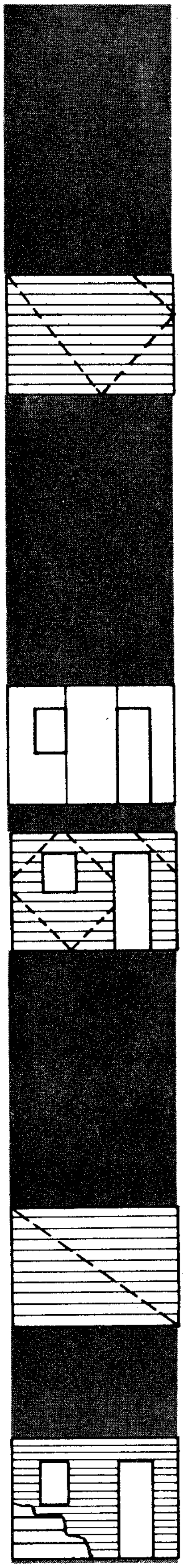
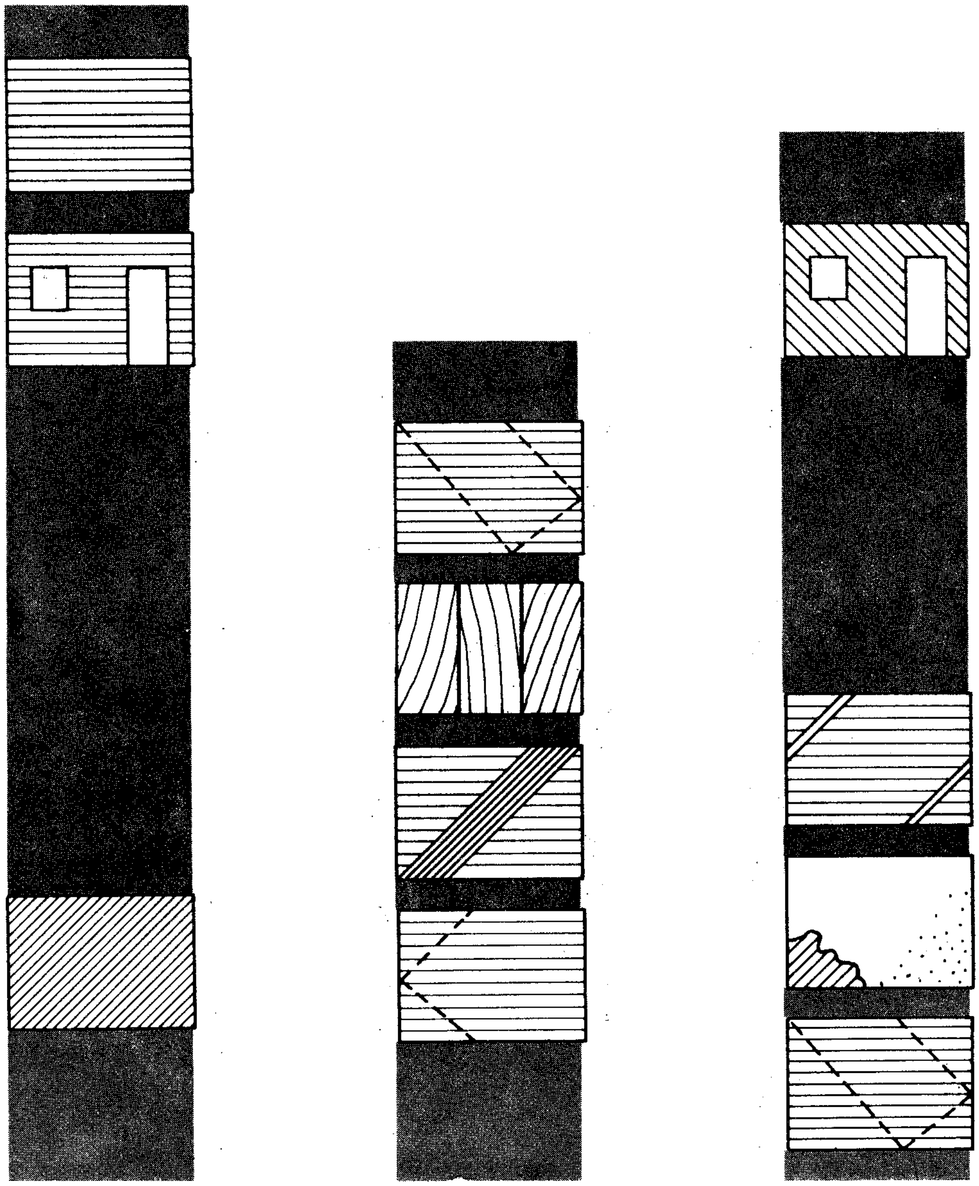
U. S. FOREST SERVICE
RESEARCH PAPER
FPL 31
AUGUST 1965

U. S. DEPARTMENT OF AGRICULTURE • FOREST SERVICE
FOREST PRODUCTS LABORATORY • MADISON, WIS.



GUIDES TO IMPROVED FRAMED WALLS FOR HOUSES



SUMMARY

Racking evaluations of wood-frame wall panels for dwellings and similar structures indicated that the following considerations were important in improving the rigidity and strength

1. If a saving in material is desired, decreasing the size of the studs was found to be better than increasing the spacing between studs in walls sheathed horizontally with lumber.
2. Although the value of diagonal wood sheathing was evident, excellent performance was also attained with plywood, fiberboard, and hardboard when used in 4- by 8-foot and longer sheets placed vertically with perimeter nailing.
3. Full-length let-in bracing at a 45° angle proved to be the best type of bracing. An exterior wall covered only with siding can be improved more than four-fold by the use of a 1- by 4-inch let-in brace.
4. Increasing the size or number of fastenings for sheathing made a substantial improvement.
5. A plaster finish was excellent.
6. Framing with medium-density softwood was better than with low-density softwood. However, this difference could be compensated by using larger or more nails in the sheathing.
7. Seasoned studs are recommended for rigid and strong walls. The use of unseasoned studs materially reduced the rigidity and strength of the wall after seasoning in place.

This paper includes information from and supersedes the following Forest Products Laboratory reports:

896 The Rigidity and Strength of Frame Walls, by G. W. Trayer. Revised February 1947

1025 Plywood as a Structural Covering for Frame Walls and Wall Units, by G. W. Trayer. August 1934

1151 Rigidity and Strength of Frame Walls Sheathed with Fiberboard, by R F. Luxford. Revised September 1953

1241 New England Eastern White Pine as a House Framing Material, by E. C. O. Erickson. September 1940

1261 The Rigidity and Strength of Braced and Unbraced Walls Covered with Bevel Siding, by E. C. O. Erickson. April 1941

1603 Rigidity and Strength of Wall Frames Braced with Metal Strapping, by E. C. O. Erickson. May 1946

2082 Diaphragm Action of Diagonally Sheathed Wood Panels, by D. V. Doyle. November 1957

2137 Adequacy of Light Frame-Wall Construction, by R F. Luxford and W. E. Bonser. November 1958

Guides to Improved Framed Walls for Houses, by A. D. Freas. Engineering News-Record 137(16): 117-120, 1946.

GUIDES TO IMPROVED FRAMED WALLS FOR HOUSES

By
L.O. ANDERSON, Engineer

FOREST PRODUCTS LABORATORY[1]
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

‡‡‡

Wood-frame construction of one type or another has been predominant in American dwellings almost since the landing of the Pilgrims. In spite of the introduction of alternate materials and construction methods during the last several decades, wood will likely maintain its popularity throughout the country. It is important, therefore, that the details of construction and the choice of materials in such dwellings provide satisfactory performance with as little maintenance as possible.

From the structural aspect, the most important elements of a house are those that provide resistance to wind forces. The walls are chiefly responsible for providing this resistance. Observations in many storm-swept areas have led to the conclusion that typical wood-framed and lumber-sheathed exterior walls have adequate strength to withstand almost any wind pressure likely to occur. More important, however, is the need for resistance to end thrust or racking forces from the action of wind on adjoining walls, as well as to other forces such as might be created by an earthquake. From the standpoint of this resistance and to provide rigidity to preserve alinement of the structure, technically sound construction is desirable.

The important factors that are most likely to influence the resistance of exterior walls to end thrust are (a) the size and location of openings in the wall, (b) the type and size of sheathing and framing materials, (c) the type of bracing, (d) the fastening methods, and (e) the moisture content of the framing and sheathing. Because most frame walls are adequately strong for supporting roof loads and resisting pressures perpendicular to their faces, design criteria covering this phase should be considered secondary to the need for incorporating good racking resistance in a frame wall. This was dramatically brought out in the 1964 Alaska earthquake where structures having walls with low resistance to racking were severely damaged.

The influence of the construction variables on the strength and rigidity of wood-frame walls has been studied at the Forest Products Laboratory for a number of years to provide information on the relative importance of each. From these data it is possible to select materials and construction methods most suitable for each need. The results of the evaluations of frame-wall constructions will point the way to improved design for wood-frame walls.

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

TEST PANEL DESCRIPTION

Racking tests of wall panels were first conducted at the Forest Products Laboratory in the late 1920's. Before this time, small frame structures had never been subjected to a thorough-going engineering analysis. Thus, these initial studies were made to obtain a better understanding and appreciation of the principles involved in wall construction that make small wood-frame buildings substantial structures free from excessive maintenance. After these initial racking studies, many others were conducted as additional information was required and as new building materials were introduced.

