PLYWOOD AS A STRUCTURAL COVERING FOR FRAME WALLS AND WALL UNITS

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PLYWOOD AS A STRUCTURAL COVERING FOR FRAME WALLS AND WALL UNITS[1]

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Several years ago a series of tests[2] was made at the Forest Products Laboratory to determine the relative resistance of different types of frame wall construction to static loads applied in the plane of the panels. The purpose of that study was to obtain a better understanding and appreciation of the principles involved in wall construction that tend to make frame dwellings and other small frame buildings substantial structures. Plywood was not included among the various coverings for the frame work used at that time. Neither was there any attempt made to develop and determine the efficiency of small wall units suitable for factory fabrication and amenable to facile assembly. Recently a second series of tests was made. The purpose of these later tests was to determine the extent to which plywood can impart strength and stiffness to a house wall, to show the relation between method of fastening the sheet to the frame and the amount of inherent stiffness and strength utilized, and to get a measure of the performance of small units that appeared to offer possibilities from the fabrication and assembly standpoint.

Description of Panels and Test Procedure

Test Panels

All test panels in the present series were 8 feet high by 12 feet long. They were either a single unit of those dimensions or an assembly of three separate units each 8 feet high by 4 feet wide. Those made as a single unit consisted of 2 by 4-inch upper and lower plates, three-piece end posts, and 2 by 4-inch studs spaced 16 inches. The end posts consisted of two 2 by 4-inch pieces spaced 3/8 inch to which a third 2 by 4 was nailed with its 4-inch side perpendicular to the 4-inch sides of the other two. One of these panels was framed for a double 26 by 28-inch window and two were framed for a double 26 by 28-inch window and a 2-foot 8 inch by 6 foot 8 inch door. Two 16d nails were driven through the upper and lower plates into the ends of the studs.

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[1]Published in Engineering News-Record, Aug. 9, 1934.

[2]"The Rigidity and Strength of Frame Walls," by G. W. Trayer. (Forest Products Laboratory Report No. R896, 1929).

The framing material was southern yellow pine and the plywood which was attached to the frame was of Douglas fir, sanded two sides, and in sheets 4 by 8 feet. The thicknesses of the plywood and the methods of attaching it to the frame are discussed in detail later.

The 4 by 8 feet units, three of which were assembled and tested in an 8 by 12-foot panel, were made in two styles, differing only as to the sheathing material used. Figure 1 is a horizontal section of these units and shows plywood attached to the studs. Horizontal sheathing was also used. The top and bottom plates were 2 by 4 inch, slotted to receive the 1/2-inch insulating board, and one 10d cement-coated nail was driven through these plates into each divided stud. Four 10d cement-coated nails driven from one side and three from the other tied each pair of divided studs together. The spline shown between the end studs where two units are joined was set in casein glue. The end studs were held snug with six 16d common nails while the glue set. The method of attaching the plywood will be discussed later. Horizontal sheathing was of nominal 8 inch width and each board was attached to the frame with two 8d common nails at each stud crossing. The inside face of the units which in actual use would have some form of plaster, wallboard, or other covering was left open in test.

Test Procedure

The purpose of the tests was to determine the resistance of the various panels to static loads applied to the upper plates and acting in the plane of the panel. In other words, the applied loads were intended to distort the outline of the panel from a rectangular form into a rhomboidal form. To accomplish this the lower plate of each panel was bolted to a heavy timber which in turn was fastened to the base of a million pound testing machine. The panel was further anchored against thrust by a stirrup between the heavy timber and the lower plate. The upper plate was also securely bolted to a heavy timber which furnished the resistance to lateral buckling always supplied to the walls by the upper floor system. At the ends of each panel long horizontal pin-connected tie bars simulated the aligning action of cross walls. Load was applied to the upper plate in a direction parallel to the length of the panel by steel cables which passed around sheaves and thence up to the movable head of the testing machine. The bearings for a shaft carrying these sheaves were attached to the large cast iron standards which support the fixed head of the testing machine. The application of horizontal load to the upper plate would, of course, induce an overturning tendency which normally would be prevented by the upper story and roof loads. The reaction to prevent overturning in test was supplied by two vertical hold-down rods, one on either side of the panel, attached at one end to the base of the testing machine and at the other to a bearing plate on top of the heavy timber to which the upper plate of the panels were attached. Roller bearings were placed between the bearing plate and the timber to provide for free longitudinal movement of the panel. The hold-down rods were placed about 1 foot from the end of the panels. Load was applied by raising the movable head of the testing machine at the rate of 0.211 inch per minute. Movement of the upper plate with respect to the lower plate was observed for various increments of load. Figure 2 is a diagrammatic sketch of the panel set-up and Figure 3 is a photograph of a panel in the machine taken after the panel had failed.

