversely with an increase in the spacing of the diagonal members.

Side-wall Bracing

Wind-loading tests have indicated that strong diagonal braces securely fastened at the side-wall plate and at the floor joists are necessary for the stability of the roof. In order to provide information regarding the connection of the brace and side wall an investigation is presently being conducted to determine the relative strength and rigidity of several types of fastenings designed to anchor the stud, plate, and knee brace at the junction of a braced rafter roof and the side wall. The joints are constructed of nominal Douglas-fir lumber, conventional hardware, and simply fabricated tie-downs. In test, the specimens are subjected to both tensile and compressive loads applied normal to the horizontal or plate members of the joint.

End-wall Mow Floor Connections

The strength and stiffness of the joints between the barn end wall and the haymow floor were determined and compared for several types of joint construction. The specimens included two variations of balloon construction and three variations of platform construction, as shown in figure 5. In these tests, the joints were loaded so as to provide a horizontal lateral shearing force between the end wall and the mow floor. The results of the tests presented in table 2, show that the joints constructed with plates or with headers were from 21 to 53 percent more rigid under initial load than the standard joint framed without horizontal members between the studs. At maximum load their rigidity was approximately 2 to 3 times that of the standard joint.

Vertical-wall Tests

The Forest Products Laboratory has published considerable information on the strength and stiffness of frame walls sheathed in various manners with several types of material (1, 3, 9, 10). This information was obtained from racking tests on wall-size house panels in which the panel was attached to a rigid base and a horizontal load applied at one end of the upper plate. The test subjects the panel to shearing forces acting in the plane of the wall and simulates the effect of wind forces acting on a wall of a building as transmitted from an adjoining wall.

While these tests were conducted mainly to provide information to be used in house construction, much of the information is also applicable to the construction of rural buildings.

The results of these tests show the superiority of diagonal sheathing over horizontal, of plywood sheathing fastened by gluing over other types of sheathing, and of let-in bracing over herringbone and cut-in braces. They also show that the addition of siding or plaster over a diagonal or sheet-covered sheathed wall will provide the wall with a large increase in strength and rigidity.

Summary

Recent research studies covering the strength of framed joints, bracing methods, and wall and floor diaphragms of the type and size commonly used in rural buildings have been conducted to provide designers and builders of farm structures with a basis for evaluating the strength and stiffness of various construction assemblies. In general, the results of the studies show that the strength and stiffness of the conventional structural units can be increased in a practical and economic manner by rearrangement of the structural members, by a nominal increase in material, or by the attachment of a simply fabricated reinforcing device.

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Table 1. --Results of lateral bending tests of 18- by 48-foot hayloft floor panels

Test No.	Stiffness factor at --		Results at termination of test		
	2,000-lb. load	4,000-lb. load	Load	Center deflection	Stiffness factor
			Pounds	Inches	
1	1.0	1.0	4,200	7.2	1.0
2	3.1	2.6	6,200	7.4	1.4
3	89.3	92.3	30,000	1.65	30.8
[1]4	2.0	....	3,150	3.25	1.6

[1]Single member bracing.

Table 2. --The strength and rigidity of the conventional compared to other types of end-wall-to-mow-floor connections

Construction type	Load at 0.15 inch deformation	Load at 0.40 inch deformation	Maximum load	Deformation at maximum load	Weight of test panel
1	100	100	100	100	100
2	141	205	266	69	113
3	135	195	248	75	125
4	121	141	188	67	135
5	153	232	280	69	133