Nine-foot ceiling heights were often used for houses constructed in the twenties rather than the 8-foot height that is now considered standard. It was natural, therefore, that wall panels 9 feet in height were tested in these first studies. While the first panels were 9 by 14 feet in size, later studies included test panels of 8 by 12 feet. Since standard procedures have been established for racking tests, most of the later studies were conducted on panels 8 by 8 feet in size. In several barn studies, however, panels as large as 12 by 18 feet were tested. Rigidity and strength data shown in the tables of this Paper were

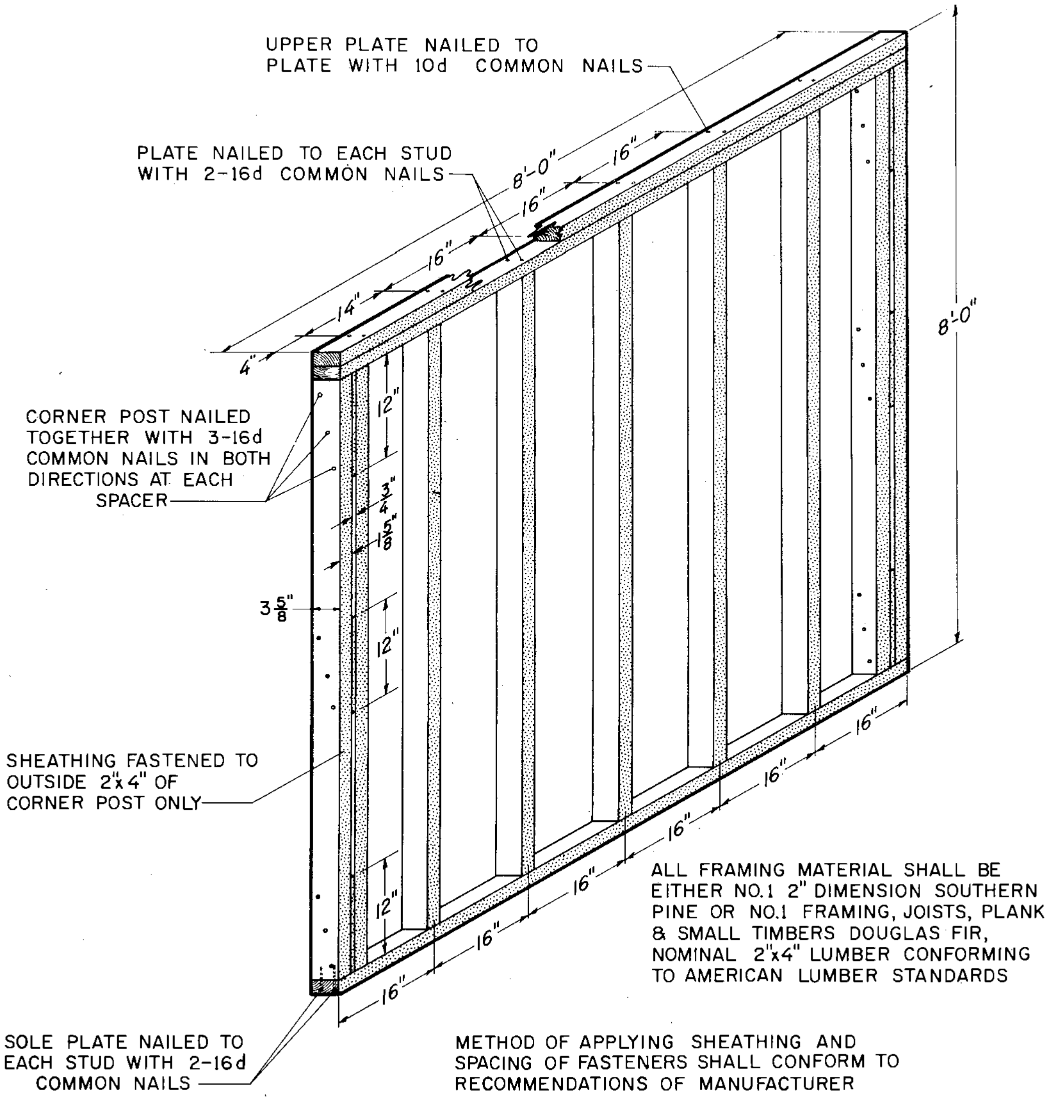


Figure 1.--Wood frame wall panel used for racking tests. (M 128 759)

calculated to compensate for size variations.

All panels used in the various tests were constructed in the same general manner, with single bottom plate and doubled top plate (fig. 1). As a rule, studs were spaced 16 inches on center, but studies also included panels with 24-inch spacing. Studs and plates were generally nominal 2- by 4-inch members, but 2- by 3-inch framing members were also evaluated. Southern pine or Douglas-fir with specific gravities ranging from 0.46 to 0.60 were generally used for framing but some studies involved the use of less dense softwoods. Construction and Standard or equivalent dimension grades of material were used with moisture content values ranging from 10 to 14 percent.

Other construction and material variables were evaluated to determine their effect on the stiffness and strength of the panels. These factors are listed below, in figure 2, and are more fully described later in the paper:

Lumber sheathing applied both horizontally and diagonally

Plywood sheathing in several thicknesses, placed vertically on the panels

Tempered hardboard sheathing used to cover one or both sides of the panel

Fiberboard sheathing in standard and medium-density grades

Panels constructed with and without door and window openings

Bracing, including let-in and cut-in wood braces and steel tension bracing

Fastenings, including adhesives as well as nails of different sizes and spacings for fastening sheathing and bracing to the framework

Wall panels with a plaster finish on one side

Panels made with seasoned and unseasoned lumber, conditioned and exposed to weathering.

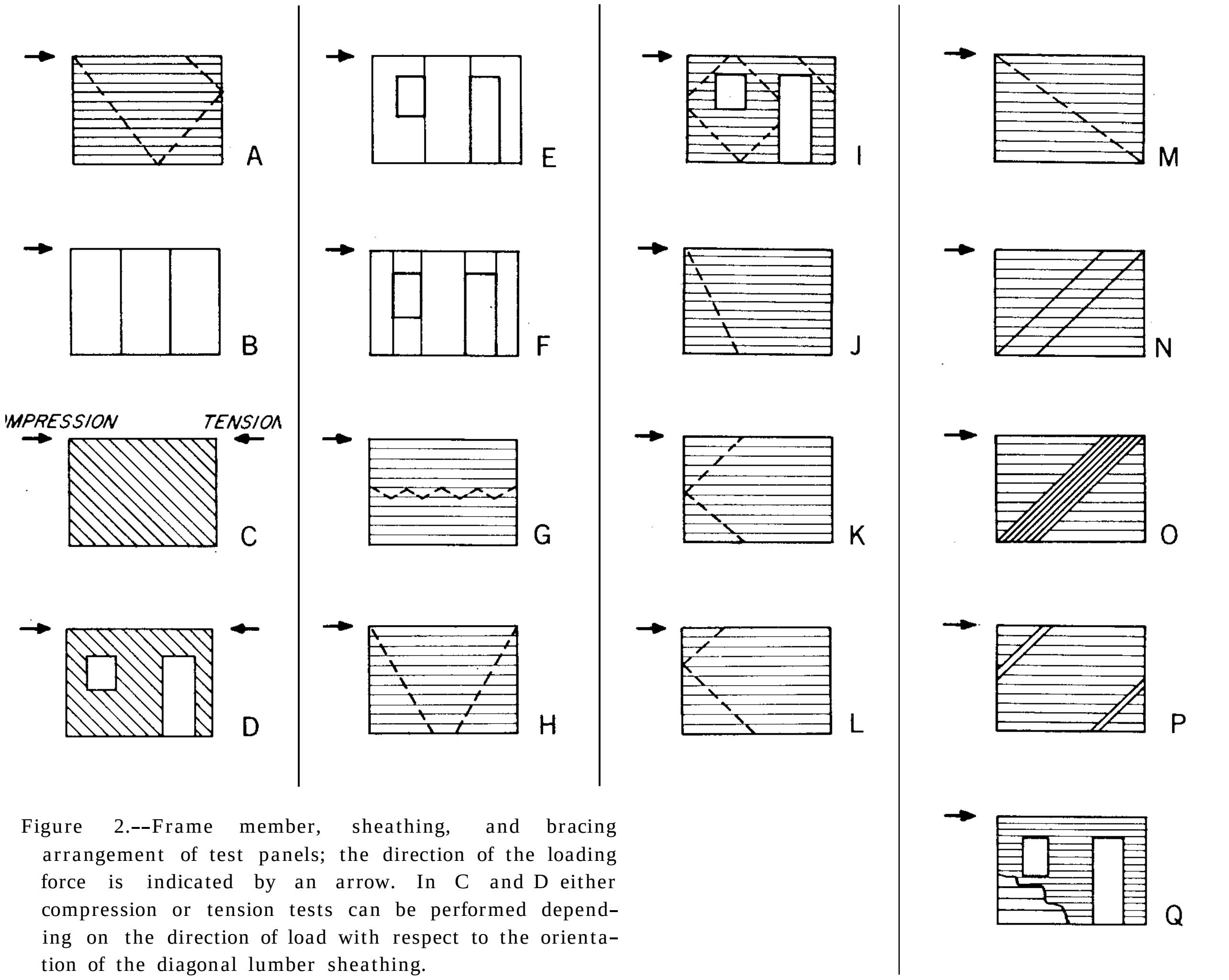


Figure 2.--Frame member, sheathing, and bracing arrangement of test panels; the direction of the loading force is indicated by an arrow. In C and D either compression or tension tests can be performed depending on the direction of load with respect to the orientation of the diagonal lumber sheathing.

METHODS OF TESTING

All wall panels in the various studies were subjected to a racking load consisting of a horizontal force applied to the upper corner of the anchored test panel. The method of test in many of the original studies at the Forest Products Laboratory consisted of bolting a timber to the top wall plate and then fastening the entire panel onto a fixed platen of the testing machine (fig. 3). Hold-down rods were placed at the loaded end of the panel to prevent uplift. Some studies used a hold-back stirrup to simulate roof and ceiling loads as well as the anchorage provided by walls at a right angle to the test panel. The head of the testing machine traveled at a rate of 0.155 inch per minute.

Later testing equipment included the use of a fixed steel frame and a hydraulic jack, as shown in figure 4.

The present American Society for Testing and Materials designation E 72, "Conducting Structural Tests of Segments of Wall, Floor, and Roof Construction," outlines procedures for testing 8- by 8-foot wall panels in racking. This standard and the test specimen were developed from the various racking tests conducted at the Laboratory and elsewhere during the last 20 to 30 years.