This movement was measured in two ways. By the first method the horizontal displacement of the upper and lower plates were read and the differences between the two taken as the movement of the upper plate with respect to the lower. Errors of variable magnitude are introduced by this method because any rocking over of the panel as a whole is included in the movement of the upper plate. Some yielding at the lower right-hand corner of the panel (see Fig. 2) and also in and at the hold-down rods is inevitable. If the movement of the plate for a given increment of load were large the increment due to rocking of the panel would introduce an error of minor magnitude, whereas in an inherently rigid panel the error introduced would be of considerable importance. This method was used when the sheathing material was nailed to the frame.

The second method was to measure the change in length of both diagonal dimensions of the panel and to convert the readings into horizontal displacement. By this method the rocking over of the panel was eliminated from the observations. The second method was used when the sheathing material was glued to the frame. Because of local distortions, particularly at the corners, it was not feasible to use the second method for the nailed panels.

Discussion of Test Results

The results of ten tests are given in Table 1. In order to get a clear picture of how the rigidity and strength of the forms of wall construction used in the present series of tests compare with that of the forms used in the previous series, the rigidity and strength of a panel 9 by 14 feet sheathed horizontally with 8-inch southern yellow pine boards nailed with two 8d nails at each stud crossing were each taken as unity. In the present series of tests the panels were 8 by 12 feet and adjustments for panel size were made on the basis that the load for a given angular distortion is independent of the height and directly proportional to the length.

It will be observed that the rigidity factors given in Table 1 are not constant, but that they increase as the movement of the upper plate increases. In other words, the general form of the load slip curve for a panel sheathed with plywood is not the same as that for a panel sheathed with lumber.

The maximum load for 9 by 14-foot panels sheathed horizontally with lumber as determined by the previous tests was 2,588 pounds. This would correspond to 2,218 pounds for an 8 by 12-foot panel. The tests were stopped at 21,000 pounds if the maximum load had not been reached before that point, which accounts for the fact that for panels P-1 and P-1-A in Table 1 the maximum strength factor is given as over 9.

Nailed Plywood Sheathing (Panels Without Openings)

Well nailed plywood sheathing supplies a stiffness to a wood frame without openings several times that afforded by horizontal sheathing. As a matter of fact, it is comparable with diagonal sheathing. The 5/8-inch plywood, panel P-1, was nailed with 8d common wire nails spaced 6 inches around the edges of the plywood sheets and 12 inches on intermediate studs. The 1/4-inch plywood, panel P-2, was nailed with 6d nails spaced 5 inches around the edges of the plywood sheets and 10 inches on intermediate studs. It has been shown in other tests that the proportional limit load of a nail in lateral resistance varies as the 3/2 power of its diameter. Therefore, an indication of the relative rigidity of panels P-1 and P-2 at small distortions can be obtained by taking into account the difference in nail diameters and number of nails thus:

$$\frac{5}{6}\left(\frac{0.131}{0.113}\right)^{3/2} = 1.04$$

Examination of Table 1 will show that at slips of 0.2 and 0.3-inch panel P-1 was about 5 percent stiffer than panel P-2. As the slips increased the superiority of the 5/8-inch plywood increased until at a 1.0-inch slip it was about 35 percent better.

No comparison of the ultimate loads can be made because the test was stopped before the maximum load of the panel with 5/8-inch plywood sheathing was reached. However, the maximum load for 1/4-inch plywood was over five times that for horizontal sheathing but less than that obtained with diagonal sheathing.

The results for panel P-2-A show the effect of adding more nails. As indicated in the table, twice as many nails were used for this panel as for panel P-2. The increase in stiffness was approximately 50 percent. A tendency of the plywood to buckle appeared to be the most important factor in preventing a further increase. In no instance are the plywood sheets perfectly flat. Therefore, under the loads developed with a 5-inch spacing of nails around the edges there would be some buckling. Under the greater loads made possible by additional security of attachment there would be more buckling. This does not mean, however, that the plywood sheets had reached the limit of their inherent rigidity because by gluing the plywood to the studs a pronounced increase in rigidity was obtained as will be shown later. Figure 3 is a photograph of panel P-2-A taken after it had failed.

