

ADEQUACY OF LIGHT FRAME-WALL CONSTRUCTION

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In Cooperation with the University of Wisconsin

ADEQUACY OF LIGHT FRAME-WALL CONSTRUCTION¹

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House construction involves material and labor costs. Reduction in the amount of either or both, especially of labor costs, would permit an appreciable saving. Labor could be lessened by using fewer members in the fabricated structure. Material volume could be reduced by decreasing member sizes or by using fewer members but of the same size. Since the use of less material through fewer members but of the same size involves also less labor, it would appear to be the most economical method. Because of the indicated cost reduction by savings of material or labor or both, the Housing and Home Finance Agency requested the cooperation of the Forest Products Laboratory in making tests on light frame-wall construction, braced and unbraced, and involving several types of sheathing, size, and spacing of studs.

The wall panels were tested for resistance to such racking and static-bending loads as might be imposed on the wall of a house due to wind.

Panel Construction

The test panels for the racking tests were 8 by 12 feet in size to be representative of story heights and to be of sufficient length to approximate practical conditions. The panel frames were of No. 1 Douglas-fir and consisted of either 2- by 4- or 2- by 3-inch studs spaced either 16 or 24 inches on center, and held in position by two nails through the plates into their ends. The plates were similar in size to the studs used in the panels. Each end post consisted of three studs of appropriate size nailed to form a channel shape (fig. 1). The braced frames contained three let-in diagonal braces placed on the

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side opposite the sheathing. One long brace extended from top to bottom plate at an angle of 45 degrees, starting at the top corner of one end of the panel. The other two were placed at the opposite end of the panel across upper and lower corners, starting near midheight of the end post and making an angle of 45 degrees with the top and bottom plates.

The panels for the static-bending tests were 4 by 8 feet in size with and without bracing. To simulate the bracing for actual construction, the long let-in diagonal brace placed at 45 degrees passed through the midlength of the panel (fig. 1). The brace was placed on the side opposite the sheathing. The panel frames, like those for the racking tests, were No. 1 Douglas-fir and consisted of either 2- by 4- or 2- by 3-inch studs spaced either 16 or 24 inches on center and held in position by two nails through the plates into their ends. The plates were similar in size to the studs used in the panel. The outside studs of the panels were only half as thick as the interior studs.

To these basic frames were added two types of sheathing: (1) horizontal boards, and (2) large sheet material. The sheathing boards were southern yellow pine, No. 1 sheathing grade, 1- by 8-inch square-edged boards; and the sheet material consisted of 4- by 8-foot sheets of 1/4-inch exterior-grade Douglas-fir plywood, sound two sides. The lumber sheathing was attached horizontally with two eight-penny nails at each stud crossing. The plywood sheets were placed with the 8-foot dimension vertical and were attached with sixpenny nails spaced 5 inches on center around the perimeter of the sheets and 10 inches on center on all intermediate studs. None of the panels had any openings.

Test Procedure

In the racking test, a horizontal load acting parallel to the length of the panel was applied at the upper corner of the panel so as to place the long diagonal brace in compression. The lower, or sole, plate of each panel was bolted to a heavy timber, which, in turn, was fastened to the fixed platen of the testing machine (fig. 2). The resistance to lateral buckling normally provided by the upper floor system was supplied, in test, by a heavy timber to which the upper plate was attached. The overturning tendency, which is resisted in service by upper-story and roof loads, was resisted in test by hold-down rods. The alining action of cross walls was simulated by two blocks equipped with rollers placed approximately 2 feet from each end of the panel. The blocks were anchored to the frame of the testing machine and positioned so that only the rollers came into contact with the timber attached to the upper plate. Cables attached to the movable platen of the testing machine and passing around sheaves permitted horizontal application of load to the panel.

Rigidity in resistance to racking loads was measured by movement of the upper plate with respect to the lower at specific loads. The strength of a panel was taken as the maximum load sustained during test.

In the static-bending test the 4- by 8-foot panels were supported, with the sheathing side up, on rollers extending across the width of the panel. The test span was 7 feet 6 inches, and the load was applied at the quarter points through two additional rollers extending across the width of the panel. Rigidity in resistance to bending was measured by the deflection at the center of panel read for specific increments of load. The strength of a panel was taken as the maximum load sustained during test.

Discussion of Results

A frame covered only with sheathing constitutes the practical minimum of shelter afforded by a wall. Since the simplest and most common type is lumber sheathing, a wall frame covered with square-edged sheathing of 1- by 8-inch lumber placed horizontally and fastened with two eightpenny nails at each stud crossing, with studs spaced 16 inches on center, and with no bracing, was taken as the standard of comparison. This standard was chosen for convenience in comparison of the test results only, and should not be construed as in accordance with generally recommended good practice or Federal Housing Administration Minimum Property Requirements. The results of the racking test are shown in table 1 and of the static-bending tests in table 2, while figures 3, 4, 5, and 6 present the data in graph form.