During tests, horizontal displacement of the upper plate was recorded at suitable load increments. Vertical uplift at the loaded end of the panel was checked by dial measurement. The usual loading procedure was to apply loads up to 150 pounds per linear foot (1,200 pounds for an 8 by 8 panel) and remove, measuring any residual displacement. Load was then increased to 300 pounds per linear foot and displacement again read after the removal of the load. Finally, loading was continued to failure or until a horizontal displacement of 5 inches occurred

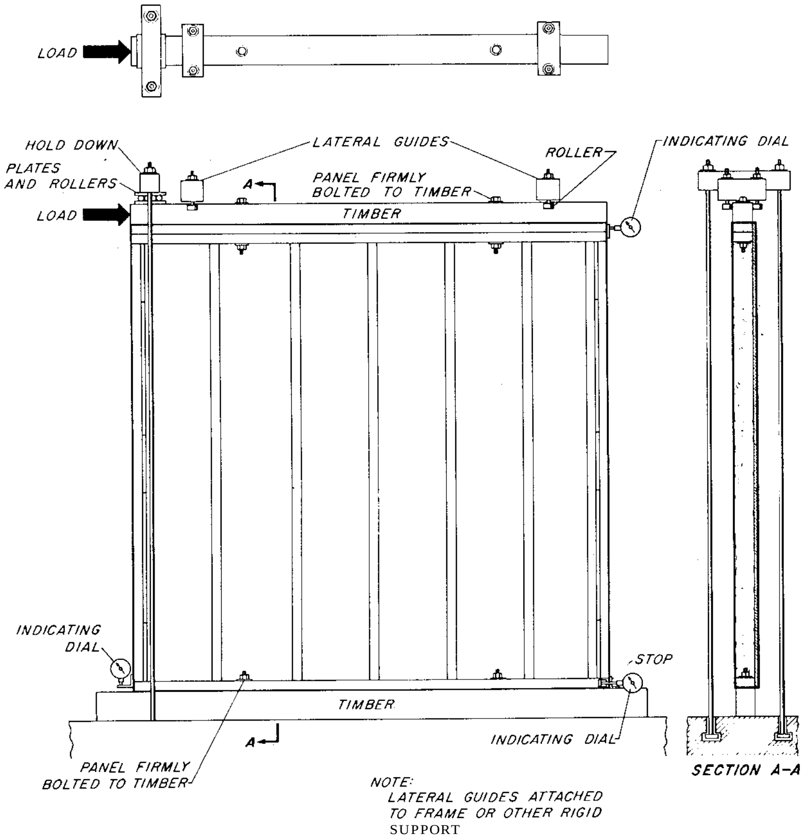


Figure 3.--Schematic diagram showing method of loading racking panels and measuring deflections. (M 123 922)

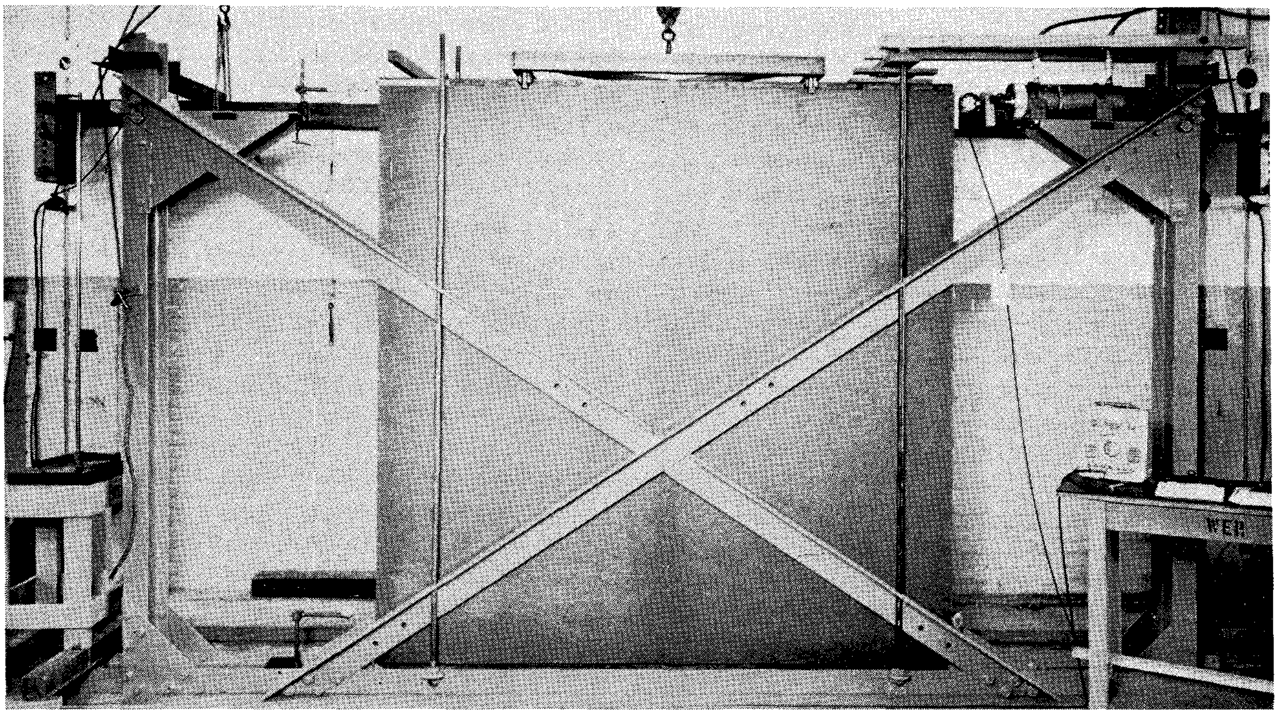


Figure 4.--Fixed steel frame used to test 8- by 8-foot panels in racking. M 126 965

at the upper plate.

Rigidity was measured according to the load at some given movement of the upper plate with respect to the lower, often 0.5 inch. In some instances, where plywood was glued to the frames, the rigidity was so great that it was necessary to use loads at smaller displacements. The strength of a panel was taken as the maximum load sustained during the test.

COMPARISON STANDARD FOR WOOD FRAMED WALL PANELS

A wood framework consisting of studs and plates covered with horizontal wood sheathing might be considered a practical minimum of shelter afforded by a wall. Thus, for purposes of comparison, a conventional frame wall without openings, made up of nominal 2- by 4-inch studs of a medium-density softwood species spaced 16 inches on center and covered with lumber sheathing, is used in this report as a control. Sheathing consists of horizontally applied nominal 1- by 8-inch square-edged lumber fastened to each stud crossing with two eightpenny common nails. Bracing is not used in the control panel.

Because of the variation in the sizes of wall panels which have been evaluated over a period of many years, the relative rigidity and strength are given rather than numerical values in pounds per linear foot. Thus, a factor of 1.0 has been assigned to the rigidity and strength of the control panels, and test results of other panels are expressed as ratios of this factor.

EFFECT OF MATERIALS AND CONSTRUCTION TECHNIQUES ON THE RIGIDITY AND STRENGTH OF WALL PANELS

Size and Spacing of Studs

Conventional wood frame walls for houses are normally constructed of surfaced 2- by 4-inch members spaced 16 inches oncenter. Information was desired on the performance of walls with different size and spacing of studs. Studies were conducted with various combinations of sheathing and bracing to determine their effect on the rigidity and strength of the walls. Nominal

2- by 4- and 2- by 3-inch studs were used with 16- and 24-inch spacing. Coverings consisted of (a) 1- by 8-inch boards placed horizontally on the wall, braced by a long 1- by 4-inch let-in brace placed at a 45° angle on the compression side and opposed by a "K" brace (fig. 2 A), and (b) 1/4-inch Douglas-fir plywood in 4- by 8-foot sheets, installed vertically (fig. 2 B). The lumber sheathing and the let-in bracing were nailed to the studs with two eightpenny common nails at each crossing. The plywood was nailed with sixpenny common nails spaced 5 inches apart along all edges and 10 inches apart at intermediate studs. Racking tests were made on all panels.

Increasing the spacing between the studs to 24 inches reduced the effectiveness of the bracing in the lumber-sheathed panels (table 1). The long brace in compression during test acted as a series of columns extending from stud to stud, and lengthening those columns by increasing stud spacing reduced resistance of the bracing to buckling as a long column. Reducing the spacing to 16 inches for both sizes of studs increased the rigidity about 60 percent and the strength about 90 percent of the values for walls having 24-inch stud spacing.

The size and spacing of studs had little effect on the wall panels sheathed with 1/4-inch plywood. All panels were about eight to nine times as rigid and carried more than four times the load of horizontally sheathed panels without bracing (control panels), regardless of stud size or spacing (table 2). This was due mainly to the use of large 4- by 8-foot sheets of plywood placed vertically. The perimeter nails of the plywood carried the majority of the racking load, so stud spacing was not as important as with other types of sheathing.

Considering the overall racking resistance of both braced lumber-sheathed panels and plywood-sheathed panels, if the use of less framing material is required, the tests indicated that studs of smaller size are more desirable than wider spacing of standard size studs.

Sheathing

The principal resistance to thrust in horizontally sheathed walls is afforded by the nail couples in the boards at each stud crossing. Although the contacting edges of the boards provide some resistance, shrinkage may eliminate the friction and then only the couples between the nails in each board at the studs are important. With the sheathing applied diagonally, there is triangulation in the wall and the nails offer far more resistance to distortion. Sheet materials, such as plywood and fiberboard, provide much of the rigidity to the wall panel by their perimeter nailing. This combination provides a diaphragm which performs in accordance with the effectiveness of the various parts, including lateral resistance of the nails, buckling of the covering material, and other factors. These sheathing variables were included in several studies conducted on wall panels,

Wood.--In the tests involving wood sheathing, it was determined that diagonal sheathing (fig. 2 C) provided from four to eight times greater rigidity and strength than horizontal sheathing (table 3). A wall panel without openings had about 70 percent greater rigidity when the diagonal sheathing was in compression than when in tension. This may have been due, in part, to the fact that the nails which were located near the ends of the boards were more effective when the sheathing was in compression.

With a window and door opening (fig. 2 D), the effectiveness of the diagonal sheathing was greatly reduced. When the sheathing was in compression, the rigidity of the panel with openings was about equal to that of the horizontally sheathed control panel. The strength of the panel was greater when the sheathing was in tension.

Fiberboard. --One study involving sheathing variables indicated that the density of fiberboard had some influence on the rigidity of wall panels without openings. As shown in table 4, the panel without openings, which was sheathed with 1/2-inch medium-density fiberboard, had about 40 percent greater rigidity than the panel with 25/32-inch fiberboard. This was likely due, in part, to the lower density of the 25/32-inch fiberboard. Nail types and spacings differed somewhat between the two types of panels, however, and may also have had some influence on the rigidity. Strength tests indicated that there was no great difference in the two types of panels. Both panels were three to four times as rigid and strong as the control panel with horizontal sheathing.

Panels containing window and door openings were tested with a low-density fiberboard sheath-

Table 1.--The effect of size and spacing of studs on rigidity and strength of frame walls horizontally sheathed with 1- by 8-inch boards[1]

Studs		Relative rigidity	Relative strength
Size	Spacing		
In.	In.		
2 by 4 (control panel)	16	1.0	1.0
2 by 4	16	4.4	3.9
2 by 4	24	2.7	2.0
2 by 3	16	3.7	3.5
2 by 3	24	2.2	1.9

[1]Walls braced with 1- by 4-inch let-in bracing at a 45° angle in compression, opposed by "K" brace (fig. 2 A).

Table 2.--The effect of size and spacing of studs on rigidity and strength of frame walls sheathed with 1/4-inch plywood[1]

Studs		Relative rigidity	Relative strength
Size	Spacing		
In.	In.		
2 by 4 (control panel)	16	1.0	1.0
2 by 4	16	8.5	4.5
2 by 4	24	8.4	4.4
2 by 3	16	8.5	4.5
2 by 3	24	7.8	4.4

[1]Plywood used vertically with perimeter nailing (fig. 2 B).

