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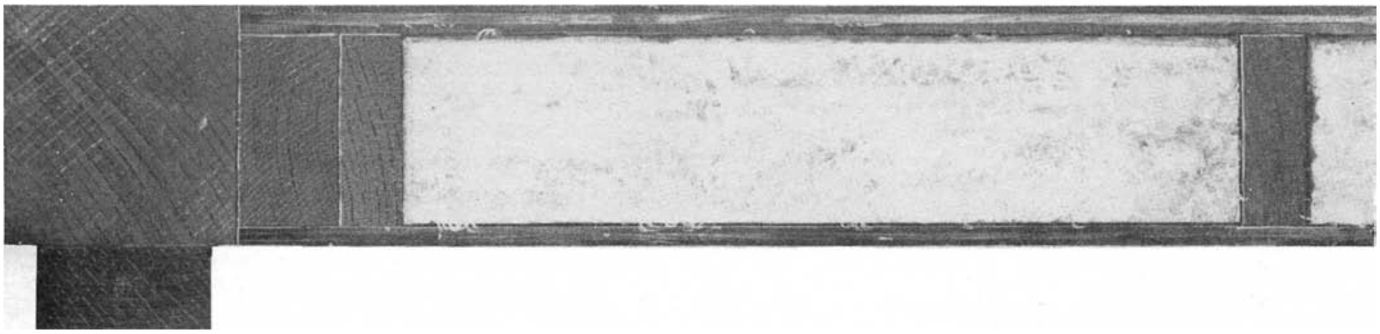
STRESSED SKIN PANEL PERFORMANCE



AFTER TWENTY-FIVE YEARS OF SERVICE

U. S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE

FOREST PRODUCTS LABORATORY MADISON, WIS.

SUMMARY

Wall panels used in construction of a prefabricated house, built in 1937, were removed in 1962 to determine their performance characteristics after 25 years' service. The panels were evaluated for stiffness and bending strength, and the glue joints in the plywood and between the plywood and the framing members were evaluated for shear strength. Replacement panels. placed in the prefabricated house in 1962, were evaluated to equivalent design loads of 20 pounds per square foot prior to being placed in the house. Panels of a construction similar to the replacement panels were evaluated to failure.

The panel stiffness evaluations showed that span deflection ratios at design load, both for panels removed after 25 years' service and for recently fabricated panels, exceeded by several times the normal allowable design values for walls. Failing load also exceeded design values by factors of more than 10.

Evaluations of plywood in shear, after the conventional exterior-type boil-dry cycle test, indicated relatively little change in quality of the glue joints after 25 years' service. Results of dry shear tests of the casein-glued joints between plywood and the framing members showed little evidence of deterioration.

The panels were designed and maintained to control moisture effects and the entry of water during the 25 years' service.

STRESSED-SKIN PANEL PERFORMANCE

AFTER TWENTY- FIVE YEARS OF SERVICE

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INTRODUCTION

Long experience has shown that wood-constructed buildings of the conventional type can be built to last for centuries, and many examples of such wood buildings are in existence. It is generally recognized that the best evaluation of the durability or length of service of a building is that obtained through experience.

In new types of construction systems which combine materials, long service records are lacking, Therefore, an evaluation of new materials and construction systems is significant.

Stressed-Skin System

In the early 1930's, the U.S. Forest Products Laboratory undertook research studies to develop a new system of construction, utilizing the stressed-skin principle developed by its research engineers. This system, in theory, is one of the most efficient structural systems for walls, floors, 'ceilings, or roofs. Its many advantages have made it extremely popular with the prefabricated industry and manufacturers of other building components used in building construction.

Fundamentally, the system uses panels made of framing members to which plywood sheets or other facing materials are bonded either by glue-nailing or gluing by other types of pressure. The gluing of these skins causes them and the framing members to act as an integral unit: therefore, under loading, the skins are stressed. The use of the skins, structurally, allows a reduction in size of the framing material, and the elimination of sheathing and interior finishing materials reduces the weight of the construction considerably. If it is desirable, the panels may be used only as a structural unit and any type of' exterior or interior finish may be applied.

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[1]Special acknowledgment is given to C. G. Roessler, Technologist, who supervised tests of the glued joints.