Racking

With horizontal lumber sheathing, the principal resistance to longitudinal thrust is afforded by the reaction couples established by the nails at the stud crossing. In any untriangulated framework such as this, rigidity comes from the fixity of the joints. The rigidity of the test panels sheathed horizontally with lumber and no bracing is obtained through each pair of nails at the stud crossings. The addition of a third nail at each stud crossing has been found not to increase panel rigidities. When sheathing wider than 8 inches was used, which required more nailing than three nails on each stud, the nails appeared to take up the loads in pairs. The outside nails nearest the edges took up the load first, and the nails second from the edges next came into action. The second pair of nails appeared to take very little, if any, load until the bending of the first pair or the crushing of the sheathing material under the nail pressure permitted the panel to deflect. Panel loads that caused bending of the outside nail in each board or crushing of sheathing under them were of such a magnitude that the resisting couple of the second pair of nails in each board as they came into action was not sufficient to materially affect the early deflections.

The rigidity in racking resistance of horizontal lumber-sheathed panels was greatly increased by the addition of let-in diagonal bracing (fig. 3). The

diagonally braced panels were from 2 to 5 times as rigid, depending upon stud size and spacing, as an unbraced panel for a load of ²100 pounds per lineal foot of panel length (table 1).

Stud size was of less importance than stud spacing. Decreasing the stud size from 2 by 4 to 2 by 3 inches increased the deflection for loads up to ¹225 pounds per lineal foot by about 25 percent. Increasing the spacing from 16 to 24 inches increased the deflection by about 75 to 100 percent for similar loads. The reduced resistance of the horizontally lumber-sheathed panels to racking with 24-inch stud spacing was undoubtedly caused largely by the fewer nail couples that resisted the longitudinal thrust. The 24-inch spacing of studs also somewhat reduced the effectiveness of the bracing by the increased space between supports. The long brace in compression during test acts as a series of columns extending from stud to stud, and lengthening of those columns by increasing stud spacing reduces resistance of the bracing to the column action. The braced panels sustained from 1-1/2 to 3 times the maximum loads of panels without bracing. Had the let-in bracing been placed on the sheathing side of the frames, instead of on the side opposite the sheathing, even greater rigidity and strength would have resulted.

Panels sheathed with 1/4-inch plywood were 8 to 9 times as rigid as unbraced panels for loads up to 100 pounds per lineal foot of panel length (table 1). They sustained about 3-1/2 times the maximum loads. The size of the stud or spacing of these members for loads up to 225 pounds per lineal foot apparently had little effect. The comparatively satisfactory performance in racking of the panels having 24-inch stud spacing and sheathed with large sheets (plywood) was due to the 4- by 8-foot sheets of material used. The perimeter nailing of these sheets carried the preponderance of the racking load. The nailing into those studs away from the edges of the sheets carried the least racking load and, therefore, stud spacing was of little importance (fig. 4). Had the plywood been 5/16-inch thick, the minimum thickness required by the Federal Housing Administration for exterior wall sheathing, the rigidity and strength might have been slightly higher.

Bending

In static bending, the unbraced wall panels were the most rigid and sustained the highest maximum loads (figs. 5 and 6). The panels having let-in diagonal bracing (wood-sheathed panels) were weakened by the notches in the studs to accommodate the bracing. Thus it would appear that a brace so beneficial in racking would be a detriment to bending resistance of a wall. This disadvantage

³ Loads of 100 and 225 pounds per lineal foot represent minimum design load and ultimate load without failure, respectively, as recommended in Performance Standards, Structural and Insulation Requirements for Houses, dated June 1947, published by Housing and Home Finance Agency, Washington, D. C.

is not as serious, however, as might be supposed. While all studs of the test panels were notched within the middle one-half of their length to receive the brace, all of the studs in a house wall would not be. Therefore, the studs in a house wall weakened in bending resistance by notching would be relatively few, and rigidity and strength of such a wall would not be reduced as much as indicated by the results of these tests on braced and unbraced 4- by 8-foot panels.