Table 3.--Effect of diagonal sheathing on the rigidity and strength of frame walls[1]

Type of panel	Diagonal sheathing in--	Relative rigidity	Relative strength
Control panel (no openings)	(Horizontal sheathing)	1.0	1.0
No openings	Compression	7.3	8+
	Tension	4.3	8+
Window and door openings	Compression	1.0	1.3
	Tension	1.4	4.0

[1] The 1- by 8-inch diagonal sheathing was applied at a 45° angle and nailed with 2 eightpenny nails at each stud crossing (figs. 2 C and D).

Table 4.--Effect of fiberboard sheathing (applied vertically) on the rigidity and strength of frame walls

Type of panel	Type of sheathing	Fastening of sheathing: Nail size	Fastening of sheathing: Nail spacing: Perimeter	Fastening of sheathing: Nail spacing: Intermediate	Relative rigidity	Relative strength
		Penny	In.	In.		
Control panel	1 by 8 horizontal	[1] 8	....	....	1.0	1.0
No openings	25/32-inch fiberboard	8	[2] 3	6	3.0	3.8
No openings[3]	1/2-inch fiberboard (medium density)	1-3/4-inch roofing	3	6	4.2	3.6
Window and door[4]	25/32-inch fiberboard (sawed out at opening) (low density)	8	[2] 3	6	1.5	1.6
Window and door[4]	25/32-inch fiberboard (full sheets--fillers at door and window) (low density)	8	[2] 3	6	1.6	2.1

[2] The spacing at top and bottom was 5-1/2 inches.
[3] Made by fastening two 4- by 8-foot panels together.
[4] See figures 2 E and F.

Table 5.--Effect of plywood sheathing (applied vertically) on the strength and rigidity of frame walls

Plywood thickness	Fastening of sheathing			Openings	Relative rigidity	Relative strength
	Nail size	Nail spacing				
		Perimeter	Intermediate			
In.	Penny	In.	In.			
Control panel	[1]8	....	....	None	1.0	1.0
5/8	8	6	12	None	4.8	9+
5/8	Glued	....	....	None	24.0	9+
[2]3/8	6	6	12	None	5.0	3.9
1/4	6	5	10	None	4.2	5.2
1/4	6	2-1/2	5	None	5.9	7.0
1/4	Glued	....	....	None	14.4	8+
1/4	6	5	10	Door and window	2.0	2.8
1/4	Glued	....	....	Door and window	3.7	4.0

[1] Two nails used for each board at every stud.
[2] Panel, 8 by 8 feet in size, was made up by fastening two 4- by 8-foot panels together.

ing applied in two manners. In one group, the fiberboard was sawed out at the openings (fig. 2 E); in the other, full sheets were used between openings and filler pieces used above both openings and below the window (fig, 2 F). While there was little difference in the rigidity of the two panels, the racking tests indicated that the panels with full sheets and filler pieces were somewhat stronger (table 4). The sawed-out fiberboard failed at the reentrant angles.

Plywood.--A number of plywood-sheathed panels were tested with both glued and nailed assemblies. The glued 5/8-inch plywood-sheathed panel was about five times as rigid as its nailed counterpart (table 5). In panels using 1/4-inch plywood, the glued panels were about three and one-half times as rigid as panels having standard nail spacings (5-inch perimeter and 10-inch intermediate) and two and one-half times as rigid as panels with double nailing. Strengths of the glued panels were about equal or slightly improved over their nailed counterparts. However, even the nailed 1/4-inch plywood panels were four times as rigid and five times as strong as the control panels with horizontal sheathing.

In the presence of door and window openings, glued panels were 80 percent more rigid and 40 percent stronger than the nailed panels using 1/4-inch plywood sheathing (table 5).

As shown in table 5, double nailing of 1/4-inch plywood sheathing increased the rigidity of the panel by 40 percent and the strength by over

30 percent when compared to standard-nailed plywood.

Tests of panels with nailed 3/8-inch plywood sheathing showed a 20 percent decrease in rigidity over the 1/4-inch plywood panels (table 5). However, the strength was not as great as that of the conventionally constructed panels with 1/4-inch plywood. This may have been due, in part, to the fact that the 3/8-inch plywood test panels were made by nailing two 4- by 8-foot wall panels together.

Tempered hardboard.--Racking tests were conducted on hardboard-sheathed panels to determine their relative resistance to forces resembling earthquakes. Considerable interest has be en shown on diaphragm design data for plywood- or hardboard-sheathed wall sections. Because little information was available on the use of tempered hardboard for such purposes, variables of double- and single-sheathed panels with nail and nail-glue fastening methods were considered. Panels were sheathed on one or two sides with 1/4-inch tempered hardboard (65 pounds per cubic foot) and fastened with sixpenny common nails spaced 3 inches around the perimeter and 6 inches at intermediate studs; 4- and 8-inch nail spacings were also evaluated. In addition, hardboard was glued and nailed to the framing members.

As shown in table 6, the rigidity and strength of the single-sheathed hardboardpanel were many times greater than the horizontally sheathed control panel. Both rigidity and strength of the double-sheathed panels were about 70 percent greater than the single-sheathed panels with 3- and 6-inchnail spacing. Increasing the nail spacing to 4 and 8 inches reduced rigidity and strength by almost 20 percent. When the hardboard was glued and nailed to the framework, the rigidity was increased only moderately but the strength was about 90 percent greater than with nailing alone.

Table 6.--The effect of 1/4-inch tempered hardboard on rigidity and strength of frame walls

Variables	Relative rigidity	Relative strength
Control panel	1.0	1.0
Hardboard sheathingone side; 3- and 6-inch nailspacing	9.8	6.9
Hardboard sheathing two sides; 3- and 6-inch nailspacing	16.2	11.6
Hardboardsheathinntwo sides; 4- and 8-inch nailspacing	13.3	8.7
Hardboardsheathingtwo sides; nail spacing 3 and 6 inches plus glue	17.6	21.4

Bracing

Most building codes require that the exterior walls of houses have some type of corner bracing unless the sheathing provides the necessary rigidity. Walls sheathed diagonally with lumber are very rigid and strong and satisfy most requirements. Plywood and fiberboard in 4- by 8-foot sheets installed vertically with perimeter nailing also produce rigid panels, as has been previously outlined. However, horizontal wood sheathing, fiberboard, and other materials in 2- by 8-foot sheets or 4- by 8-foot sheets installed horizontally, usually require some type of bracing to meet rigidity and strength requirements. The results of tests of wall panels conducted at the Laboratory showed the effect of several types of bracing on the rigidity and strength.

Horizontally sheathed walls.--Two types of braces commonly used in walls are the "cut-in" and "let-in" types. The "cut-in" brace is a series of 2- by 4-inch members which are cut to fit between the studs. The "let-in" brace is a 1 by 4 or wider member which fits into prepared notches in the studs so that the face of the brace is flush with the edges of the studs.

A herringbone pattern of cut-in braces (fig, 2 G), located midway to the height of a horizontally sheathed panel, did not add materially to the rigidity and strength (table 7). When the cut-in braces were placed in pairs at about a 60° angle from each top corner to the bottom plate (fig. 2 H), the rigidity was 60 percent greater and the strength 40 percent greater than in the horizontally sheathed control panel. However, this type of bracing provided only about 60 percent the rigidity and 40 percent the strength of 1- by 4-inch let-in braces in the same 60° angle pattern.

As shown in table 7, a let-in brace located at the upper corner of the rectangular wall panel and extending through the wall height to the bottom plate at a 45° angle, together with a "K" brace (fig. 2 4, provided high

Table 7.--Effect of bracing on horizontally sheathed walls[1]

Bracing		Nails for bracing	Relative rigidity	Relative strength
Size	Type and reference			
None	Control panel[1]	No brace	1.0	1.0
2 by 4	Cut-in - fig. 2 G	Nailed to studs	1.3	1.1
2 by 4	Cut-in - fig. 2 H	Nailed to studs	1.6	1.4
1 by 4	Let-in - fig. 2 H	2 eightpenny	2.6	3.6
1 by 4	Let-in - fig. 2 A	2 eightpenny	4.2	3.5
1 by 4	Let-in - fig. 2 I	2 eightpenny	1.5	2.2
1 by 4	Let-in - fig. 2 J	2 eightpenny	2.9	3.3
1 by 4	Let-in - fig. 2 K	2 eightpenny	1.4	2.2
1 by 4	Let-in - fig. 2 L	2 eightpenny	1.8	2.8
1 by 4	Let-in - fig. 2 M	2 eightpenny	4.1	4.4

[1]Standard panel, consists of 2- by 4-inch studs and 1- by 8-inch horizontal wood sheathing with 2 eightpenny nails per board at each stud.

rigidity and strength. Horizontally sheathed 8- by 8-foot wall panels with full-length (extending from the top to the bottom plate) 1- by 4-inch let-in braces placed at a 45° angle (fig. 2 M) also had excellent rigidity and strength (table 7). Any variation of this full 45° pattern, such as placing the brace at a steeper angle or the presence of windows and doors preventing the use of a long brace (figs. 2 I, J, K, and L), reduced the rigidity significantly and the strength materially (table 7). For example, the plate-to-plate let-in brace of figure 2 J, placed at an angle of approximately 60°, had twice the rigidity and half again the strength of the equal-leg "K" brace of figure 2 K.

Unsheathed frames.--Racking tests conducted on a series of unsheathed wall frames indicated that spacing of the 2- by 4-inch studs affected the rigidity and strength of a wall panel as much as the size of the let-in brace. For example, as shown in table 8, a wall with 24-inchstud spacing and a 1- by 6-inch full-length 45°-angle let-in brace had about the same rigidity and strength as the panels with 1 by 4 braces and 16-inch stud spacing. All braced but unsheathed panels were from two to three times more rigid than the horizontally sheathed control panels. Strength was also improved from about one-third to more than two and one-half times, even though some of the braced panels had 24-inch stud spacing.

Steel tension straps on horizontally sheathed walls.--In order to find a simple method of improving the racking resistance of walls already covered with horizontal sheathing, a study utilizing steel tension straps was conducted. Strapping was 1 by 0.031 inches insizeandwas prepunched. Strapping was placed at a 45° angle, to act in tension, and nailed to the studs or sheathing.