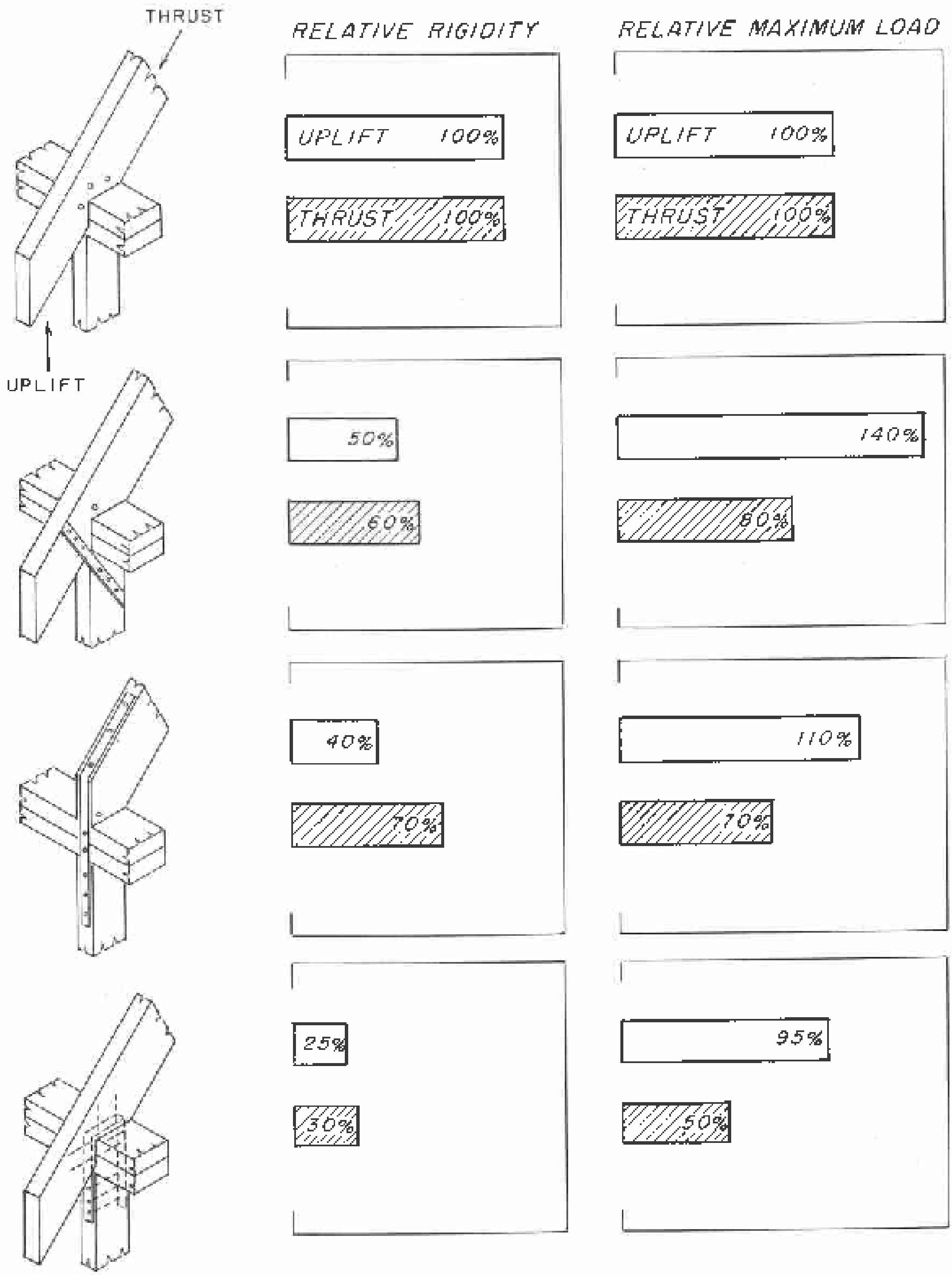

Figure 1.--Comparison of the rigidity and maximum loads for various types of rafter-to-plate connections. The test members were fabricated of nominal 2 x 4 and 2 x 6 Douglas-fir lumber. The straps were made from 24-gage galvanized metal 1 inch wide. The nails were fourpenny and tenpenny common wire nails.

