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RIGIDITY AND STRENGTH OF WALL FRAMES BRACED WITH METAL STRAPPING

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RIGIDITY AND STRENGTH OF WALL FRAMES BRACED WITH METAL STRAPPING

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Purpose and Scope

Racking tests were made to study the behavior of horizontally sheathed wall panels braced with metal strapping in lieu of let-in and other types of bracing. Included also was a study of the effectiveness of metal-strap bracing as influenced by variations in nailing and in number and position of straps. Data on panels with horizontal sheathing in combination with let-in diagonal braces and on panels with horizontal sheathing alone were obtained for comparison.

Seven room-size panels without door or window openings were tested. These included five with metal-strap bracing, one with let-in diagonal braces in combination with horizontal sheathing, and one with horizontal sheathing only. All panels were constructed to be as nearly identical in both material and workmanship as possible. Likewise, the construction and method of test conformed as closely as possible to previous racking tests.[1]

Materials

Framing, let-in bracing, and sheathing were of No. 1 dense (average specific gravity about 0.65 based on weight and volume when oven dry) southern yellow pine having a moisture content of about 12 percent. The framing material was 1-5/8 by 3-5/8 inches; the bracing, 25/32 by 3-5/8 inches; and the sheathing, 25/32 by 7-1/2 inches, all S4S.

The metal strapping was 1.025 inches wide by 0.03 inch thick with 9/64-inch punched holes spaced at about 4-inch centers along the centerline of the strap. It was described as heavy punched strapping with a tensile strength of approximately 1,400 pounds. It was black (not galvanized) and was probably manufactured from low carbon, hot-rolled steel.

Large-head, barbed roofing nails, 1 inch long (galvanized) were used in nailing the strapping. These nails had 7/16-inch diameter heads and No. 11 gage shanks (approximately 1/8-inch diameter).

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[1] "The rigidity and strength of frame walls," by Geo. W. Trayer, Forest Products Laboratory Report No. R896, 1929, and "New England white pine as a house framing material," by E. C. O. Erickson, Forest Products Laboratory Report No. R1241, 1940.

Construction of Panels

The panels were 9 feet high by 14 feet long. Frames consisted of single upper and lower plates and studs spaced 16 inches on centers, except at the ends of the frame, where the spacing was 12 inches from the outer face of the end post to the center of the first stud. End posts consisted of two studs with 1-1/4 inches between studs to which a third stud was nailed flatwise with its edge flush with the end of the panel. Two 16-penny common wire nails were driven through upper and lower plates into the ends of each stud. Construction of the various panels with respect to sheathing bracing, and application of metal strapping is indicated in table 1. Details relative to specific features follow.

Each frame was assembled in a horizontal position and a temporary diagonal brace nailed to one face (except for the one frame wherein nominal 1- by 4-inch diagonal let-in bracing was permanently installed) after which the upper plate was bolted to a 5- by 6-inch timber with six 1/2-inch bolts. The frame was then placed in a vertical position and the horizontal sheathing applied with two 8-penny common wire nails per stud crossing, using as a spacer a metal strap 0.028 inch thick between the edges of adjacent boards.

Each panel required 14 full width sheathing courses plus one piece about 2-1/4 inches wide. The narrow piece was at the bottom in No. 6, and at the top in other panels. Except for top and bottom courses, which were full length, each of the 13 intermediate sheathing courses consisted of two pieces meeting at the center of a stud. The joints were alternated on the two central studs. Most of the sheathing boards were used on several panels in succession in order to insure the best possible matching of panels. In order to provide material for cutoffs to obviate nailing repeatedly at the same points in the length, 16-foot boards were cut into two pieces (8 feet 6 inches and 7 feet 6 inches long) and the ends allowed to project beyond the ends of the panels. All sheathing was nailed to frames with two 8-penny common wire nails per stud crossing.

The let-in braces of panel No.7 were notched into the sheathing face of studs and plates at an angle of 45 degrees and nailed to the frame with two 10-penny nails per stud and four 10-penny nails at the plates. The pattern consisted of a long brace extending from an upper corner of the panel to the lower plate and two shorter braces running from near midheight of the end post, one to the lower plate near the lower end of the long brace, and one to the upper plate (table 1). Sheathing boards were not nailed to the braces. The panel was so placed that in the test the long brace acted in compression.

In panels Nos. 2 to 6, inclusive, braced with metal straps, the strapping was applied at an angle of 45 degrees and so positioned as to act in tension. Since metal straps are effective only in tension, it is obvious that a double system of diagonal straps will be required to properly brace an actual wall against racking forces. As only one of these systems will be effective against forces from one direction, only one system was used in these tests, except that a double system was applied to panel No. 6 (figs. 1 and 2). In order to avoid variations in initial tension, each strap was first anchored at the bottom end with one nail and then a nail was driven at the upper end while the strap was under a pull of 50 pounds applied through a spring scale. Nailing then proceeded from the bottom end to the top with nails as specified driven normal to the plane of the panel.