Nailed Plywood Sheathing (Panels With Openings)

When a double 26 by 28-inch window was framed into an 8 by 12-foot panel the stiffness with 1/4-inch plywood nailed to the studs was less than that for a panel without openings. The reduction varied from about 10 percent for small distortions to about 20 percent for large distortions. As a basis of comparison the rigidity factor for a diagonally sheathed 9 by 14-foot panel with a double 28 by 28-inch window was approximately 3.

For movements of the upper plate greater than 0.1 inch the rigidity factors of the panel with 1/4-inch plywood sheathing are greater than 3, see panel P-3, Table 1. The maximum load with plywood sheathing was less than that obtained with diagonal sheathing.

When a double 26 by 28-inch window and a 2 foot 8 inch by 6 foot 8 inch door were framed into an 8 by 12-foot panel, see panel P-4, the stiffness with 1/4-inch plywood was still further reduced to about half that for a panel similarly sheathed but without openings. Again referring to the former tests it was found that the rigidity factor for a diagonally sheathed 9 by 14-foot panel with a double 28 by 28-inch window and a 3 by 7-foot door averages about 1.2. The rigidity factors given for panel P-4 are all greater than this. However, it was found in the previous tests that the tendency of diagonal sheathing to distort the framing around windows and doors was greatly reduced when siding was added. With the additional triangulation supplied by the siding slightly greater stiffness was obtained with diagonal sheathing than with 1/4-inch plywood. It is not expected that the addition of siding to the plywood sheathing would have any material effect upon its rigidity.

Plywood Glued to Studs (Panels Without Openings)

Gluing the plywood to the studs greatly increased the rigidity of the panels. Failure to obtain readings for panel P-1-A at distortions larger than 0.1 inch makes it impossible to compare the performance of 1/4-inch and 5/8-inch plywood when glued to the studs. Suffice to say that the increase in rigidity over that obtained with nailing is enormous and that the inherent rigidity of either thickness is not even approached with normal nailing. Comparison of the various forms of nailing and of gluing shows conclusively that the inherent rigidity of the plywood sheet is developed only in a measure commensurate with the adequacy of its attachment to the frame.

Plywood Glued to Studs (Panels With Openings)

Comparison of the results for panels P-4 and P-5 both of which had a window and door, the former having 1/4-inch plywood nailed to the studs and the latter glued, show an increase in stiffness with gluing of from about 36 percent for small distortions to about 100 percent for large distortions. Again the importance of secure attachment of the plywood to the panel frame is apparent.

Fabricated Wall Units

Two styles of wall units 8 feet high by 4 feet wide were tested. They differed only as to the sheathing on the outside face. As shown in Figure 1 they consisted of upper and lower 2 by 4-inch plates, 2 by 4 inch end studs, two pairs of intermediate divided studs with insulating board between them, and a covering on the outside face. The upper and lower plates and the end studs were slotted to receive the insulating board. Adjacent units were joined by wood splines set in casein glue.

Panel P-6, Table 1, consisted of three such units with 8-inch horizontal sheathing nailed with two 8d common wire nails at each stud crossing. Figure 4 shows the outside face of one end of the assembled panel. Its performance at small distortions was the same as that of a large panel constructed with one-piece upper and lower plates, 2 by 4-inch studs spaced 16 inches and sheathed with 8-inch boards laid horizontally. At larger distortions the insulating board came into bearing against the upper and lower plate of each unit as shown in Figure 5. Examination of Figure 5 will show crushing of the insulating board at the lower right hand and upper left hand corners. The result of such bearing was a stiffness factor greater than unity at the larger distortions.

Panel P-7, Table 1, consisted of three units 8 feet high by 4 feet wide with 1/4-inch plywood sheathing nailed to the outside face with 6d common wire nails. The spacing was 5 inches around the edges of the 4 by 8-foot plywood sheets and 10 inches at intermediate studs. The performance of this panel was only slightly superior to that of panel P-2 which had the same sheathing, nailed in the same way but to an integral 8 by 12-foot frame consisting of 2 by 4-inch plates and 2 by 4-inch studs spaced 16 inches. The 10 to 20 percent superiority in stiffness is partly accounted for by the fact that the insulating board in the units of panel P-7 came into bearing, as already mentioned in connection with panel P-6. There was also some slight advantage in the nailing at the vertical edges where the units come together because the double studs at these points permitted nailing farther from the edges of the plywood sheets.