Plywood sheathing (4- by 8-foot sheets) tended to add rigidity in bending over those panels having wood sheathing for loads of 15 to 30 pounds per square foot (table 2, figs. 5 and 6). The practically unavoidable space between edges of wood sheathing is largely responsible for the difference. Increasing the stud spacing reduced bending strength and stiffness less than decreasing the stud size (table 2 and figs. 5 and 6). For example, increasing the spacing of studs of panels with plywood coverings from 16 to 24 inches reduced the bending strength about 30 percent, while reducing the stud size decreased the bending strength about 45 percent. Similarly, by increasing the stud spacing, the stiffness was decreased about 30 percent, the same as the bending strength. Decreasing the stud size, however, decreased the stiffness about 60 percent, which is a considerably greater decrease than that in bending strength. The decreases in bending strength and stiffness for panels with 8-inch wood sheathing, because of increased stud spacing or decreased stud size, were rather erratic. These deviations were probably caused by the notches in the studding made to receive the bracing. These notches were also an important factor in the lower maximum loads of the panels with 8-inch wood sheathing as compared to panels with plywood sheathing and unnotched studs.

Conclusions

In the racking test, panels with plywood sheathing and with complete perimeter nailing performed similarly regardless of size of studs or spacing. Lumber-sheathed panels with bracing were affected in racking more by stud spacing than by stud size. In static bending, panels with plywood sheathing or lumber sheathing were affected both by stud size and by stud spacing, but stud size was of most importance.

In house construction the performance of a panel in racking is sometimes considered more critical than in bending. Under this assumption and, if less framing material is to be used, small-size studs would be more desirable than wider spacing of framing members. Smaller studs, however, have a disadvantage in that millwork is usually fabricated on the basis of 2- by 4-inch studs. On the other hand, if wider spacing is used in wall construction, selection of interior finish must be made so that the deflection of the covering between studs is not objectionable.

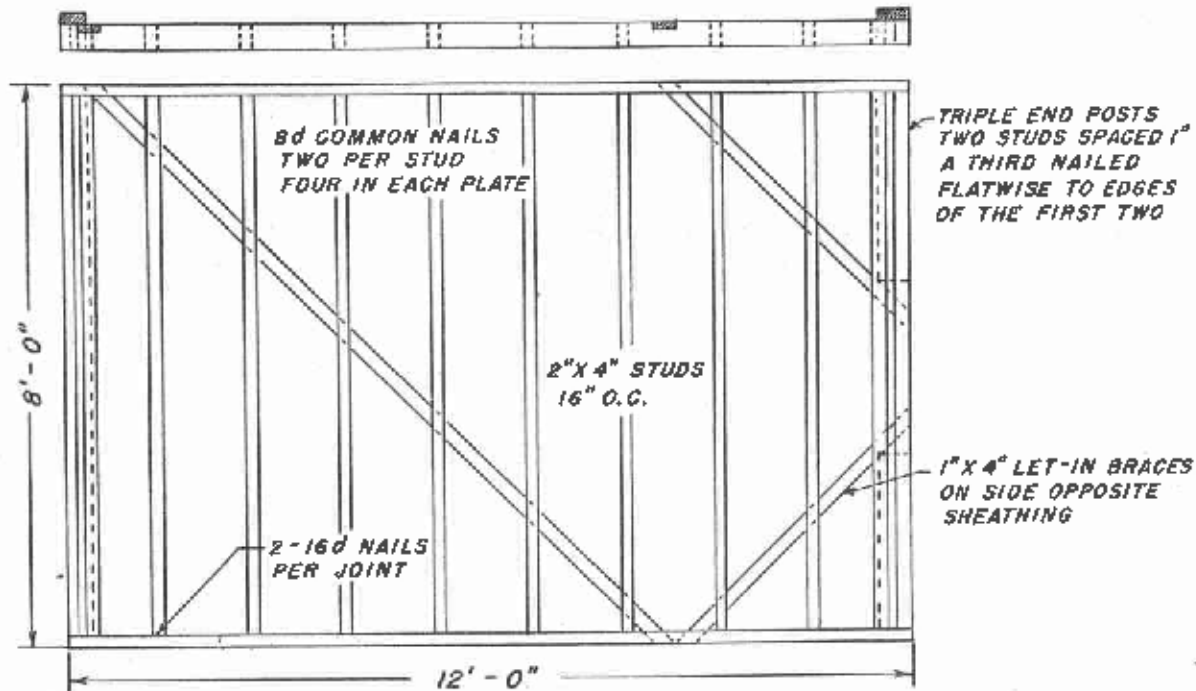
Table 2.--Results of static-bending tests¹ of 4- by 8-foot wall panels of various constructions