Two straps were placed in the same relative positions in each of panels 2,3, and 4, as indicated in table 1. The straps were nailed directly to the frame of panel No. 2 (before the sheathing was applied) with nine 1-inch roofing nails in each strap. One nail was driven at each of 7 stud crossings and 1 nail into the plate at each end of each strap. Three nails in each strap were in prepunched holes, and the remaining 6 were driven without prepunching or drilling. In all other panels nailing was in prepunched holes and through the sheathing. The strapping on panel No. 3 was nailed to the sheathing with 1 nail per sheathing board, or 15 nails in each strap. In panel No. 4 the strapping was similarly nailed, but with 2 nails per board, or 30 nails in each strap.

The strapping on panel No. 5 consisted of straps placed 51 and 57 inches from each of two opposite corners of the panel as shown in figure 3 with 14 nails in each shorter piece and 16 in the longer.

Each of the 7 full-length straps applied in both directions on panel No. 6 were nailed with 2 nails per 8-inch sheathing board and 1 nail in the narrow bottom board, or 29 nails per strap.

Tests of Strapping

Preliminary to the tests of the wall panels a few exploratory tests were made to get some idea of the behavior to be expected of the strapping in the large panels.

First, two specimens of the strapping were tested in tension. These failed through prepunched holes at loads of 1,390 and 1,380 pounds, respectively. The strapping was 1.025 by 0.031 inches in cross-section with 9/64-inch holes spaced about 4 inches apart.

Next, several short lengths of the strapping were nailed with 3 and 4 large-head, barbed roofing nails (nails of the same kind as for the main tests) spaced 2 inches apart to sheathing of the same average density and moisture content as that to be used in the main tests. With the sheathing board firmly anchored, a pull applied to the straps in line with the nailing and in the plane of the sheathing face caused the strap anchored with 4 nails to fail in tension through a prepunched hole at 1,300 pounds. All 4 nails were slightly tipped during the test, but were still well seated and withdrawal had not begun. Two of the nails were through prepunched holes and 2 were through 1/8-inch drilled holes. Each of two specimens with 3 nails per strap was then tested and both failed by withdrawal of the nails showing that the 3 nails did not have sufficient holding power to develop the full strength of the strapping. The maximum loads developed were 980 and 1,150 pounds, or an average maximum lateral resistance of 355 pounds per nail. Two of these nails in each strap were through prepunched holes and the other through a drilled hole 1/8-inch in diameter.

Tests of Panels

Each panel was tested as indicated in the diagrammatic sketch, figure 4. The lower or sole plate was bolted with three 3/4-inch bolts to a 6- by 8-inch timber, which was keyed to the base of the testing machine to prevent sliding. A hold-back stirrup with one end framed into the base timber and the other bearing against a maple block 1-7/8 inches deep abutting against the lower corner of the panel, prevented the panel from sliding on the base timber.

Two horizontal struts, one near each end of the panel, attached to the heavy top timber and to a wall by swivel joints braced the top of the panel against lateral movement without interfering with longitudinal movement.

The load was applied to one end of the panel and in a direction parallel to the length of the panel, by steel cables attached to a bearing block and passing around sheaves to the movable head of the testing machine. The block was so placed as to bear against the end of the top plate and the upper 2-1/2 inches of the end post assembly. Vertical hold-down rods, placed one on each side of the panel and 2 feet from the end to which the load was applied, were fastened to the base of the testing machine and to a bearing plate above the heavy timber at the top of the panel, to prevent the rotation that otherwise would result from the application of the horizontal force at the upper plate. Rollers placed between this bearing plate and another plate resting on the top timber permitted free longitudinal movement of the panel.

Load was applied by raising the movable head of the testing machine at a rate of 0.21 inch per minute. An initial load of 200 pounds was applied to each panel, except panel No. 2 for which an initial load of 100 pounds was used.

Readings of deformation were taken at successive load increments of 100 pounds on panels 1 and 2, and at 200-pound increments on panels 3 to 7, inclusive. Simultaneously with readings of load, measurements were taken of the horizontal movements of the upper and lower plates of the panel with steel scales, graduated to 0.01 inch, fastened to the top and bottom plates near their centers, and read by means of telescopes against a vertical wire attached to stationary supports. The difference between the readings on the two scales gave the net horizontal movement of the upper plate; that is its movement relative to the lower plate.

The hookup and test procedure for the panels in this series was identical to that used in previous racking tests of wall panels.

Presentation of Data

A diagrammatic sketch and brief description of each panel, together with data from tests are presented in table 1. The comparison for rigidity between different constructions is based on the loads corresponding to a deformation or net horizontal movement of upper plate of 1/2 inch. The load at 1/2-inch deflection for each construction was divided by the corresponding load for the basic unbraced horizontally-sheathed panel No. 1, and the resulting ratio entered as the rigidity factor for the construction represented.