Conclusions

The limited number of tests in this particular series precludes definite numerical comparison of different types of wall construction. However, by virtue of the results from a related series previously obtained and the broader general aspects of our knowledge concerning the performance of wood and wood fastenings, certain general conclusions are warranted.

Plywood in large sheets, 1/4-inch or more in thickness, well nailed to a frame wall affords several times the rigidity and strength that is afforded by horizontal sheathing. In this respect it compares favorably with diagonal sheathing.

The extent to which the inherent rigidity and strength of large plywood sheets are utilized depends upon the security with which the plywood is attached to the frame. It is entirely possible, for example, to obtain greater rigidity with 1/4-inch plywood well nailed to the frame than with 5/8-inch plywood inadequately nailed. By gluing plywood to the frame a rigidity is obtained that is far superior to anything possible with nailing.

Wall units of convenient size for factory fabrication and facile erection can be assembled with glued splines in such a way that in rigidity and strength they are fully equal to similarly sheathed large wall panels framed in the conventional manner. A design for such units is described in the report. It is quite likely that modifications of the design will be necessary from a production standpoint, but it is believed that its structural and insulation characteristics are essentially sound.

Table 1.--The rigidity and strength of wall panels with various forms of sheathing expressed as ratios of corresponding characteristics for horizontal sheathing[1].

Panel	Description: Type	Description: Sheathing	Nails: Size	Nails: Spacing[2]	Distortion by	Rigidity factor at slip in inches of -- 0.1	0.2	0.3	0.4	0.6	0.8	1.0	Maximum load factor
			(d)	(Inches)									
P-1	Full panel	5/8-inch plywood	8	6	Plate movement	2.6	3.6	3.9	4.4	5.1	5.7	6.5	[3] over 9
P-1-A	Do	5/8-inch plywood[4]	--	--	Diagonal measurement	24.0	[5]--	---	---	---	---	---	over 9
P-2	Do	1/4-inch plywood	6	5	Plate movement	2.9	3.4	3.7	4.0	4.3	4.5	4.8	5.2
P-2-A	Do	1/4-inch plywood	6	2-1/2	Plate movement	4.5	5.2	5.5	5.9	6.5	6.8	7.2	7.0
P-2-B	Do	1/4-inch plywood[4]	--	--	Diagonal measurement	8.8	11.0	12.9	14.4	[6]--	---	---	8.6
P-3	Window opening	1/4-inch plywood	6	5	Plate movement	2.7	3.1	3.3	3.4	3.7	3.8	4.0	3.7
P-4	Window and door openings	1/4-inch plywood	6	5	Plate movement	1.4	1.7	1.6	1.8	2.1	2.2	2.3	2.8
P-5	Window and door openings	1/4-inch[4] plywood	--	--	Diagonal measurement	1.9	2.6	2.8	3.3	4.0	4.0	4.3	4.0
P-6	Three-unit	Horizontal	8	--	Plate movement	1.1	0.9	1.0	1.2	1.3	1.6	1.8	2.2
P-7	Do	1/4-inch plywood	6	5	Plate Movement	1.5	3.0	4.1	4.4	4.9	5.2	5.8	6.2

[1] The rigidity and strength afforded by southern yellow pine boards 8 inches wide, laid horizontally, and nailed to southern yellow pine framing with two 8d common wire nails at each stud crossing are both taken as unity.

[2] The nail spacing indicated is that around the four edges of each plywood sheet. The spacing at intermediate studs was double that given in the table.

[3] Test stopped at 21,000 pounds.

[4] Glued to frame.

[5] Reading stopped at 0.12 inch.

[6] Readings stopped at 0.56 inch.

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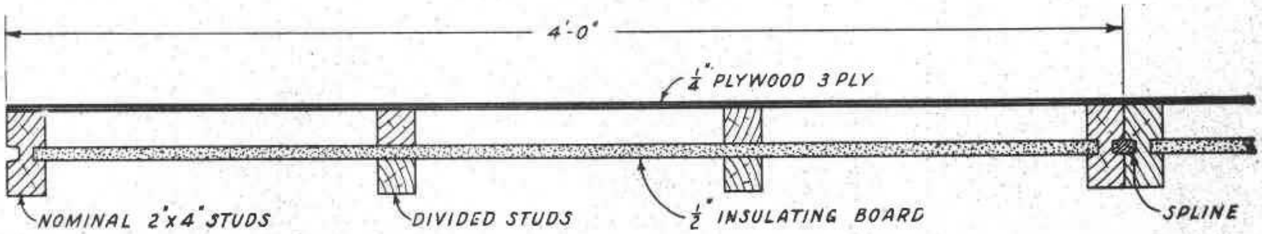