Panel Number	Size of frame members	Center-to-center spacing	let-in bracing	4-inch Panel weight	Frame	Average moisture content	Average specific gravity ²	Maximum Deflection: load at maximum load	Quarter-point loading	Equivalent maximum load if uniformly distributed	For a uniform load of 15 lb. per sq. ft.	For a uniform load of 20 lb. per sq. ft.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
In.	In.	In.	Percent	Lb.	Percent	Lb.	Lb.	In.	Lb. per sq. ft.	In.	In.	In.
SOUTHERN YELLOW PINE SHEATHING (NOMINAL 1 BY 8 INCHES)												
LB-1a	2 by 4	16	None	118	10.7	0.51	8,150	3.06	254	0.143	1/630	0.191
LB-3a	2 by 3	16	None	108	10.7	.51	4,350	4.14	141	.292	1/510	.395
LB-1	2 by 4	16	Yes	121	12.6	.50	3,170	3.17	99	.163	1/550	.220
LB-2	2 by 4	24	Yes	114	11.4	.51	2,480	3.57	78	.211	1/425	.280
LB-3	2 by 3	16	Yes	110	10.6	.49	1,330	3.92	42	.390	1/230	.530
LB-4	2 by 3	24	Yes	105	10.8	.50	770	3.75	24	.680	1/130
1/4-INCH DOUGLASS-FIR PLYWOOD SHEATHING (4- BY 8-FOOT SHEETS)												
PB-1	2 by 4	16	None	62	11.6	.51	8,230	2.07	257	.081	1/1,110	.116
PB-2	2 by 4	24	None	54	11.9	.49	5,600	2.81	175	.126	1/715	.171
PB-3	2 by 3	16	None	53	11.4	.52	4,450	2.69	139	.211	1/425	.294
PB-4	2 by 3	24	None	46	11.0	.51	3,340	3.73	104	.275	1/325	.386

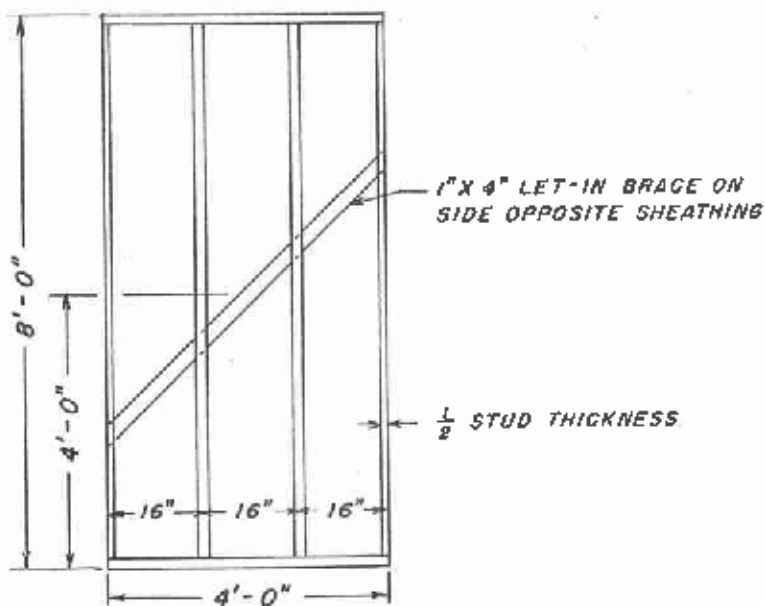
¹Each value in the table is an average for three panels.

²Based on weight when oven-dry and volume at test.

³Performance standards frequently limit deflection-span ratios to 1/360 for plastered walls and 1/240 for unplastered walls.



PANEL CONSTRUCTION FOR RACKING TESTS



PANEL FRAME FOR STATIC-BENDING TESTS

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Figure 1. --Details of light frame construction. Studs were either 16 or 24 inches on centers for both racking and static-bending tests. The 8- by 12-foot panels were used for racking, and the 4- by 8-foot panels for static bending. Studs and plates were either nominal 2 by 4 or 2 by 3 inches.