Strength factors, based on maximum loads are also indicated for each particular construction. The reported maximum load of panel No. 1 occurred at a deformation of about 3-3/4 inches. A higher load was obtained when with continuation of the test the deflection became sufficient to cause friction between the edges of sheathing boards, but this load was not considered significant. All other reported maximums are the loads at which the first failure in the bracing system occurred. Maximum loads in the braced panels occurred at deformations of 1-1/4 to 2 inches, or considerably before the loads producing such deformations could include any influence from friction between the edges of the sheathing boards.

Discussion

The results of tests on panels 2, 3, and 4, each with 2 straps of the same size and quality, and in the same relative positions, were not markedly different, although each pair of straps was nailed differently. In each instance the nailing was sufficient to cause the strap to break. Although fastened with the least number of nails, 9 per strap, the strapping nailed directly to the studs in panel No. 2 was the most effective. This panel not only developed a higher maximum load than did panels 3 and 4, but also was more rigid.

The effectiveness of the different methods of attachment may possibly be explained as follows:

In panel No. 2, the sheathing prevented the nails from being withdrawn, and this was largely responsible for the more complete triangulation of this panel because the straps were wholly active between the top and bottom plates. The 3 nails nearest the lower end in each strap developed sufficient holding power to cause the two straps to break simultaneously through open holes between studs at about one-third panel height at maximum load. After further distortion of the panel, the upper portion of these straps also broke. Again the failure of the 2 straps was simultaneous, through open holes.

In panel No. 3 the end nails of both straps in the top and bottom sheathing courses began to pull out soon after the test was underway. The two end nails at both ends of the straps were inclined and practically withdrawn shortly before the straps failed near the center of the panel height. The strap nearest the end of the panel to which load was applied failed at maximum load, and failure of the other strap followed at a decreased load. The lower 4 nails of both straps had pulled out and others had loosened prior to stopping the test at a deformation of 4-3/4 inches. It is believed that extra or double nailing at the ends of these straps would have increased their effectiveness considerably. The progressive loosening of the nails at the lower end of the strapping was accompanied by a proportionate loss of bracing action and was responsible for the increased deflection before the straps failed at maximum load. The load deflection curve of this panel (panel No. 3), however, was practically identical to that of panel No. 4, up to about 0.3-inch deflection, after which the loss of effectiveness of end nails caused it to fall off slightly faster.

The strapping in panel No. 4 with 2 nails per sheathing board in each strap was almost as effective as that in panel No. 2. With double the nailing used in panel No. 3, nails were not loosened before the initial strap failures at maximum load. In fact, the increased nailing developed sufficient holding power to break each strap at three different places during a deformation of 4 inches. Except for the fact that the straps were on the outer face of the sheathing and were therefore farther removed from the plane of action at the face of the framing members, no explanation as to why panel No. 4 was less effective than panel No. 2 presents itself.

In panel No. 5 diagonal straps were applied across opposite corners of the panel. The total length of these straps and the number of nails used was the same as in panel No. 4. This arrangement was much less effective in rigidity than full length straps as used in panel No. 4.

The reason for the superiority of full length straps over an equal length in shorter pieces is perhaps more readily understood when one considers their behavior. For instance, in panel No. 4 the slips between adjacent sheathing boards were nearly the same at all junctions until the first strap failure occurred, at which time the slip at the junction in line with the point of failure increased to nearly twice that at others where slips were still restrained by the action of the remaining unbroken portions of the straps. In panel No. 5 this restraining influence is not as continuous.

The data on panels Nos. 1, 4, and 6 afford an opportunity to evaluate the effect of number of straps. Based on the loads at 1/2-inch deflection as given in table 1 it is evident that 7 straps add less proportionately to the rigidity of a horizontally sheathed panel than do 2 straps. Had the 7 straps (panel No. 6) produced proportionately as great an increase in rigidity over an unbraced panel (panel No. 1) as did 2 straps (panel No. 4), panel No. 6 would have taken a load of about 5,500 pounds at 1/2-inch deflection and would have been considerably more rigid than the panel (panel No. 7) with the 1- by 4-inch let-in bracing. The actual load for panel No. 6 was, however, only 4,370 pounds and considerably below that (5,040 pounds) for panel No. 7. It may be noted from figure 5 that up to deflections of about 1/4 inch loads were not significantly less for panel No. 6 than for No. 7. It may be further noted from the data of table 1 that 7 straps (panel No. 6 compared to panel No. 1) added proportionately more to maximum load than did 2 straps (panel No. 4 compared to panel No. 1).