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

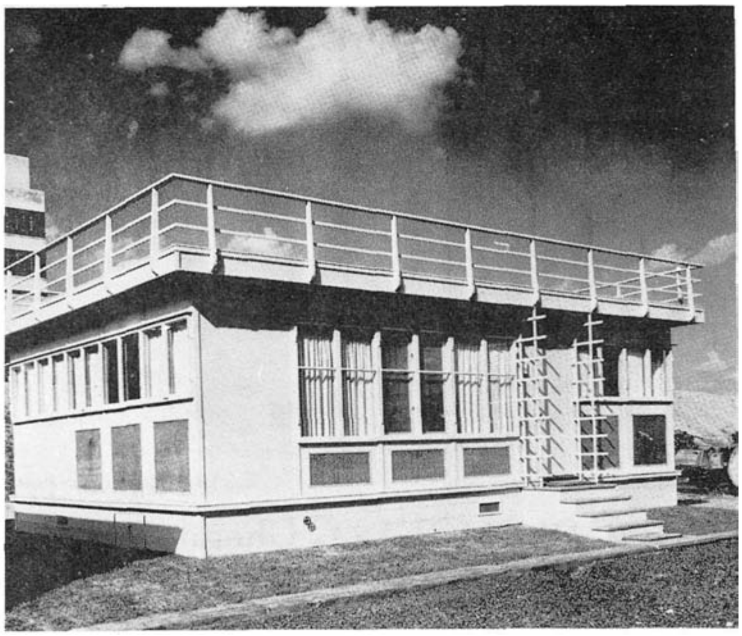

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Figure 1.--First experimental house built at the U.S. Forest Products Laboratory in 1935 as part of its research in developing the stressed-skin cover principle.

Experimental Houses

The U.S. Forest Products Laboratory's first experimental prefabricated house was built in 1935 (fig. 1); the second, a one-story, and the third, a two-story, in 1937 (fig. 2). Panels were removed from the one-story house (fig. 2) for evaluation purposes. The panels and the components used in the first experimental house were fabricated at the Laboratory. The panels and the components used in the second and third experimental houses were fabricated by a private contractor in accordance with plans and specifications furnished by the Laboratory.

The one-story prefabricated house erected in 1937 was the first truly engineered structure of its kind ever built in this country. It was constructed largely of plywood and contained a living room, kitchen, two bedrooms, a bath, closets, and a utility room (fig. 3).

It should be recognized that this new system of construction, which involved gluing large panels and frame units together, was then in its infancy and neither gluing techniques nor gluing equipment for such use were developed to their present extent.

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Figure 2.--Prefabricated houses developed by the U.S. Forest Products Laboratory in 1937. Panels were removed from the one-story house (foreground) for evaluation purposes.

This report is concerned with the effect of time on the materials and its relationship to the physical properties of the 4- by 8-foot panels removed from the experimental prefabricated house in 1962 after 25 years of service in Madison, Wis.