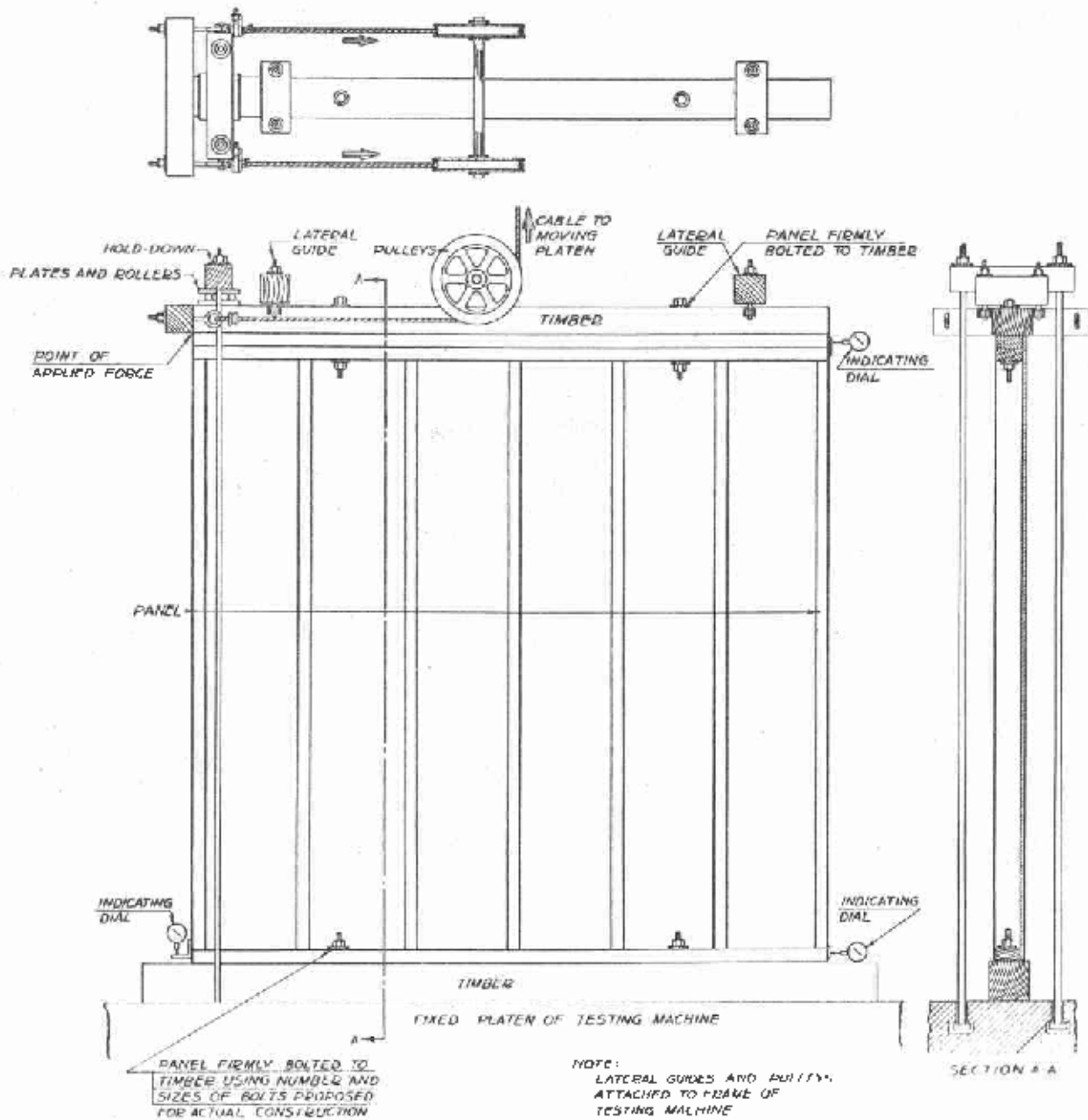
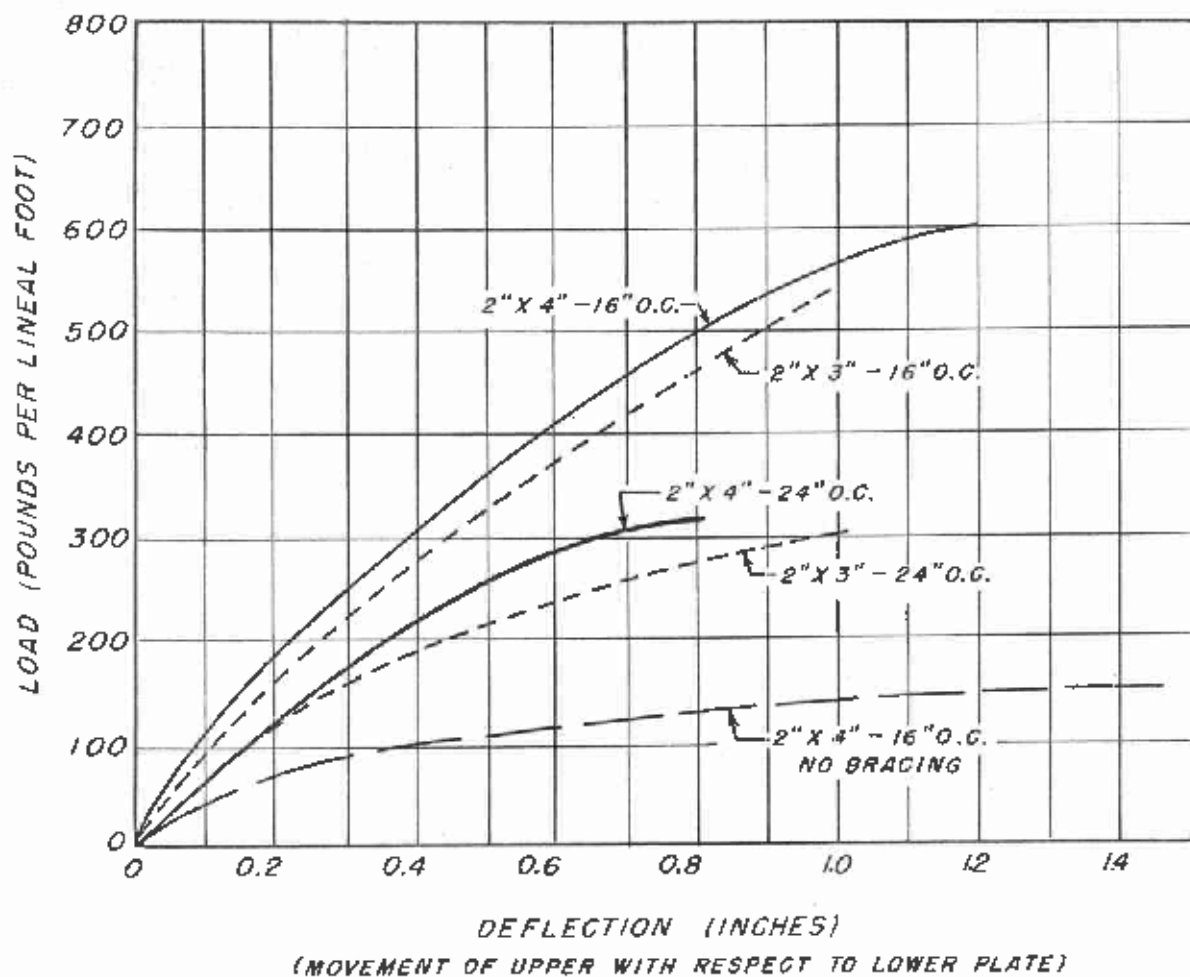