FIGURE 1--HORIZONTAL SECTION THROUGH 4-FOOT PANEL UNIT

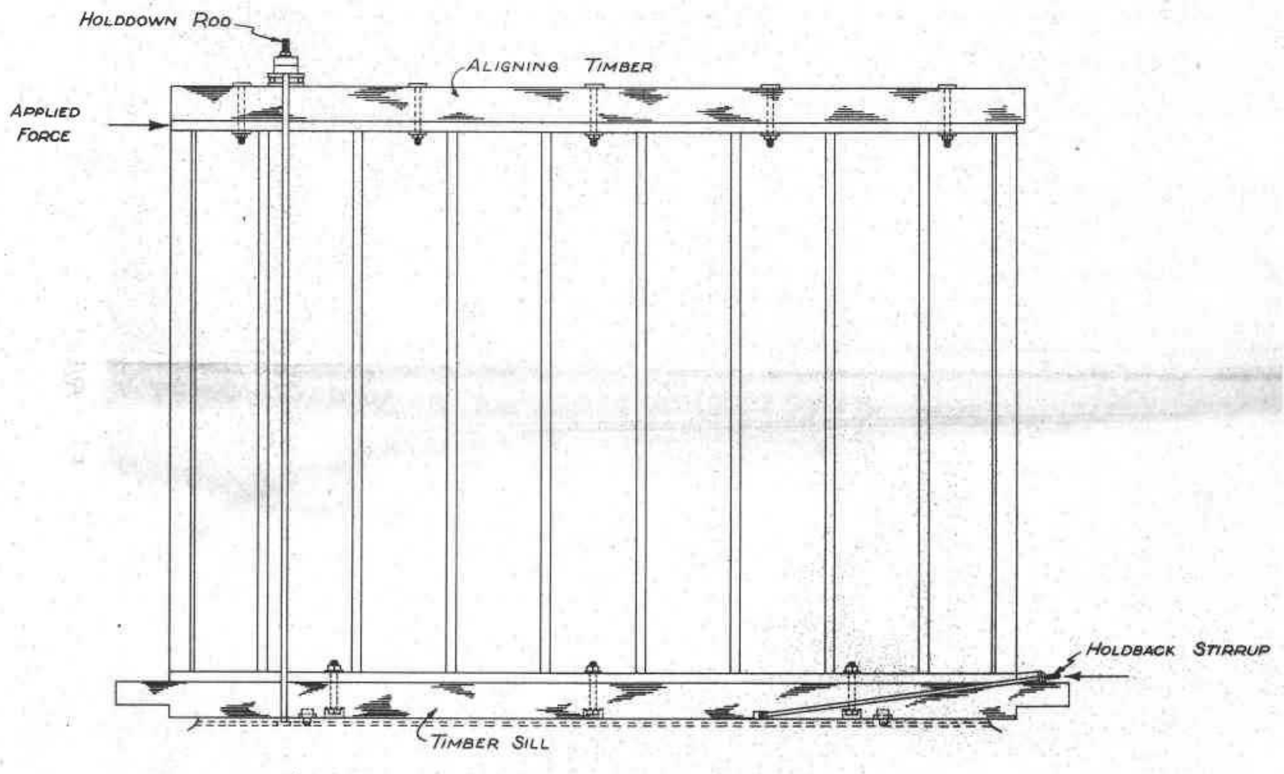

FIGURE 2. --METHOD OF APPLYING LOAD TO THE TEST PANELS.

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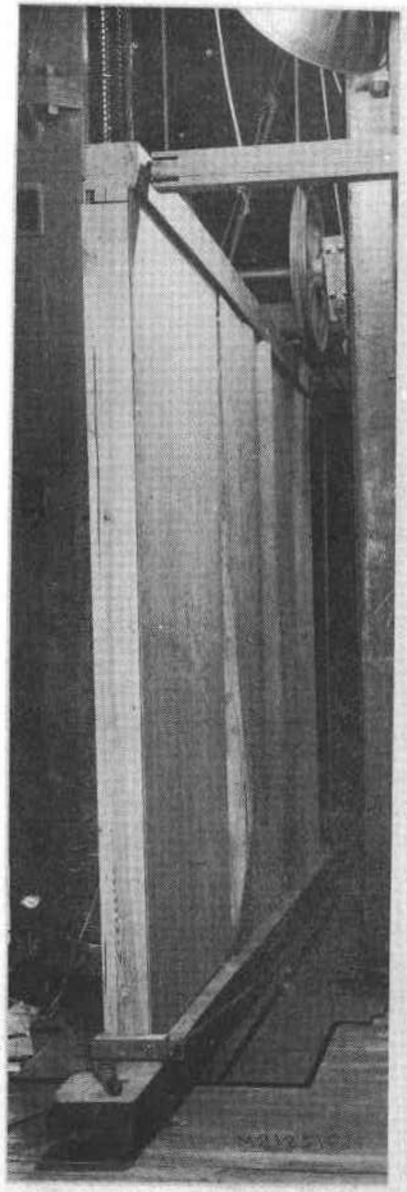
FIGURE 3