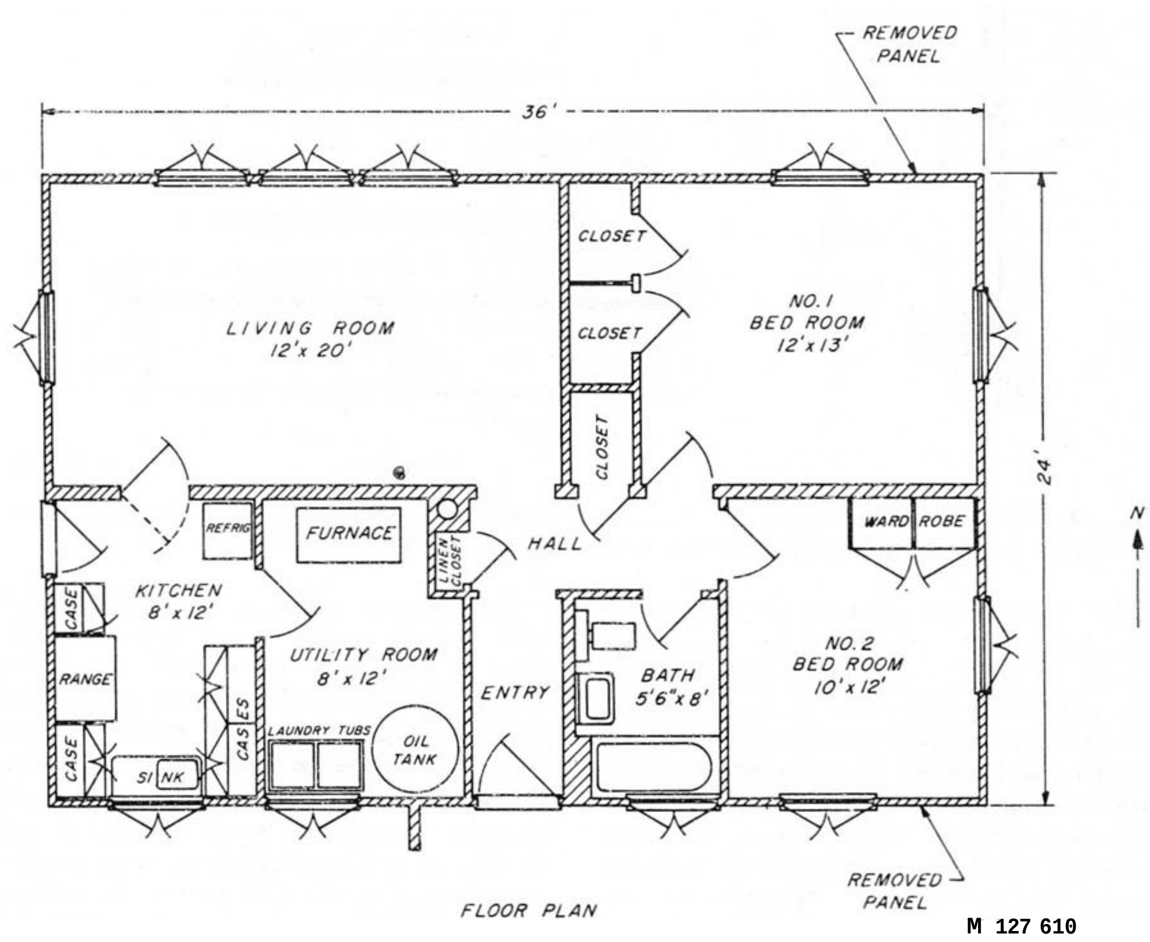

Figure 3.–Room layout of the one–story prefabricated house and location of the removed panels.

DESCRIPTION OF WALL PANELS

Two wall panels were removed from the building in October 1962 for observation and physical testing, not because of any observed unsatis- 'factory performance.

Materials and Dimensions

The wall panels were 4 feet wide, 8 feet high, and 3 inches thick. Facing materials consisted of 3/8–inch three–ply Douglas–fir plywood on the exterior and 1/4–inch three–ply plywood on the interior. The plywood was some of the earliest full–size exterior–type Douglas–fir plywood produced commercially and was designated as resin–bonded exterior–type plywood. The vertical framing members were made of Douglas–fir 1–inch material 2–3/8 inches wide, spaced approximately 12 inches apart with a top and bottom member. The plywood facing members were nail–glued to the framing members with a commercial water–resistant casein glue.

Fourpenny casing nails, 3 inches on center, were used for the 1/4–inch plywood and sixpenny casing nails, 3 inches on center, for the 3/8–inch plywood. The nails were not removed after