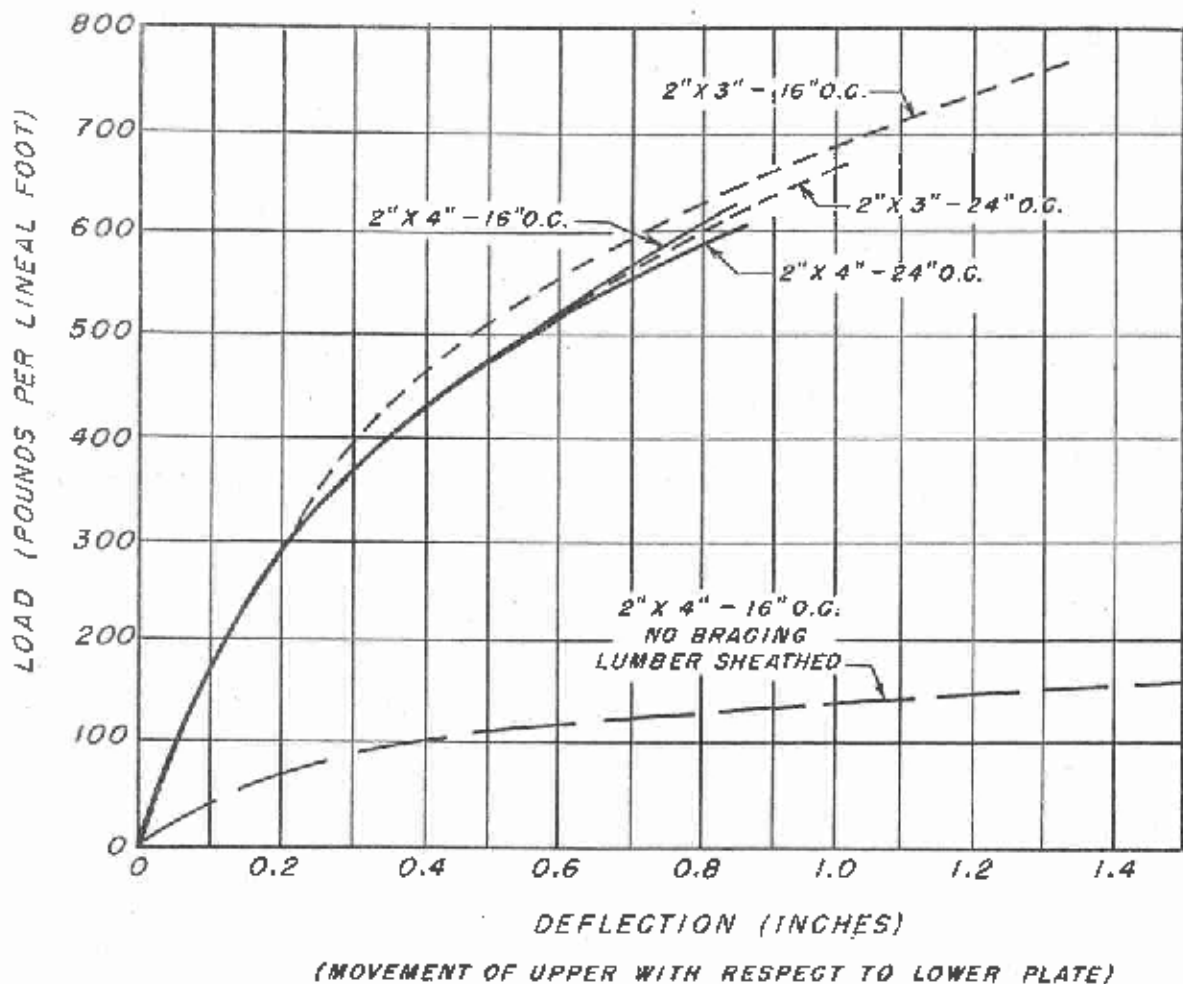
Figure 2. --Schematic drawing showing anchorage and method of loading and of measuring panel deformations under racking loads.