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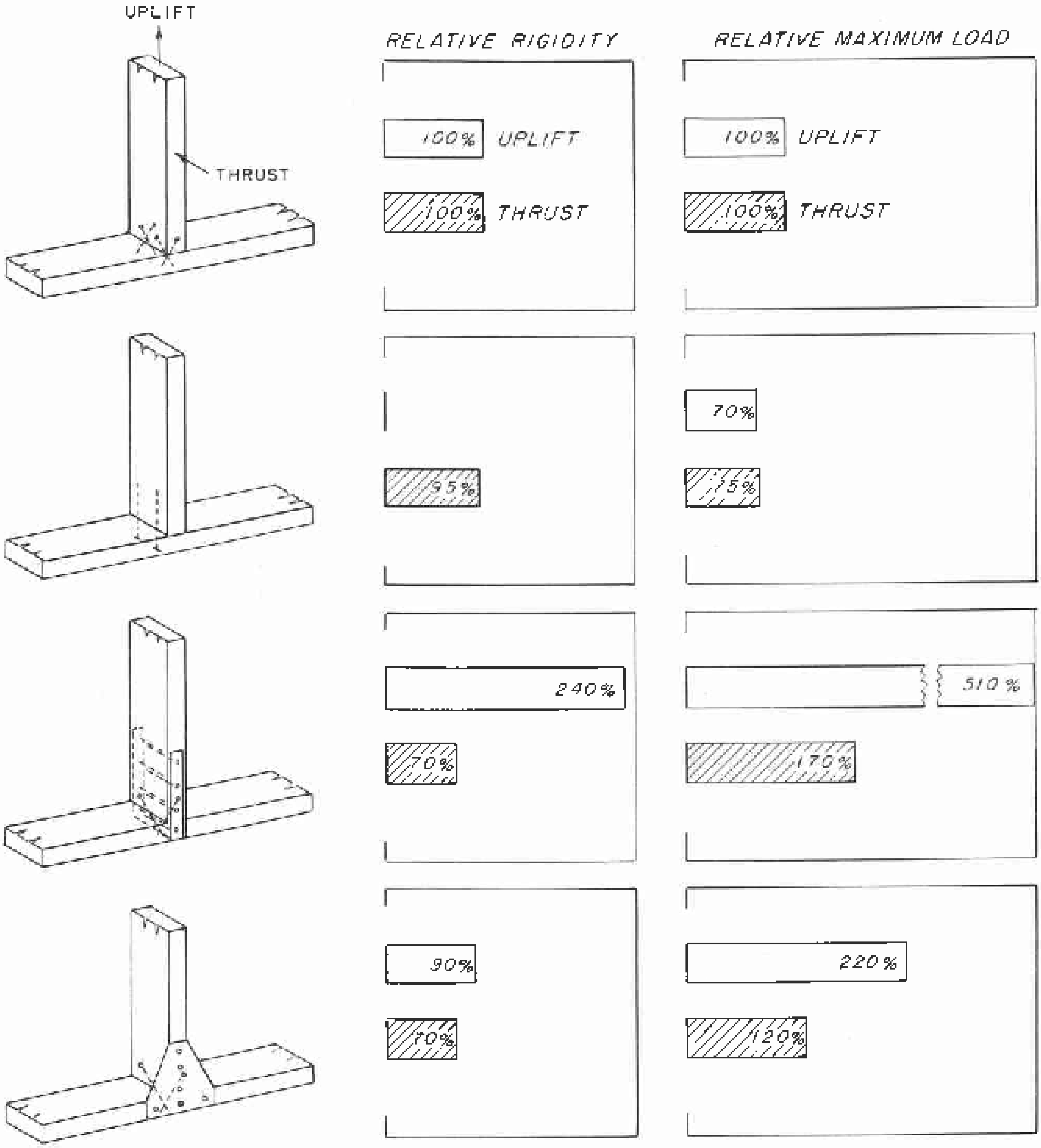

Figure 2.--Comparison of the rigidity and maximum loads for various types of stud-to-sill connections fabricated of nominal 2 x 4 Douglas-fir lumber. The straps and gusset were made from 24-gage galvanized metal. The straps were 1 inch wide, and the gusset at base was 5 inches wide. The nails were eightpenny and sixteenpenny common wire nails.