As the number of straps was increased, the rigidity and strength of the panel were improved (table 9). The use of two full-length steel straps (fig. 2 N) almost doubled the rigidity and increased the strength by 40 percent over the sheathed control panel without bracing. Seven full-length

Table 8--Effect of bracing on unsheathed frames[1]

Stud spacing	Bracing [2]	Relative rigidity	Relative strength
16 inches on center (with 1 by 8 horizontal sheathing)	Control panel (no brace)	1.0	1.0
16 inches on center	1 by 4	2.6	2.0
24 inches on center	1 by 4	2.3	1.3
16 inches on center	1 by 6	3.0	2.6
24 inches on center	1 by 6	2.5	2.0
16 inches on center	1 by 4 (tenpenny nails) [3]	2.0	2.1

[1] Standard frame of 2- by 4-inch studs, bottom plate, and double top plate.

[2] All bracing let-in, at 45° angle, tested in compression and nailed with 2 eightpenny nails at each stud, similar to arrangement in figure 2 M.

[3] One long diagonal at 45° and an opposed "K" brace, similar to arrangement in figure 2 A. These panels were longer than preceding panels.

Table 9.--Effect of steel strap tension bracing on the strength and rigidity of frame walls[1]

Strapping	Relative rigidity	Relative strength
No straps, sheathing only (control panel)	1.0	1.0
2 straps, 45°, nailed to each board with 2 nails per board, figure 2 N	1.9	1.4
7 straps, 45°, nailed to each board with 2 nails per board, figure 2 O	3.3	2.9
2 straps at each corner, 45°, nailed to each board with 2 nails, figure 2 P	1.4	1.3

[1] When used over wall panel with 1- by 8-inch horizontal sheathing.

straps (fig. 2 O) increased the rigidity by more than three times and the strength almost three times that of the control panel. However, two short straps, located at two opposite corners (fig. 2 P), increased the rigidity and strength by only one-third.

Thus, if there is no other convenient means of improving the racking resistance of an existing sheathed wall, the use of full-length steel tension strapping will increase the rigidity and strength materially.

Spaced Diagonal Sheathing

Several wall panels were tested to determine the requirements for spaced diagonal sheathing when vertical siding was used, Studs were spaced 24 inches on center, and the 1- by 4-inch diagonals, placed at a 45° angle, were spaced about 16 inches on center. Vertical siding consisted of 1- by 8-inch boards. Panels were tested with the diagonals in tension and in compression.

When tested with diagonals in tension, the wall panel was three and one-half times as rigid and four times as strong as the horizontally sheathed control panel without bracing. When tested with diagonals in compression, panels were almost five times as rigid and strong as the control panel. Thus, diagonal bracing or sheathing should be placed so that it acts in compression for higher rigidity and strength values.

Double-Sheathed Panels

In a study of structural components for farm buildings, racking tests were made on a number of 12- by 12-foot wall panels with spaced diagonal sheathing. The diagonally sheathed panels were tested with the sheathing both in compression and in tension. One panel was double-sheathed so that when tested the sheathing on one side was in compression and on the other side in tension. This double-sheathed panel was about three times as rigid as the single-sheathed panels.

Wall Panels with Glazed Openings

Racking tests were made on a wall containing a large plate-glass window to determine its effect on the rigidity and strength of the wall. Two-foot areas on each side of the 8-foot-wide glass and the wall above and below were sheathed with fiberboard or plywood. With the glass in place, the rigidity was approximately twice as great as when tested unglazed. The strength was about three and one-half times greater than the unglazed wall panel.

Siding

Many smaller or secondary buildings are constructed with only siding nailed over a framework of studs. This is common practice for garages and, in some areas, for low-cost houses. However, most codes require the use of some type of bracing to provide more racking resistance than can be obtained from the siding alone. In order to determine the contribution of the siding to the rigidity and strength of a frame wall, tests were made on bevel siding used alone as well as with bracing and with sheathing.

The use of 1/2- by 6-inch bevel siding over a stud wall provided only about 70 percent of the rigidity and 50 percent of the strength of framed walls covered with 1- by 8-inch horizontal sheathing (table 10). When larger 3/4- by 8-inch bevel siding was used, rigidity was the same as that of the control panels with horizontal sheathing but strength was somewhat lower.

When 1- by 4-inch let-in braces were used before application of the siding, both the rigidity and the strength were more than three times greater than the control panel for both sizes of siding (table 10).

Siding slightly improved the strength and rigidity of framed walls containing window and door openings when used over horizontal sheathing (fig. 2 Q). The addition of let-in bracing, together with horizontal sheathing and bevel siding, increased the rigidity and strength of the wall about two and one-half times over the same type of panels without the bracing (table 10). In walls with window and door openings bevel siding over diagonal sheathing was tested with the sheathing both in compression and tension. This combination performed better than similar panels with only horizontal sheathing and siding.

Fastening Methods

The methods used to fasten sheathing and bracing to the studs played an important part in the relative rigidity and strength of the wall. Because nails are the most common fastener, the majority of the test panels were fabricated by nailing. However, a number of panels were assembled by gluing plywood sheathing to the framing. Adhesives are being constantly improved, and their use in the field as a supplemental fastening method is highly probable in the future.

Horizontally sheathed walls. --Horizontal wood sheathing boards in 6- and 8-inch widths are usually fastened with two eightpenny nails at each stud crossing. The addition of a third nail in the center of 1- by 8-inch horizontal sheathing in nailing to the stud provided no increase in the rigidity or strength of the panel (table 11). Because nail couples are more effective as the distance between them increases, a nail at the center merely acts as a pivot as racking forces are applied. The use of four nails, however, increased the rigidity and strength by 40 percent.

Wall openings	Siding size [1]	Sheathing or bracing	Relative rigidity	Relative strength
	In.			
None (control panel)	None	1- by 8-inch horizontal sheathing	1.0	1.0
None	1/2 by 6	Siding only	.7	.5
None	3/4 by 8	Siding only	1.0	.8
None (similar to figure 2 A)	1/2 by 6	1 by 4 let-in brace--diagonal and "K" brace	3.2	3.3
None (similar to figure 2 A)	3/4 by 8	1 by 4 let-in brace--diagonal and "K" brace	3.1	3.7
Door and window (figure 2 Q)	1/2 by 6	1 by 8 horizontal sheathing	1.1	1.3
Door and window (similar to figure 2 I)	1/2 by 6	1 by 8 horizontal sheathing and 1 by 4 let-in braces	2.7	3.4
Door and window (similar to figure 2 D)	1/2 by 6	1 by 8 diagonal sheath. ing (tested in tension)	3.3	5.4
Door and window (similar to figure 2 D)	1/2 by 6	1 by 8 diagonal sheath. ing (tested in compression)	2.0	3.3

Table 10.--Effect of siding on frame walls

[1]Eightpenny nails used to nail 3/4-inch siding; sevenpenny used for 1/2-inch siding.

The use of nails larger than eightpenny for sheathing also provided additional rigidity and strength. As shown in table 11, two tenpenny nails were equivalent to four eightpenny nails.

A series of wall panels were made entirely of eastern white pine with horizontal sheathing and 1- by 4-inch let-in braces. In one group the horizontal sheathing was nailed to the studs with two eightpenny nails at each stud crossing, and the bracing to the studs with two tenpenny nails (fig. 2 A). Panels were also tested in which the sheathing, in addition, was nailed to the brace between each stud with six eightpenny nails, As shown in table 11, the additional nailing of the sheathing to the brace provided a 40 to 50 percent increase in rigidity and strength over panels with no nailing between the studs.

Diagonal wood sheathing.--As in horizontal sheathing, 6- and 8-inch diagonal sheathing is normally nailed with two nails at each stud crossing. However, unlike horizontal sheathing, test results showed that the use of three nails improved the rigidity and strength of the diagonally sheathed panels. For example, three nails increased the rigidity by over 20 percent and four nails by more than 70 percent (table 12). The

Table 11.--Effect of fastenings on horizontal sheathing and bracing

Nailing			Relative Rigidity	Relative strength
Number	Size	Part		
	Penny			
2	8	Sheathing (control panel)	1.0	1.0
3	8	Sheathing	1.0	.9
4	8	Sheathing	1.4	1.4
2	10	Sheathing	1.5	1.4
2	12	Sheathing	1.3	1.1
[2]2	10	Bracing	3.7	3.7
[2]2	12	Bracing		
6	8	Sheathing to bracing (between each stud	5.6	5.8

[1]Standard panel consists of southern pine 2-by 4-inch studs spaced 16 inches on center and 1-by 8-inch southern pine sheathing nailed to studs.

[2]Framing and sheathing of eastern white pine.

use of two tenpenny nails rather than two eightpenny nails also increased the rigidity and was almost the equivalent of three eightpenny nails. Strengths of the panels did not vary under conditions of the tests.

Fiberboard and plywood sheathing--Corner bracing for walls is not ordinarily required if 4-foot-wide sheets of fiberboard or plywood are applied vertically with proper nailing. Normally, spacing nails 3 inches apart around the perimeter and 6 inches apart at intermediate studs insures good performance for fiberboard sheathing. For plywood sheathing, nail spacing is often 6 and 12 inches, although 5-inch perimeter and 10-inch intermediate spacing is also used. In several racking tests, 3- and 6-inch nail spacing in fiberboard sheathing resulted in three times the rigidity and almost four times the strength of the horizontally sheathed control panel. Double nailing (1-1/2-and 3-inch spacing) increased the rigidity and strength by 50 to 60 percent (table 13). However, in the presence of window and door openings, double nailing provided only a small increase in rigidity and strength over regular nail spacing.

Normal nailing, 5- and 10-inch spacing, of 1/4-inch plywood resulted in four to five times the rigidity and strength of the horizontally sheathed control panel. Double nailing of the plywood sheathing (2-1/2- and 5-inch spacing) increased the rigidity and strength by 35 to 40 percent over the 5- and 10-inch spacing (table 13). Gluing plywood to the studs increased the rigidity of the panel more than three times over the panel with nail spacing of 5 inches around the perimeter and 10 inches at intermediate studs. The strength of the glued panel was increased by almost 60 percent (table 13).

Lath and Plaster

In developing minimum standards for the rigidity and strength of a wood-frame wall, the contribution of the interior wall finish is usually

Table 12.--Effect of fastenings on panels with diagonal wood sheathing[1]

Nailing of sheathing: Number	Nailing of sheathing: Size	Relative rigidity	Relative strength
	Penny		
Control panel	....	1.0	1.0
2	8	4.3	8 +
3	8	5.2	8 +
4	8	7.5	8 +
2	10	5.1	8 +

[1] Panels of 2- by 4-inch studs spaced 16 inches on center with 1- by 8-inch diagonal sheathing, tested in tension.

discounted. This is necessary because common interior covers such as vertical or horizontal strip paneling, wood or wood fiber tile and plank, and similar forms may add little to the rigidity or strength of the wall itself. However, a plastered interior finish may provide much additional rigidity and strength. Thus, a study was conducted to determine the effect of plaster on the rigidity and strength of a wall. It was found that plastering a conventionally framed wall without sheathing or bracing resulted in a panel more than seven times as rigid and four times as strong as the horizontally sheathed control panel (table 14). Wood lath was used because materials such as rock lath had not been developed at the time of the study. Thus, no comparison could be made with rock lath or other plaster–base materials. However, it is felt that the rigidity of a plastered wall is obtained mainly from the plaster. The keying of the plaster between each wood lath or the adhesion of the plaster to rock lath makes the entire wall surface act as a unit under racking loads.