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Figure 3. --Racking resistance of wall panels with lumber sheathing, variable in size and in spacing of studs, and with let-in diagonal bracing, compared to a lumber-sheathed panel with no bracing.

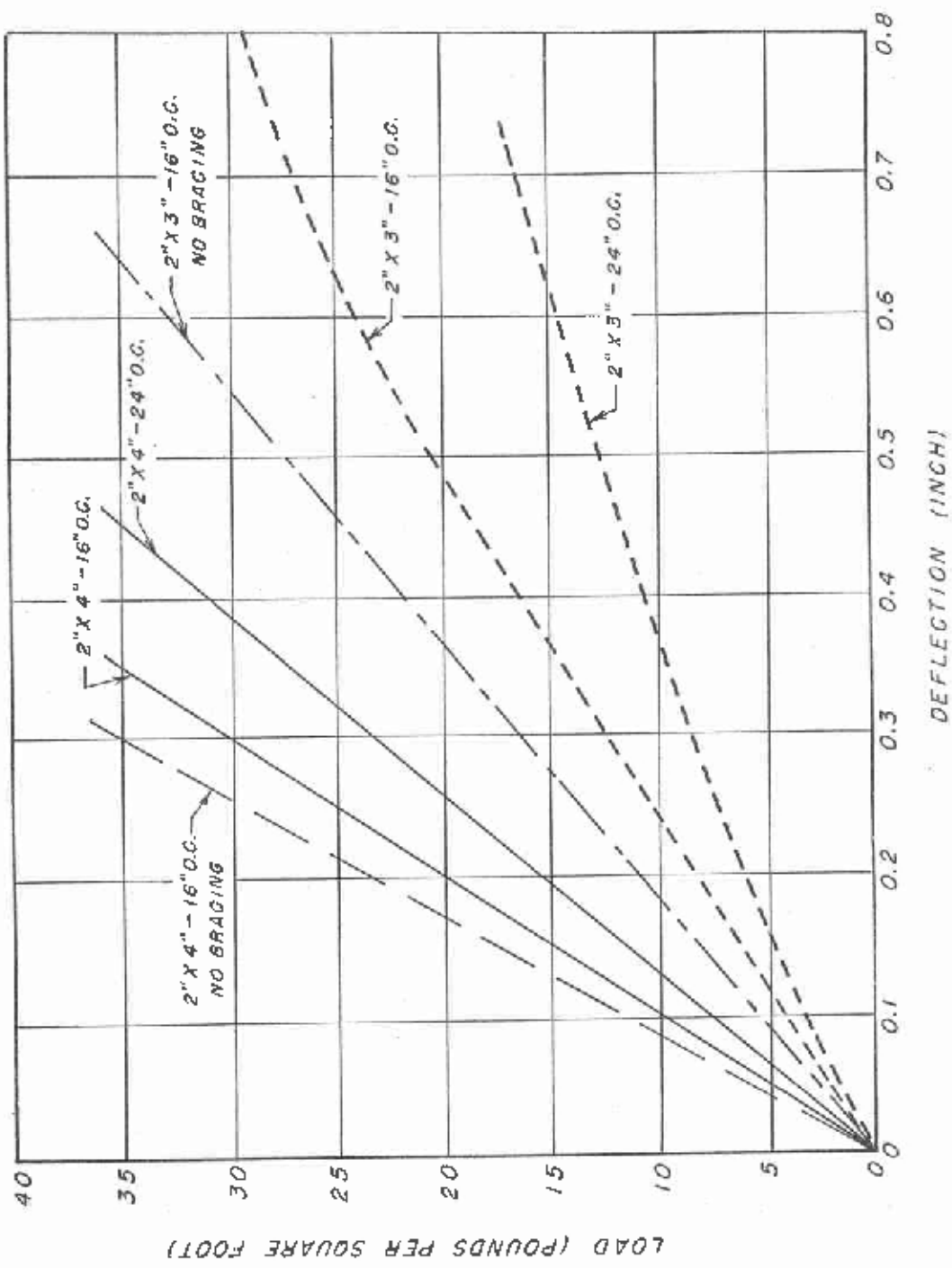
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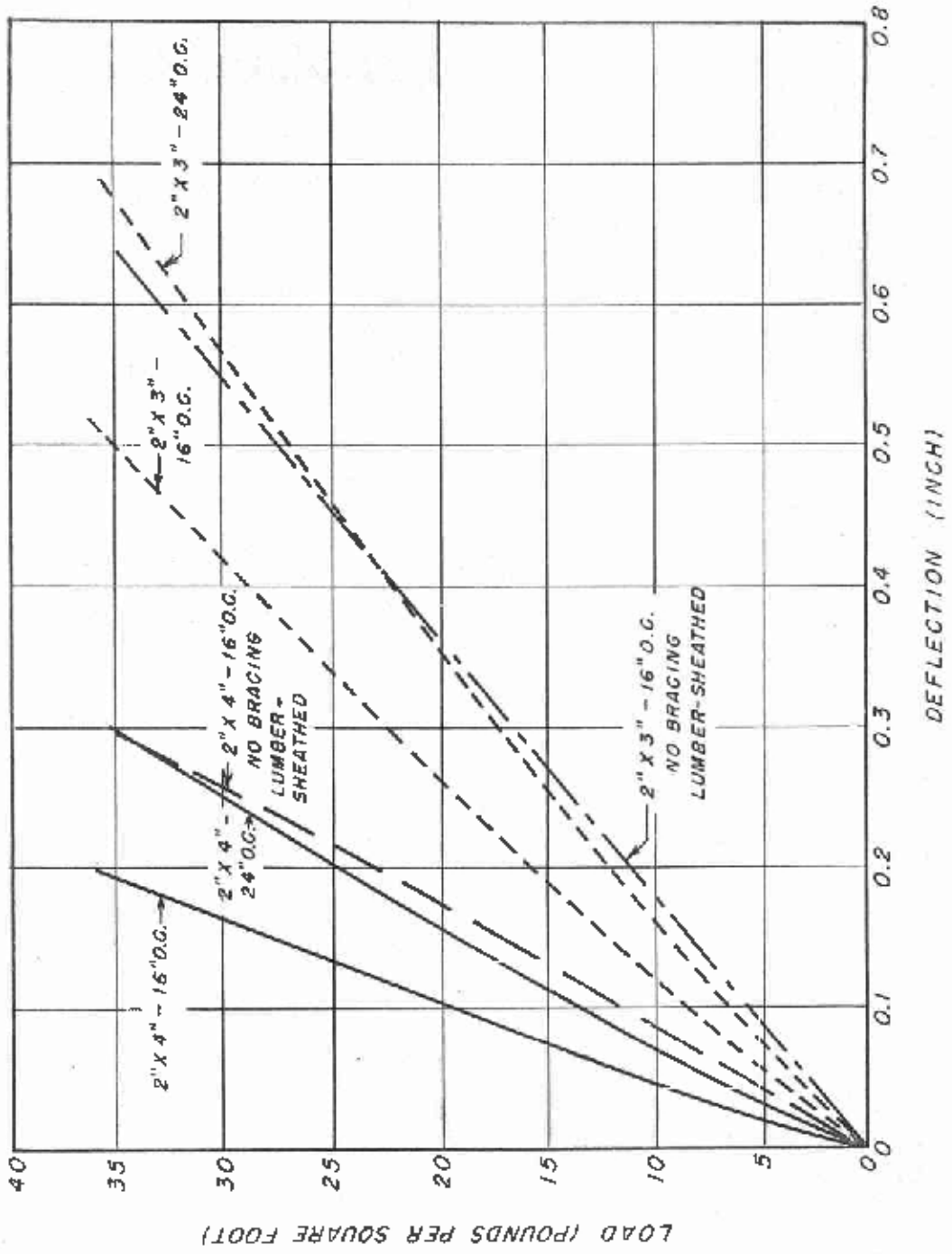
Figure 4. --Racking resistance of wall panels with plywood sheathing, variable in size and in spacing of studs, and with no bracing, compared to a lumber-sheathed panel with no bracing.

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Figure 5. -- Bending resistance of wall panels with lumber sheathing, variable in size and in spacing of studs, and with let-in diagonal bracing, compared to lumber-sheathed panels having variable stud size and no bracing.



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Figure 6. --Bending resistance of wall panels with plywood sheathing, variable in size and in spacing of studs, and with no bracing, compared to lumber-sheathed panels having variable stud size and no bracing.

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