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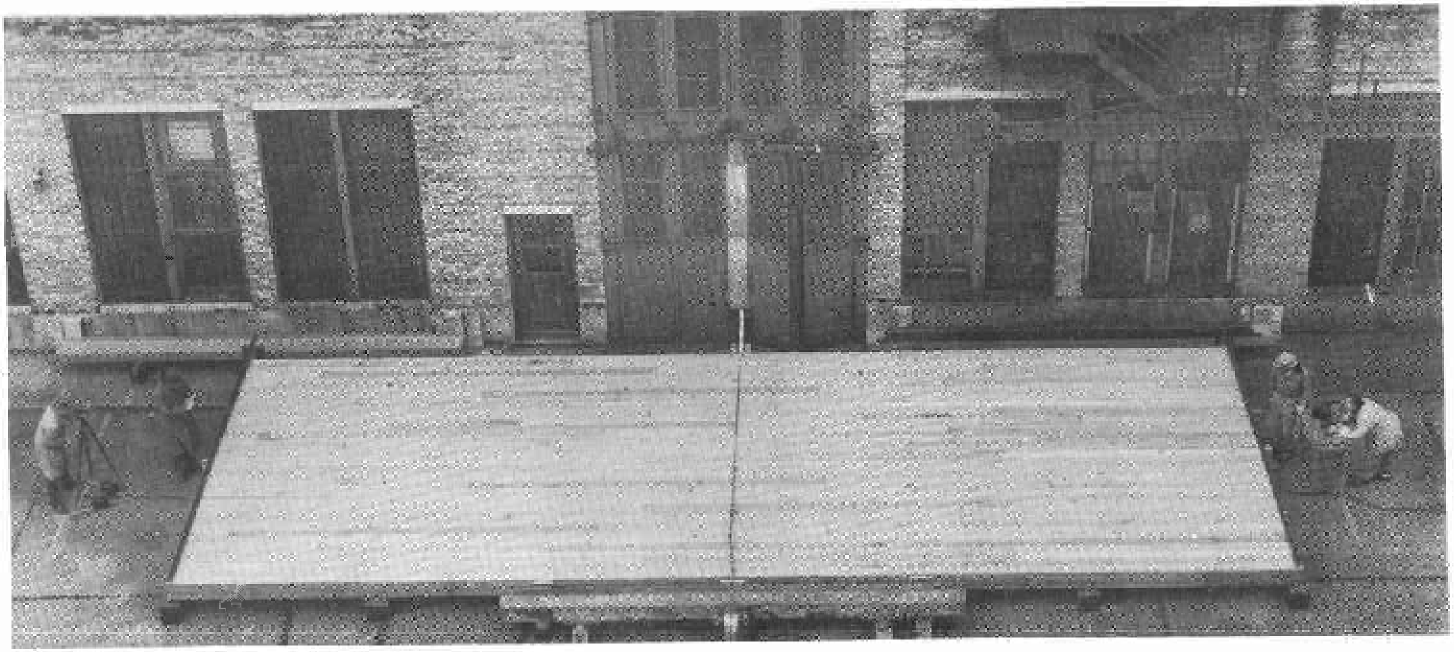

Figure 3.--Test set-up for an 18- by 48-foot hayloft floor panel. A testing machine within the building applies the load through a 5/8-inch wire rope to the steel I-beam spanning the loading blocks located at the third points of the panel. The steel I-beams on the far side of the panel transmit the loads at the reactions to the columns of the Laboratory building. A hydraulic weighing capsule mounted between the wire rope and the I-beam measured the load on a dial gage, also located within the Laboratory building.