The addition of horizontal sheathing to the opposite side of the plastered wall increased the rigidity 10 percent and the strength 40 percent (table 14). Diagonal sheathing, however, increased the rigidity 30 percent and the strength more than 80 percent.

Door and window openings greatly reduced the rigidity and strength of a wall regardless of the type of covering material used. As noted in table 14, the addition of horizontal or diagonal sheathing only slightly improved the rigidity of the panels over those having only plaster. The same types of panels without openings were more than three times as rigid. The addition of diagonal sheathing significantly increased the strength of panels with openings, however. The addition of horizontal sheathing with let–in braces increased the rigidity 80 percent and the strength more than 100 percent over the unsheathed plastered wall panel with openings.

Species Density

Wood–framed walls for houses are constructed of many different species of softwoods, ranging in average specific gravity from 0.36 to 0.60. Because stresses of roof loads and direct winds are easily resisted by most species of lumber commonly used in the construction of conventionally framed walls, lumber with a high density and bending resistance is not normally required for studs. It was desirable to determine the effect of the density of the framing on the racking resistance of a wall. Thus a series of racking tests was conducted to determine the difference in racking resistance of wall panels constructed with a low–density softwood and panels with a medium–density softwood.

Based on test results, a horizontally sheathed wall panel constructed with a low–density lumber had only about 70 percent the rigidity and 90 percent the strength of one made with a medium–density lumber. However, by fastening the sheathing with two tenpenny nails at each stud crossing, the rigidity and strength of the low–density panel approached those of the medium–density control panel with two eightpenny nails (table 15).

With diagonal sheathing, the low–density panel had only about 70 percent the rigidity and strength of the same type of panel constructed with a medium–density wood. Again, improvement of the low–density panel was achieved by using two tenpenny nails or three eightpenny nails (table 15).

A series of racking tests was conducted to determine the relative performance of plywood–sheathed wall panels (a) with low–density softwood framing members (S.G. = 0.37) and (b) with medium–density softwood framing members (S.G. = 0.51). Four– by 8–foot sheets of 5/16–inch

Table 13.--Effect of fastenings on fiberboard and plywood sheathing [1]

Sheathing type	Fastening of sheathing			Relative rigidity	Relative strength
	Nail size	Nail spacing			
		Perimeter	Intermediate		
	Penny	In.	In.		
Horizontal (control panel)	8	....	....	1.0	1.0
Fiberboard	8	[2] 3	6	3.0	3.8
Fiberboard	8	Double	Double	4.5	6.1
Fiberboard [3]	8	[2] 3	6	1.6	2.1
Fiberboard [3]	8	Double	Double	1.7	2.6
Plywood	6	5	10	4.2	5.2
Plywood	6	2-1/2	5	5.9	7.0
Plywood	Glued	....	....	14.4	8 +

[1] The 25/32-inch fiberboard and 1/4-inch plywood sheathing in 4-foot-wide sheets, was installed vertically over the full height of the panels.

[2] Top and bottom plate: nails spaced 5-1/2 inches.

[3] Panel has window and door framing, figure 2 F.

plywood were placed vertically on 8- by 8-foot panels and nailed with sixpenny common nails spaced 6 inches around the perimeter and 12 inches at intermediate studs. As shown in table 15, the rigidity of the medium-density panel was about 15 percent greater than that of the low-density softwood. A greater difference was noted in the strength, however, as the medium-density panel was about 30 percent stronger than the low-density frame.

Seasoning and Exposure

Unseasoned or partially seasoned wood (wood which has a higher moisture content than it reaches in service) is sometimes used for framing and sheathing. Tests were made at the Forest Products Laboratory to determine the effect of unseasoned wood on the rigidity and strength of a wall. Both horizontally and diagonally sheathed panels were made of unseasoned lumber and allowed to dry indoors for 1 month before being tested. As shown in table 16, the horizontally sheathed panels were 50 percent and the diagonally sheathed panels 40 percent as rigid as similar panels made of seasoned material. Exposure of horizontally sheathed panels made of seasoned lumber to outdoor conditions of wetting and drying reduced the rigidity 30 percent and the

Table 14.--Effect of lath and plaster on wood-framed walls[1]

Wall openings	sheathing (1 by 8)	Relative rigidity	Relative strength
None (control panel)	Horizontal	1.0	1.0
None	None	1.2	4.4
None	Horizontal	7.9	5.6
None	Diagonal (tension)	9.2	8+
Door and window	None	2.3	1.6
Door and window	Horizontal	2.4	2.2
Door and window	Diagonal (tension)	2.8	4.4
Door and window[2]	Horizontal	4.1	3.6

[1]All panels plastered on one side except control panel. Wood lath used, as it was a standard plaster base at the time teats were conducted.

[2]The 1- by 4-inch let-in bracing around the door and window was similar to figure 2 I.

Table 15.--Effect of species density on stiffness and strength (low- and medium-density softwoods)[1]

Density of lumber[1]	Sheathing		Relative rigidity	Relative strength
	Type	Nails		
		Penny		
Control panel (medium)	1 by 8 horizontal	2-8	1.0	1.0
Low	1 by 8 horizontal	2-8	.7	.9
Low	1 by 8 horizontal	2 - 10	.9	1.2
Medium	1 by 8 diagonal[2]	2-8	4.3	8+
Low	1 by 8 diagonal[2]	2-8	2.9	6.0
Low	1 by 8 diagonal[2]	2 - 10	3.6	7.7
Low	1 by 8 diagonal[2]	3 - 8	3.8	8
Medium	5/16-inch plywood	[3]6	4.8	4.3
Low	5/16-inch plywood	[3]6	4.2	3.3

[1]Medium-density softwood - specific gravity = 0.50 average.
Low-density softwood - specific gravity = 0.36 average.

[2]A11 diagonally sheathed panels tested with sheathing in tension.

[3]Spaced 6 inches around perimeter and 12 inches at intermediate studs.

Table 16.--Effect of seasoning and exposure				
Sheathing or covering	Condition of lumber at assembly	Exposure before testing	Relative rigidity	Relative strength
1 by 8 horizontal sheathing	Seasoned	None (control pane1)	1.0	1.0
1 by 8 horizontal sheathing	Unseasoned	Seasoned indoor, 1 month	.5	.7
1 by 8 horizontal sheathing	Seasoned	Exposed to rain and sunshine 1 month	.7	.8
1 by 8 diagonal sheathing[1]	Seasoned	None	4.3	8+
1 by 8 diagonal sheathing [1]	Unseasoned	Seasoned indoor 1 month	1.7	(2)
1 by 8 horizontal sheathing--lath and plaster on inside	Seasoned	None	7.9	5.6
1 by 8 horizontal sheathing--lath and plaster on inside	Unseasoned	Seasoned indoor 1 month	6.0	4.9
25/32-inch fiber-board	Seasoned	None	3.0	3.8
25/32-inch fiber-board	Seasoned	and 94 percent relative humid-ity 1 month		3.3

[1]Tested in tension.

[2]Test carried only to determine rigidity.

strength 20 percent. Similar panels with wood lath and plaster on one face and horizontal sheathing on the other were tested dry and after seasoning. The reduction in rigidity was about 20 percent and about 10 percent in strength.

Wall panels constructed of seasoned studs and sheathed with 4-foot-wide sheets of 25/32-inch fiberboard were exposed for 1 month to 40° F. and 94 percent relative humidity. Reduction of rigidity and strength was about 10 to 15 percent compared to unexposed panels.

The effect of long-time exposure to wind impacts, street traffic, and other vibrating influences was also explored. After as many as 1 million cycles of vibration, lumber-sheathed panels assembled green and seasoned 1 month showed no reduction in rigidity and strength as compared with similar panels not vibrated.

SUMMARY AND CONCLUSIONS

The old "braced–timber" frame which originated in New England had, perhaps, more rigidity than was needed, but the hundreds of old houses still standing bear witness to the fact that rigidity goes hand in hand with permanence. Today, such a heavy and time–consuming type of construction is too expensive for moderately priced houses. In fact, bracing of the walls is sometimes omitted and horizontal sheathing is used because it is cheaper to apply than diagonal sheathing. The introduction of sheet materials, however, has provided a means of obtaining improved rigidity and strength. Thus, whether the house is low or high in cost, certain fundamental principles of construction should be kept in mind so that the completed structure will be adequate and require only normal maintenance. The cost of bracing or the proper selection and use of sheet covering materials will hardly be noticed in the total cost of the building.

It has been observed that the houses which have survived severe hurricanes that damaged or destroyed less well–built structures are those that were diagonally sheathed and well nailed. Such has been the experience in numerous Florida hurricanes, and in that region diagonal sheathing is referred to by the older builders as "storm sheathing." This resistance to nature's forces has also been borne out in the 1964 Alaska earthquake where wood–frame houses with plywood sheathing or with a braced frame and wood sheathing sustained little damage even though many were subjected to landslides as well as shocks.

The following summary outlines the most important factors resulting from the tests of walls which have been made at the Forest Products Laboratory over a period of years relating to the rigidity and strength of a panel under racking loads. The effect of these variables is also shown in figures 5 to 13.

1. Size and spacing of studs (fig. 5)
   a. When horizontal wood sheathing and let–in bracing are used and material saving is an important factor, greater rigidity and strength are obtained by reducing the size of the stud rather than increasing the spacing between studs.
   b. When using sheet material such as plywood, with vertical application and perimeter nailing, variation of the spacing and size of studs does not materially affect the rigidity and strength of the wall in resisting racking loads.
2. Wall sheathing (figs. 6 and 7)
   a. Wood sheathing
      (1) Horizontal wood sheathing requires bracing under most conditions.
      (2) Greater rigidity is achieved in walls without openings when diagonal sheathing is in compression.
      (3) When windows or doors are near the corner, diagonal sheathing in tension results in greater rigidity and strength.
   b. Fiberboard sheathing
      (1) Use vertically in 4– by 8–foot or longer sheets with perimeter and intermediate nailing for best rigidity and strength.
      (2) In fiberboard–sheathed walls, window and door openings reduce rigidity and strength by more than 50 percent when compared to a wall without openings.
   c. Plywood sheathing
      (1) For greatest rigidity and strength in nailed panels, use plywood vertically in 4– by 8–foot or longer sheets with perimeter nailing,
      (2) Gluing plywood on walls without openings results in two to five times greater rigidity than nailing.
      (3) Wall panels with 1/4–inch nailed plywood are only slightly less rigid than panels with 5/8–inch nailed plywood and are not as strong.
      (4) Glued plywood in walls with window and door openings increases rigidity by more than 80 percent over nailed plywood.
   d. Tempered hardboard sheathing (1/4–inch thickness)
      (1) Tempered hardboard in 4– by 8–foot sheets with perimeter nailing provides slightly more rigidity and about the same strength as 1/4–inch plywood.
      (2) Tempered hardboard sheathing nailed to both sides of a wall increases the rigidity by about 60 percent over a panel with hardboard only on one side.