These apparently inconsistent findings may perhaps be due to failure of straps to act together at the smaller deflections despite the care used to get uniform initial tension. On the other hand, virtually simultaneous failure at maximum load of all 7 tension straps on panel No. 6 indicates that at that stage all tension straps were in effective action and that their effects were additive. From the maximum loads on strapped panels Nos. 4 (2 straps) and 6 (7 straps) the contribution of the sheathing may be computed as about 1,900 pounds. That this is less than the maximum load (2,590 pounds) found for the unbraced panel is to be expected because when the straps broke the maximum resistance of the sheathing-to-stud nailing had not been developed. (The load on the unbraced panel at the deflection at which maximum load occurred in the panel with 7 straps was 2,150 pounds.)

Conclusions

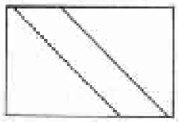
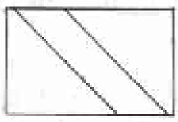
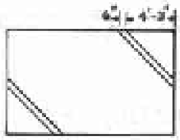
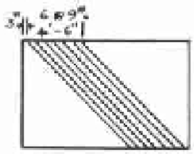
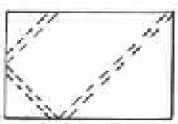
Metal strapping placed diagonally in a wall affords a ready means of increasing resistance to racking above that afforded by well-nailed, horizontal sheathing alone.

Straps nailed directly to framing members with 1 nail each to top and bottom plates and to studs spaced 16 inches are slightly more effective than straps placed outside the sheathing and nailed with 2 nails to each 8-inch sheathing board and requiring some three times as many nails.

A considerable number of straps are required to afford as great rigidity and strength as can be obtained from let-in braces. Since metal strapping will function only in tension, it must, of course, be applied diagonally from opposite corners to resist forces from different directions.

Metal straps are most effective when applied in lengths extending from top to bottom plate.

Table 1.--Results of racking tests of wall frames horizontally sheathed and braced with metal strapping compared with horizontally sheathed frames with and without let-in bracing

Panel	Panel details[1] showing location and number of metal strap braces: Type of panel	Construction details	Moisture content[2]: Framing	Moisture content[2]: Sheathing	Load at 1/2-inch deflection	Rigidity factor	Maximum load	Strength factor
			Percent	Percent	Pounds		Pounds	
1		1- by 6-inch horizontal sheathing, two 8d nails per stud crossing. (No braces)	12.5	12.5	1,325	1.0	2,590	1.0
2		2 straps nailed to studs with 1 nail per stud. 9 nails per strap.	12.9	12.3	2,740	2.1	3,850	1.5
3		2 straps nailed to sheathing with 1 nail per board. 15 nails per strap.	12.9	12.3	2,340	1.8	3,470	1.3
4		2 straps nailed to sheathing with 2 nails per board. 30 nails per strap.	12.5	11.9	2,520	1.9	3,500	1.4
5		2 straps each corner nailed to sheathing with 2 nails per board. 14 and 16 nails per strap.	12.5	11.9	1,910	1.4	3,400	1.3
6		7 straps nailed to sheathing with 2 nails per board. 30 nails per strap.	12.8	12.9	4,370	3.3	7,500	2.9
7		1- by 4-inch let-in bracing nailed to studs with two 10d common nails per stud and four 10d nails at plates.	11.4	12.1	5,040	3.8	11,530	4.4

[1] All panels were 9 feet high by 14 feet long and were without door or window openings. Frames were of Southern yellow pine. All panels were horizontally sheathed with 1- by 8-inch Southern yellow pine and nailed with two 8d common wire nails per stud crossing. All framing material was matched for density, and all sheathing was similarly matched. (Average density about 0.65 based on weight and volume when oven dry.) The same framing was used for panels 1 and 7, 2 and 3, and 4, 5, and 6. The same sheathing was used for panels 1 and 7, and 2, 3, 4, and 5. Sheathing for panel 6 was used only once.

[2] Readings obtained with an electric moisture meter and corrected for species.