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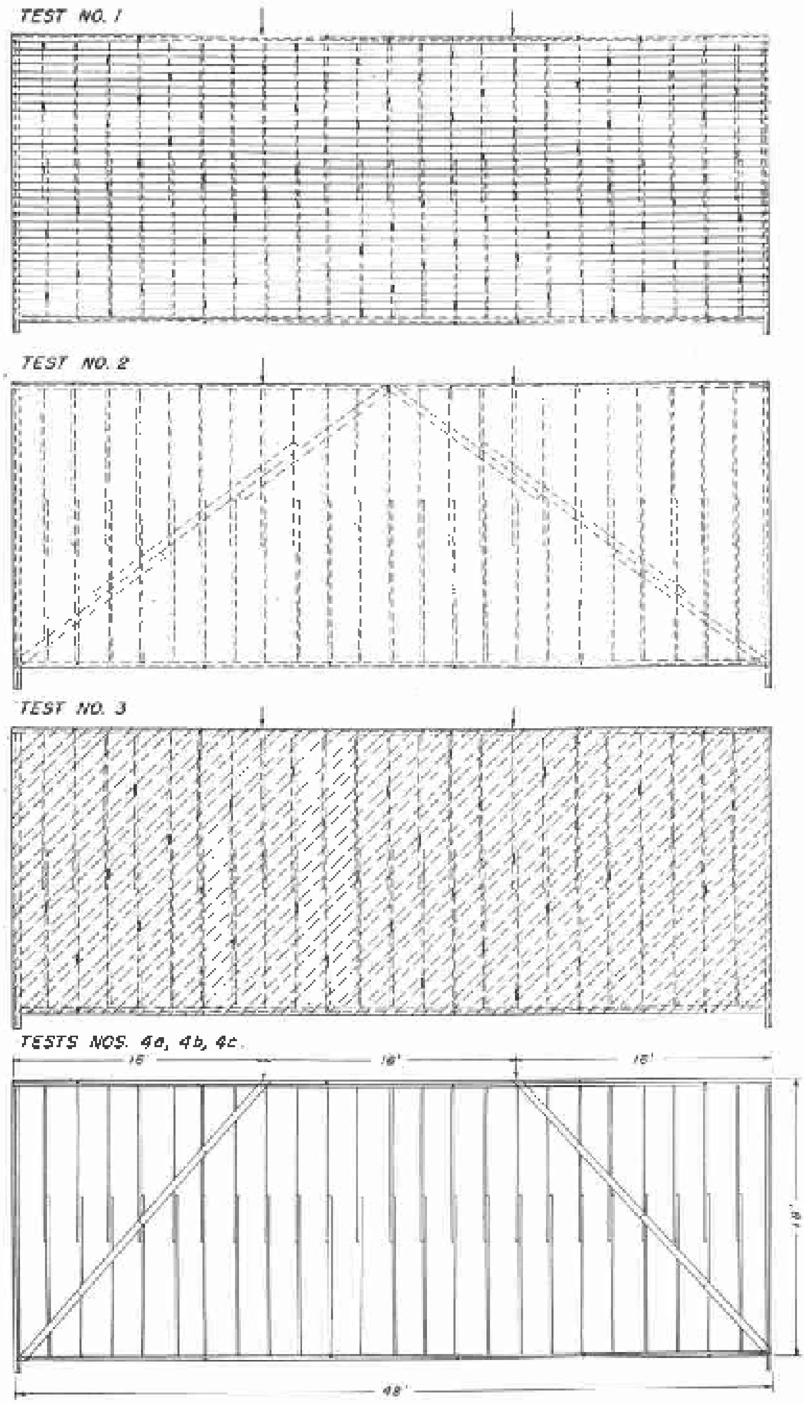

Figure 4.--Construction details of 18- by 48-foot hayloft floor panels. Test No. 1: Longitudinal 1- by 6-inch sheathing spaced 1/8 inch between boards and 3/64 inch between boards and joists and nailed at each joist crossing with two eightpenny nails. Test No. 2: Same as test No. 1 with 1- by 6-inch boards nailed to the underside of the joists, as shown, with two eightpenny nails at each joist crossing. Test No. 3: Diagonal 1- by 6-inch boards spaced 8-3/4 inches between boards and nailed to joists with two eightpenny nails. Longitudinal 1- by 6-inch sheathing laid over diagonal sheathing and nailed with two eightpenny nails at each board crossing. Test No. 4: Diagonal 2- by 6-inch continuous bracing nailed at each joist crossing with two sixteenpenny nails.