(3) Gluing in double–sheathed panels increases the rigidity only slightly but almost doubles the strength of double–sheathed nailed panels.

3. Bracing (fig. 8)

a. Let–in type bracing provides greatest rigidity and strength in braced panels. The brace should be used in compression, from top plate, at 45° angle full length, to the bottom plate.

b. In narrow panels it is better to use a high angle compression brace from top to bottom plate than a "K" brace.

c. In unsheathed walls, a 1 by 6 let–in brace with studs spaced 24 inches is about equal in rigidity and strength to 16–inch stud spacing and a 1- by 4–inch brace.

d. On a wall with horizontal sheathing and no let–in bracing, the use of metal straps in tension at 45° will increase rigidity and strength; full–length strapping provides the greatest improvement.

4. Siding (fig. 9)

a. A wall with 1/2- by 6–inch bevel siding and no sheathing usually requires some type of bracing, as it is only 70 percent as rigid and 50 percent as strong as a wall with horizontal wood sheathing.

b. The addition of let–in braces increases the rigidity of a wall covered only with siding by more than four times and the strength by more than six times.

5. Fastenings (fig. 10)

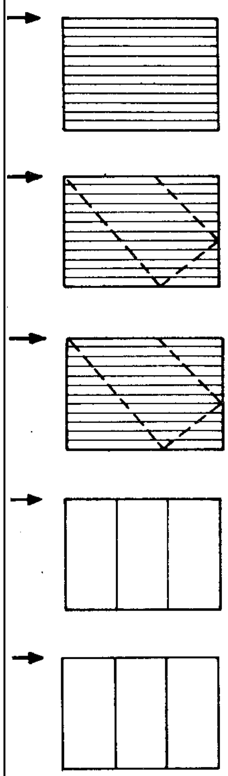
a. Horizontal wood sheathing

(1) Using two tenpenny nails rather than two eightpenny nails for each sheathing board at each stud increases the rigidity and strength by 40 to 50 percent.

(2) Nailing the sheathing to let–in bracing adds more than 50 percent to the rigidity and strength.

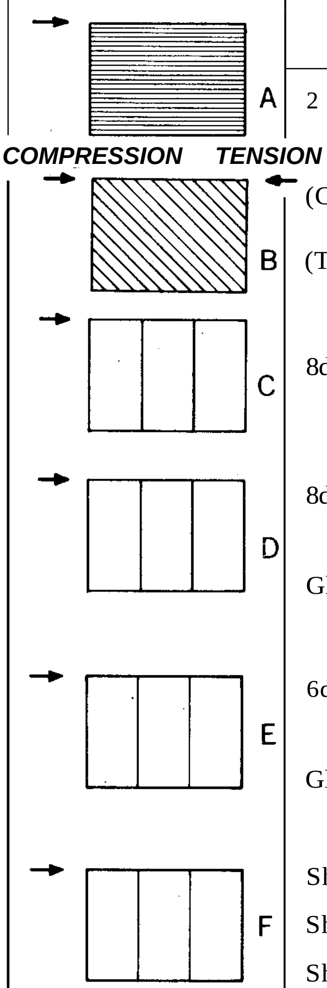
b. Diagonal sheathing (fig, 10)

Increasing the number and size of nails increases the rigidity but has no great



Panel	Panel Description	Relative Rigidity	Relative Strength
A	2 x 4–inch studs - 16 in. o.c.	1.0	1.0
B	2 x 4–inch studs - 16 in. o.c.	4.4	3.9
	2 x 3–inch studs - 16 in. o.c.	3.7	3.5
C	2 x 4–inch studs - 24 in. o.c.	2.7	2.0
	2 x 3–inch studs - 24 in. o.c.	2.2	1.9
D	2 x 4–inch studs - 16 in. o.c.	8.5	4.5
	2 x 3–inch studs - 16 in. o.c.	8.5	4.5
E	2 x 4–inch studs - 24 in. o.c.	8.4	4.4
	2 x 3–inch studs - 24 in. o.c.	7.8	4.4

Figure 5.––Effect of size and spacing of studs on frame walls. A, B, and C, 1- by 8-inch lumber; D and E, 1/4–inch plywood; B and C, 1- by 4–inch let–in brace.



Panel	Panel Description	Relative Rigidity	Relative Strength
A	2 8d nails per stud crossing	1.0	1.0
B	(Compression) 2 8d nails per stud crossing	7.3	8 +
	(Tension) 2 8d nails per stud crossing	4.3	8 +
C	8d nails spaced 3 inches on vertical edges, 6 inches on intermediate edges, 5-1/2 inches on plates	3.0	3.8
D	8d nails space 6 inches on all edges, 12 inches on intermediate studs	4.8	9 +
	Glued	24.0	9 +
E	6d nails spaced 5 inches on all edges, 10 inches on intermediate studs	4.2	5.2
	Glued	14.4	8 +
F	Sheathed 1 side - Nailed - 3 inch and 6 inch spacing	9.8	6.9
	Sheathed 2 sides - Nailed - 3 inch and 6 inch spacing	16.2	11.6
	Sheathed 2 sides - Glued and nailed	17.6	21.4

Figure 6.--Effect of sheathing on frame walls having no openings. A and B, 1- by 8-inch lumber; C, 25/32-inch fiberboard; D, 5/8-inch plywood; E, 1/4-inch plywood; F, 1/4-inch tempered hardboard,

effect on strength.

c. Fiberboard and plywood sheathing
Double nailing (twice the number recommended) increases the rigidity and strength about 50 percent for fiberboard and about 40 percent for plywood over normal nailing.

d. Gluing rather than nailing plywood to framing members has more effect on the rigidity than on the strength.

6. Plaster (fig. 11)

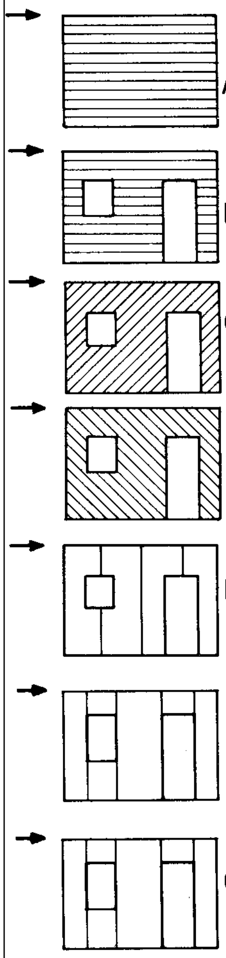
a. Plaster on unbraced and unsheathed wall results in excellent rigidity and moderate strength.

b. Addition of sheathing (horizontal and diagonal) to the unplastered side increases the rigidity up to 40 percent and the strength up to 80 percent.

c. Plaster on one side of a wall with openings provides greater rigidity than nailed 1/4-inch plywood sheathing.

7. Species density (fig. 12)

a. The relative rigidity and strength of a lumber-sheathed wall panel made with a medium-density softwood and one with a low-density softwood are about proportional to their specific gravity. In the softer woods this difference can be compensated for by using larger nails in horizontal sheathing and larger or more nails in diagonal sheathing.



Panel	Panel Description	Relative Rigidity	Relative Strength
A	2 8d nails per stud crossing	1.0	1.0
B	2 8d nails per stud crossing	0.7	0.8
C	2 8d nails per stud crossing	1.4	4.0
D	2 8d nails per stud crossing	1.0	1.3
E	8d nails spaced 3 inches at all vertical edges, 6 inches on intermediate studs, 5–1/2 inches on plates. Fiberboard sawed out for openings	1.5	1.6
F	Nailing as above. Continuous sheets of fiberboard	1.6	2.1
G	6d nails spaced 5 inches on all edges and 10 inches on intermediate studs	2.0	2.8
	Glued	3.7	4.0

Figure 7.––Effectof sheathing on frame walls with window and door openings. A, B, C, and D, 1- by 8–inch lumber; E and F, 25/32–inchfiberboard; G, 1/4–inch plywood.

b. In plywood–sheathed wall panels, the increase in strength is greater than the increase in rigidity for panels with medium–density framing when compared to similar panels with low–density framing.

8. Seasoning and exposure (fig. 13)

a. Horizontally sheathed walls made of unseasoned lumber are only one–half as rigid and two–thirds as strong after 1 month of drying as a wall made of dry lumber.

b. This loss also occurs to a lesser degree in panels with seasoned lumber and exposed 1 month to rain and sunshine before testing.

c. A diagonally sheathed wall panel of unseasoned lumber, after drying 1 month, has only about 40 percent the rigidity of a panel made of dry lumber.

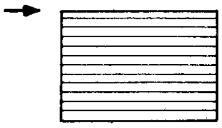
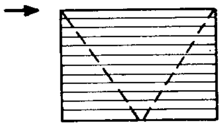
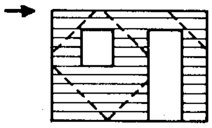
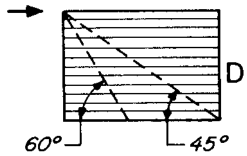
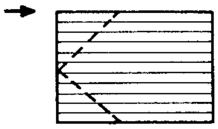
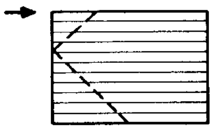
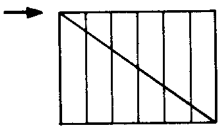
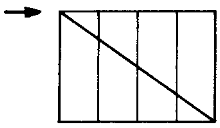
	Panel Description	Relative Rigidity	Relative Strength
 A	2 8d nails per stud crossing	1.0	1.0
 B	2 x 4–inch cut–in braces	1.6	1.4
	1 x 4–inch let–in braces	2.6	3.6
 C	1 x 4–inch let–in braces, window and door openings	1.5	2.2
 D	1 x 4–inch let–in brace - 60° angle	2.9	3.3
	1 x 4–inch let–in brace - 45° angle	4.1	4.4
 E	1 x 4–inch let–in equal–leg K brace	1.4	2.2
 F	1 x 4–inch let–in long–leg K brace	1.8	2.8
 G	1 x 4–inch let–in brace - studs 16 in. o.c.	2.6	2.0
	1 x 6–inch let–in brace - studs 16 in. o.c.	3.0	2.6
 H	1 x 4–inch let–in brace - studs 24 in. o.c.	2.3	1.3
	1 x 6–inch let–in brace - studs 24 in. o.c.	2.5	2.0

Figure 8.––Effect of bracing on frame walls. A, B, C, D, E, and F, 1- by 8–inch lumber; G and H, no sheathing.