Z M 67909 F

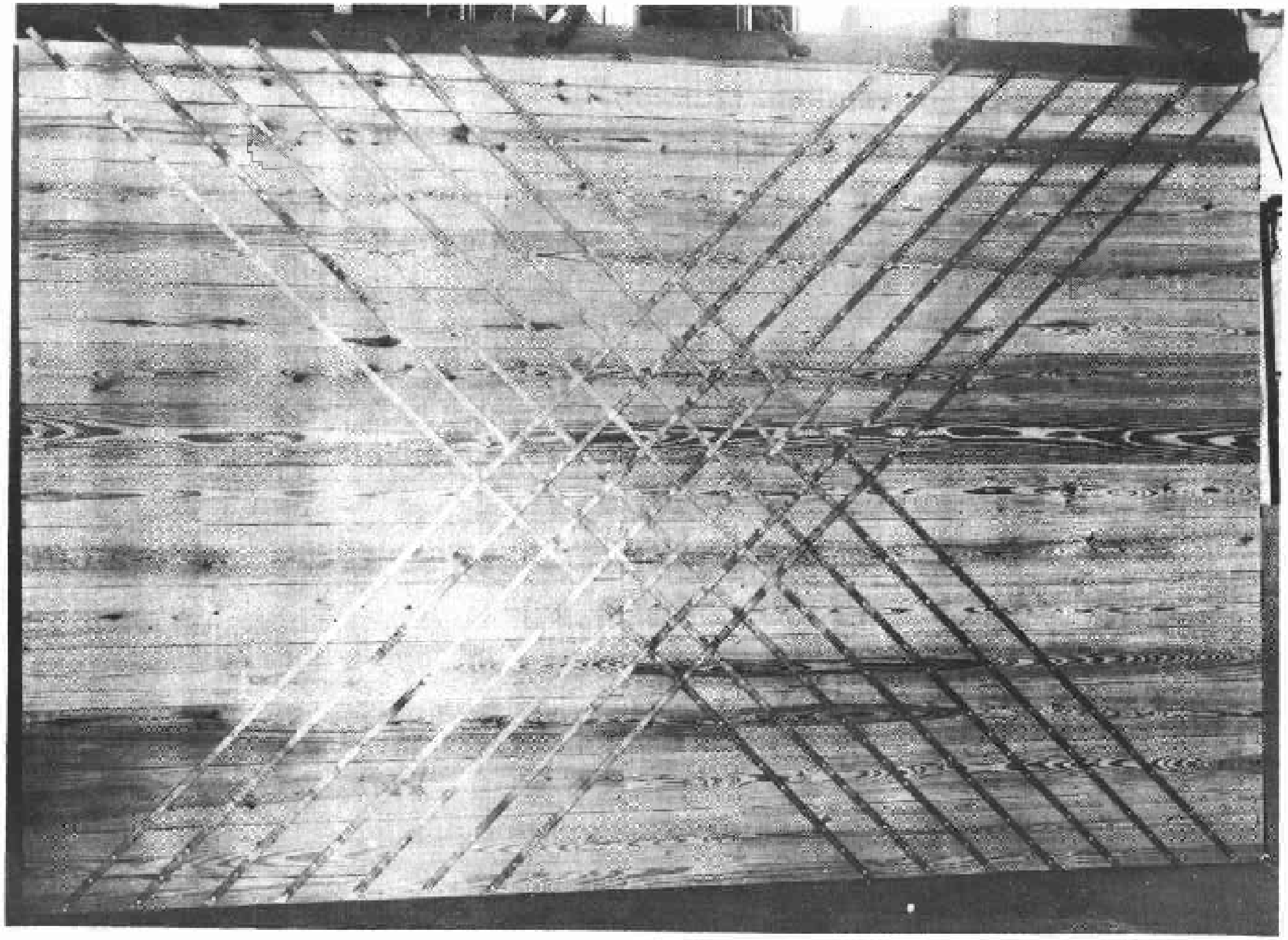


Figure 1.--Panel No. 6 with 14 metal straps, 7 placed diagonally from upper right to lower left, and the other seven from upper left to lower right. Nailed with 2 nails per board, or a total of 30 nails per strap.