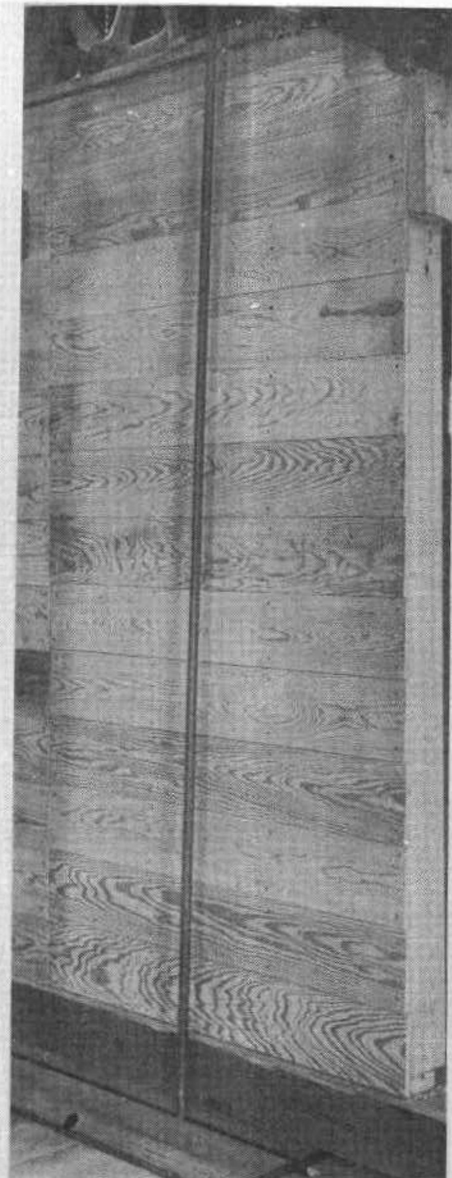
FIGURE 4

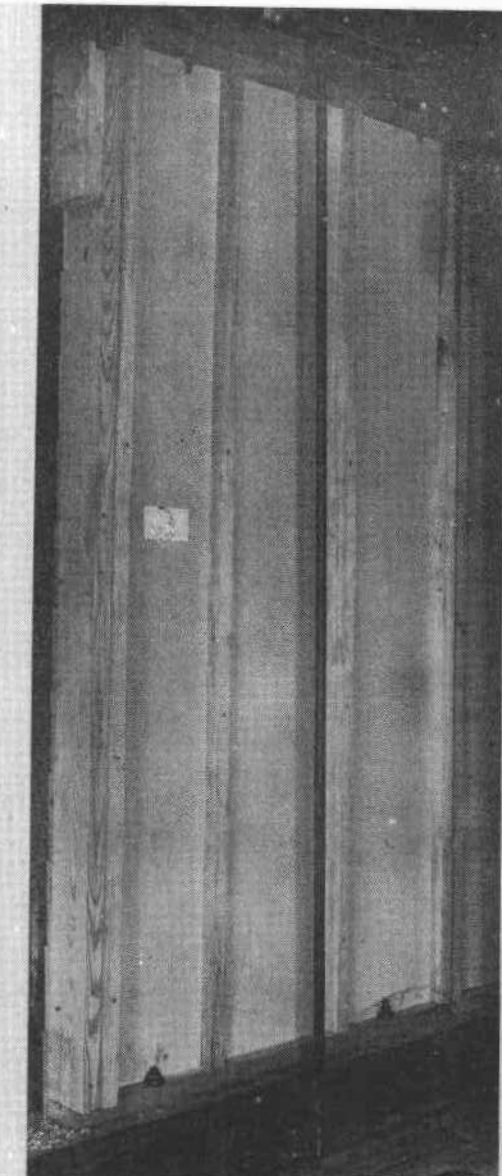
FIGURE 5

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