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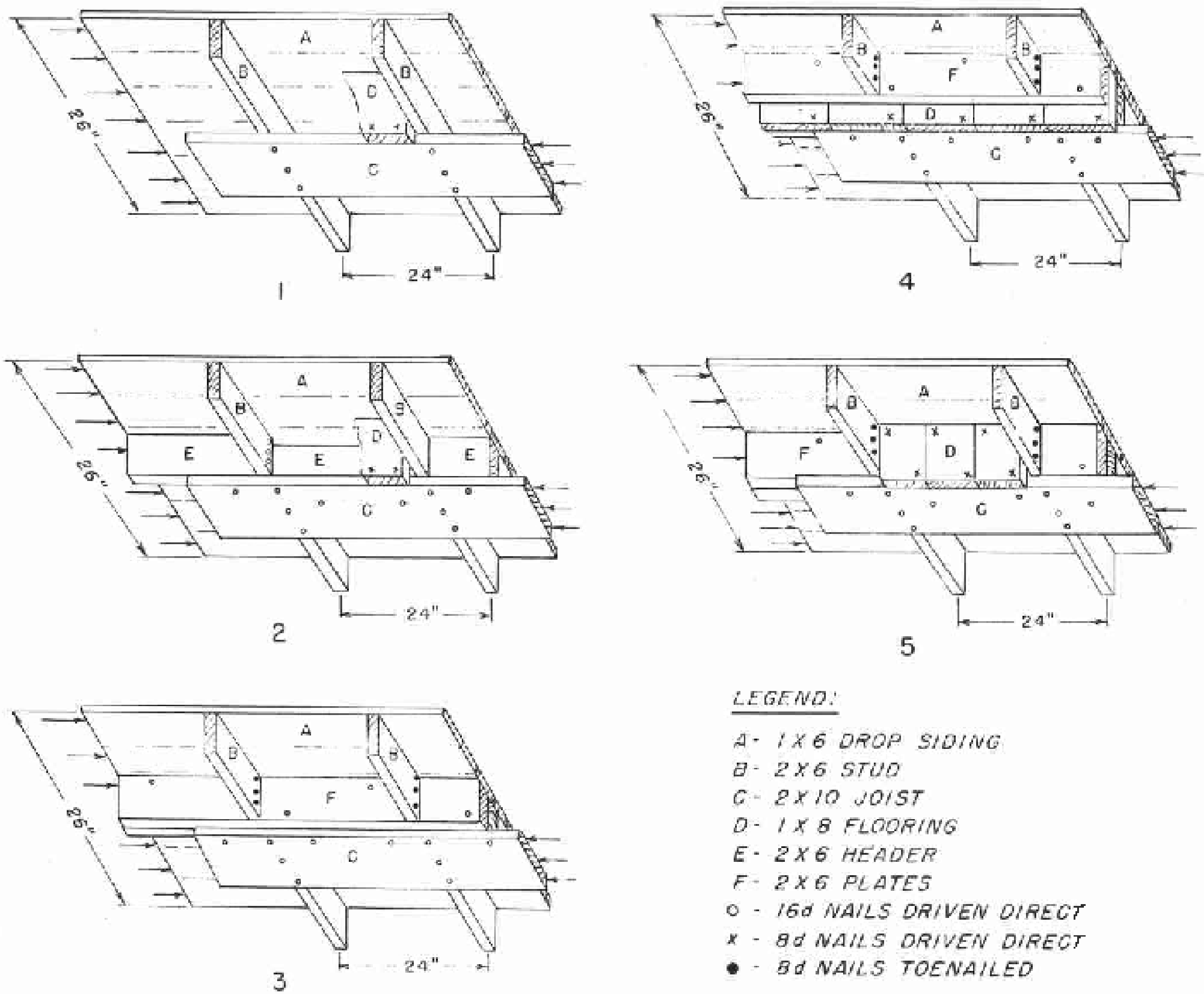

Figure 5.--Details of five construction methods used to determine the strength and rigidity of various connections between the barn end wall and the haymow floor.

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