Z M 68258 F

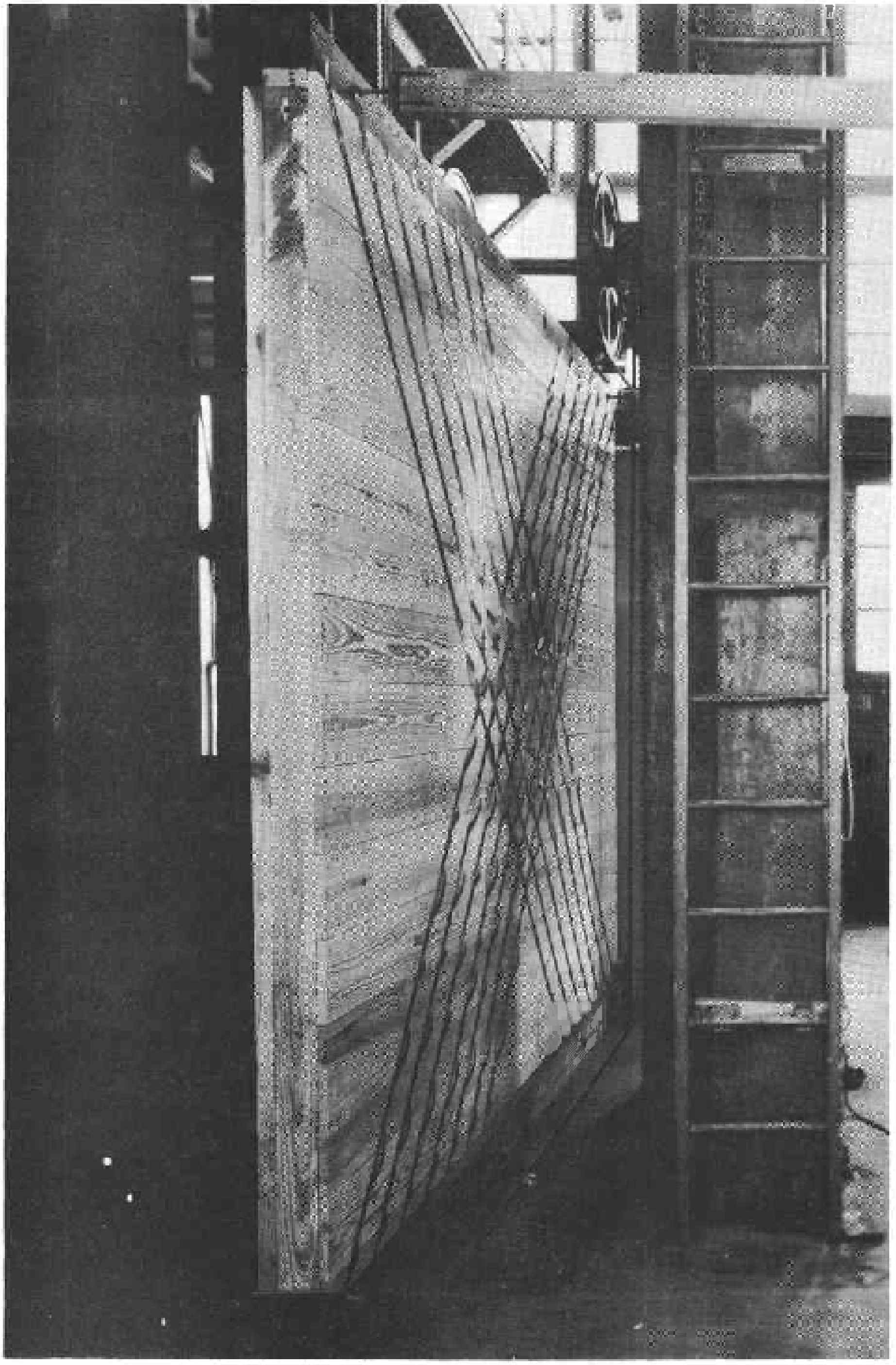


Figure 2.--Panel No. 6 after test showing tension break in straps extending from upper left to lower right and buckling of those extending from upper right to lower left.