As a result of these tests, the advantages of using seasoned lumber, diagonal sheathing, let–in bracing, or sheet materials are clear. Mini–mizing cracked plaster and out–of–square door and window frames through the use of these simple means of improving the rigidity and strength of the structure will reduce maintenance cost enough to far outweigh the so–called initial savings from the use of less sound construction.

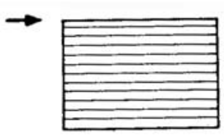
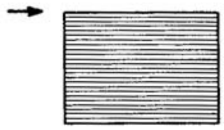
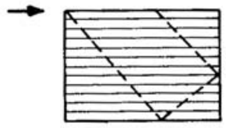
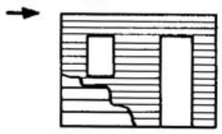
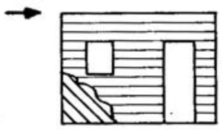
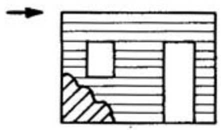
	Panel Description	Relative Rigidity	Relative Strength
 A	2 8d nails per stud crossing	1.0	1.0
 B	1/2– by 6–inch siding - 7d nails	0.7	0.5
	3/4- by 8–inch siding - 8d nails	1.0	0.8
 C	1/2– by 6–inch siding - 7d nails	3.2	3.3
	3/4- by 8–inch siding - 8d nails	3.1	3.7
 D	1/2– by 6–inch siding	1.1	1.3
 E	1/2- by 6–inch siding	2.0	3.3
 F	1/2– by 6–inch siding	3.3	5.4
 G	1/2- by 6–inch siding and 1 by 4–inch let–in braces	2.7	3.4

Figure 9.--Effect of siding on frame walls. A, D, E, F, and G, 1- by 8-inch sheathing; B, bevel siding only; C and G, bevel siding and let-in braces.

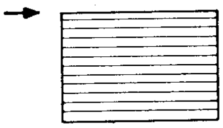
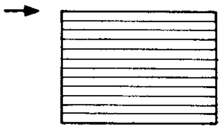
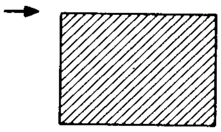
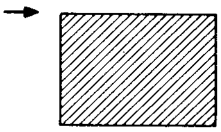
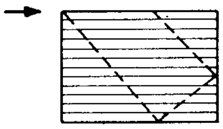
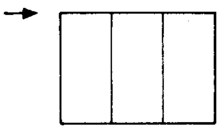
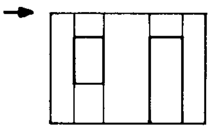
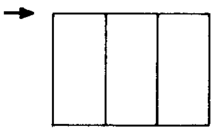
Panel	Description	Relative Rigidity	Relative Strength
 A	2 8d nails per stud crossing	1.0	1.0
	3 8d nails per stud crossing	1.0	0.9
	4 8d nails per stud crossing	1.4	1.4
 B	2 10d nails per stud crossing	1.5	1.4
	2 12d nails per stud crossing	1.3	1.1
 C	2 8d nails per stud crossing	4.3	8 +
	3 8d nails per stud crossing	5.2	8 +
	4 8d nails per stud crossing;	7.5	8 +
 D	2 8d nails per stud crossing	4.3	8 +
	2 10d nails per stud crossing	5.1	8 +
 E	1 by 4-inch let-in bracing	3.7	3.7
	Same, except sheathing nailed to brace with 6 8d nails per space	5.6	5.8
 F	8d nails spaced 3 inches on vertical edges, 6 inches on intermediate studs, 5-1/2 inches on plates	3.0	3.8
	Double nailing	4.5	6.1
 G	8d nails spaced 3 inches on vertical edges, 6 inches on intermediate studs, 5-1/2 inches on plates	1.6	2.1
	Double nailing	1.7	2.6
 H	6d nails spaced 5 inches all edges, 10 inches on intermediate studs	4.2	5.2
	Double nailing	5.9	7.0
	Glued	14.4	8 +

Figure 10.--Effect of fastenings on frame walls. A, B, C, D, and E, 1-by 8-inch sheathing; F and G, 25/32-inch fiberboard; H, 1/4-inch plywood.

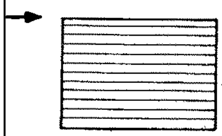
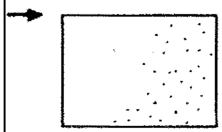
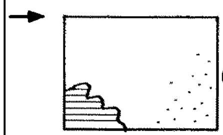
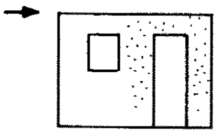
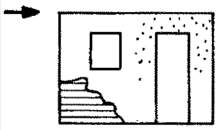
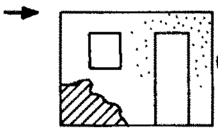
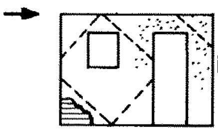
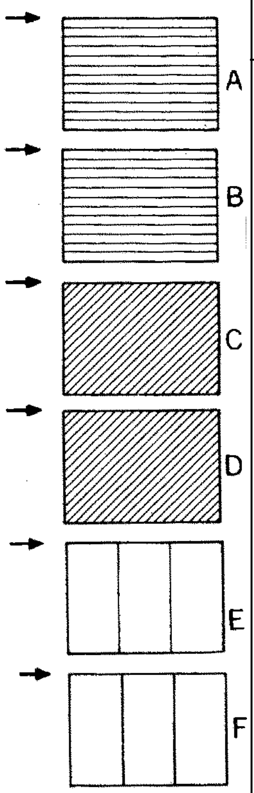
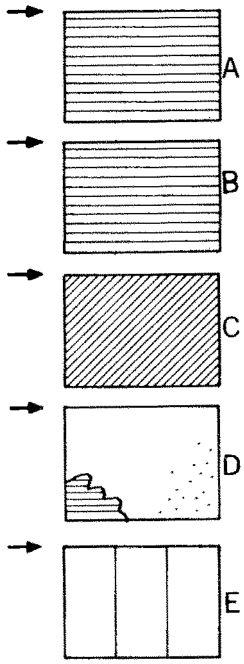
	Panel Description	Relative Rigidity	Relative Strength
 A	2 8d nails per stud crossing	1.0	1.0
 B	No sheathing or bracing	7.2	4.4
 C	2 8d nails per stud crossing	7.9	5.6
 D	2 8d nails per stud crossing	9.2	8 +
 E	No sheathing or bracing	2.3	1.6
 F	2 8d nails per stud crossing	2.4	2.2
 G	2 8d nails per stud crossing	2.8	4.4
 H	1 by 4–inch let–in bracing	4.1	3.6

Figure 11.--Effect of plaster on frame walls. A, 1- by 8-inch sheathing; B and E, plaster on wood lath only; C, D, F, G, and H, plaster, wood lath, and sheathing.



Panel	Panel Description	Relative Rigidity	Relative Strength
A	Medium density 2 8d nails	1.0	1.0
B	Low density 2 8d nails	.7	.9
	Low density 2 10d nails	.9	1.2
C	Medium density 2 8d nails	4.2	9 +
D	Low density 2 8d nails	2.9	6.0
	Low density 2 10d nails	3.6	7.7
	Low density 3 8d nails	3.8	8 +
E	Medium density studs	4.8	4.4
	6d nails - 6 inch and 12 inch spacing		
F	Low density studs	4.2	3.3
	6d nails - 6 inch and 12 inch spacing		

Figure 12.––Effect of species density on frame walls. A, B, C, and D, 1- by 8-inch lumber; E and F, 5/16-inch plywood.



Panel	Panel Description	Relative Rigidity	Relative Strength
A	Seasoned lumber	1.0	1.0
B	Unseasoned lumber - Seasoned indoors 1 month	.5	.7
	Seasoned lumber - Outdoor exposure 1 month	.7	.8
C	Seasoned lumber	4.3	8 +
	Unseasoned lumber - Seasoned indoors 1 month	1.7	- - -
D	Seasoned lumber	7.9	5.6
	Unseasoned lumber - Seasoned indoors 1 month	6.0	4.9
E	Seasoned lumber	3.0	3.8
	Seasoned lumber - Exposed to 40° F., 94 per R.H. 1 month	2.6	3.3

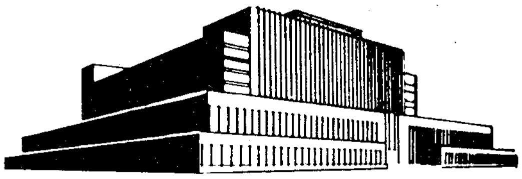
Figure 13.--Effect of seasoning and exposure on frame walls. A, B, and C, 1– by 8–inch lumber; D, lath and plaster and 1- by 8–inch lumber; E, 25/32–inch fiber–board.

PUBLICATION LISTS ISSUED BY THE FOREST PRODUCTS LABORATORY

The following lists of publications deal with investigative projects of the Forest Products Laboratory or relate to special interest groups and are available upon request:

- Architects, Builders, Engineers, and Retail Lumbermen
- Box, Crate, and Packaging Data
- Chemistry of Wood
- Drying of Wood
- Fire Protection
- Fungus and Insect Defects in Forest Products
- Furniture Manufacturers, Woodworkers, and Teachers of Woodshop Practice
- Glue and Plywood
- Growth, Structure, and Identification of Wood
- Logging, Milling, and Utilization of Timber Products
- Mechanical Properties of Timber
- Structural Sandwich, Plastic Laminates, and Wood-Base Components
- Thermal Properties of Wood
- Wood Fiber Products
- Wood Finishing Subjects
- Wood Preservation

Note: Since Forest Products Laboratory publications are so varied in subject matter, no single catalog of titles is issued. Instead, a listing is made for each area of Laboratory research. Twice a year, December 31 and June 30, a list is compiled showing new reports for the previous 6 months. This is the only item sent regularly to the Laboratory's mailing roster, and it serves to keep current the various subject matter listings. Names may be added to the mailing roster upon request.



FOREST PRODUCTS LABORATORY
U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE - - - MADISON, WIS.

In Cooperation with the University of Wisconsin