Z M 68259 F

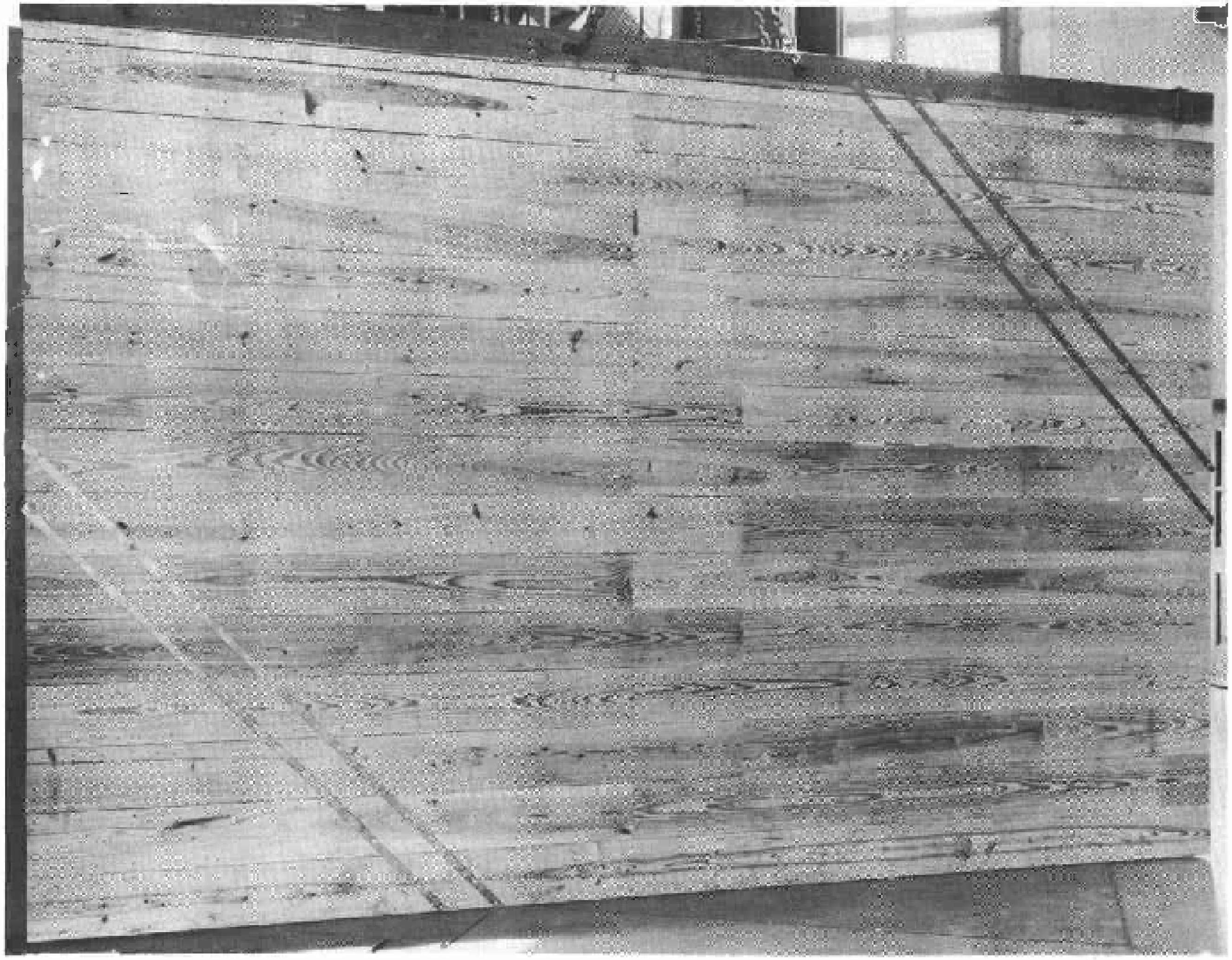
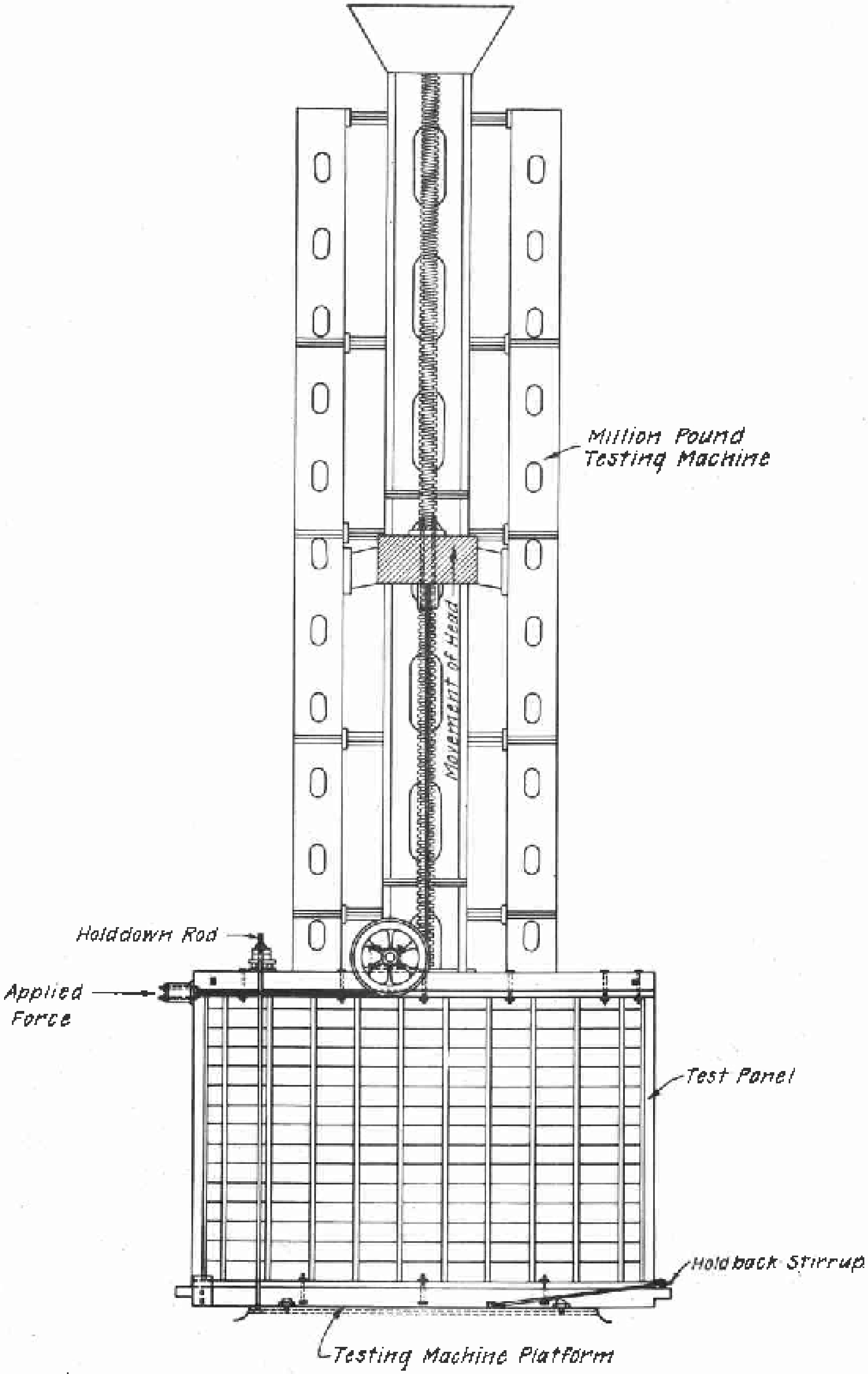


Figure 3.--Panel No. 5 with two straps at each corner nailed to sheathing with two nails per board.

Z M 68260 F


Million Pound
Testing Machine
Movement of Head
Holddown Rod
Applied
Force
Test Panel
Holdback Stirrup
Testing Machine Platform

Z M12201 F

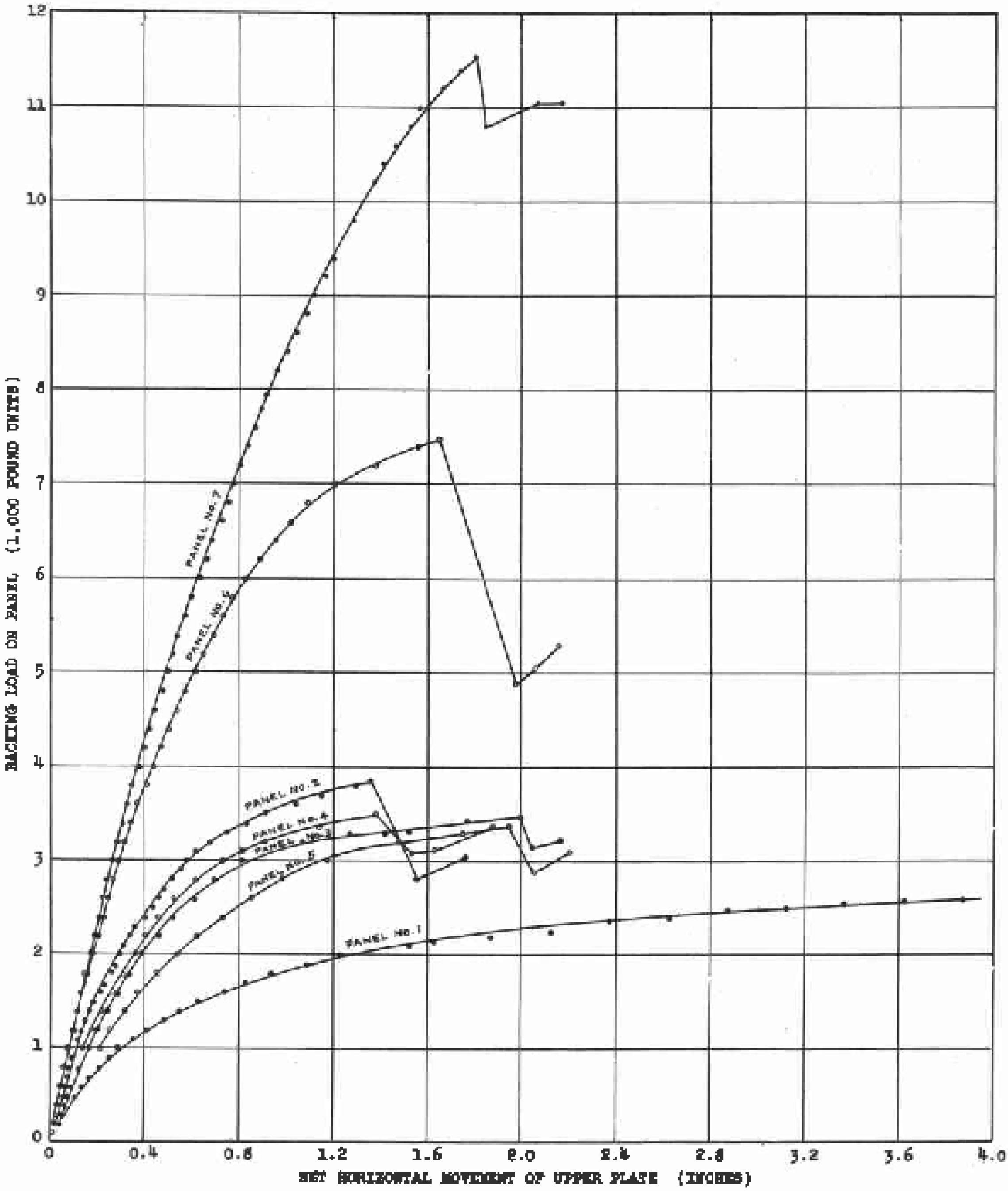


Figure 5.--Load-deflection curves of wall panels without bracing, with metal strapping braces, and with let-in wood braces.

ZM 67119 F