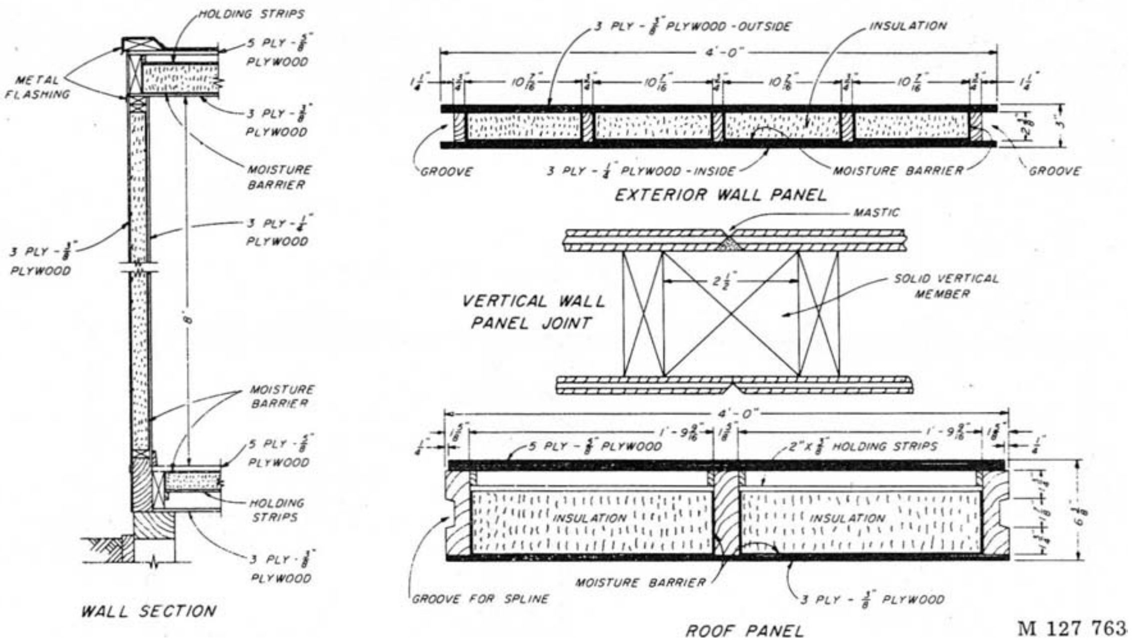

Figure 4.--Construction details of prefabricated one-story stressed-skin plywood house developed at U.S. Forest Products Laboratory, showing wall section, exterior wall panel, and roof panel.

the glue had set. The plywood projected 1-1/4 inches beyond the framework entirely around the panel to form a continuous groove, 2-3/8 inches wide and 1-1/4 inches deep. A 2-1/2-by 2-3/8-inch solid vertical member was fitted into the groove and served as a connecting piece between the panels (fig. 4).

The space between the framing of the panels was entirely filled with a mineral-wool insulation having a "U" factor (overall heat transmission coefficient) of approximately 0.13 British thermal unit.

Moisture Barriers

A moisture barrier was placed in each space between the framing members. It consisted of a single piece of asphalt-impregnated and surface-coated paper so folded as to fit tightly against the inside face of the plywood and along the sides of the framing members. Those parts of the side of the framing members that were in contact with the moisture barriers were given a brush coat of asphalt paint just before the barriers were inserted. The barriers were held to the framing members with wire staples.

The vertical edges of the exterior plywood were beveled on the outside and inside edges to form a pocket so that a sufficient amount of mastic could be placed between panels, thereby providing a permanent seal against the entry of water, moisture, and air infiltration (fig. 4).

The structure was designed carefully and much attention was given to its subsequent maintenance so that no moisture problems were likely to be encountered in the wall panels. In addition, as a part of the research program, above-normal humidification was maintained in the building to determine the efficiency of the moisture barrier. In recent years, the humidification has been

Figure 5.--Cutting edges of inside panel surface for removal from the wall.

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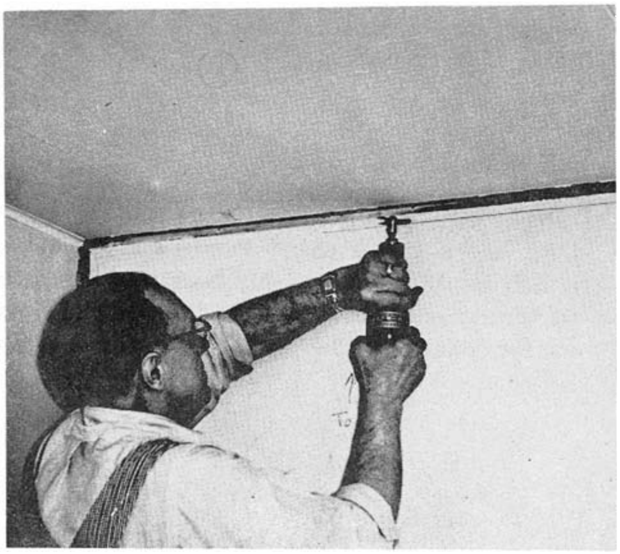

discontinued while the building is being used for office space by the Laboratory.

Removal of Panels

Two panels were taken from the one-story prefabricated house--one from the northeast corner of the north wall and the other from the southeast corner of the south wall (fig. 3).

To remove these panels, all the mechanical fastenings were first removed from the edges of the interior and exterior faces of the panel. A saw kerf was made around the interior face of the panel 1-1/4 inches from the edge of the plywood (fig. 5). After removing the 1-1/4-inch strip from the sides, top, and bottom of the panel, the panel was then removed from the wall.

REPLACEMENT PANELS

The replacement panels (fig. 6), built in 1962, were similar in construction to the original panels. One panel in the south wall of the structure was constructed with a 1/4-inch tempered hardboard facing on the exterior and interior faces. The screened face of the hardboard was sanded to

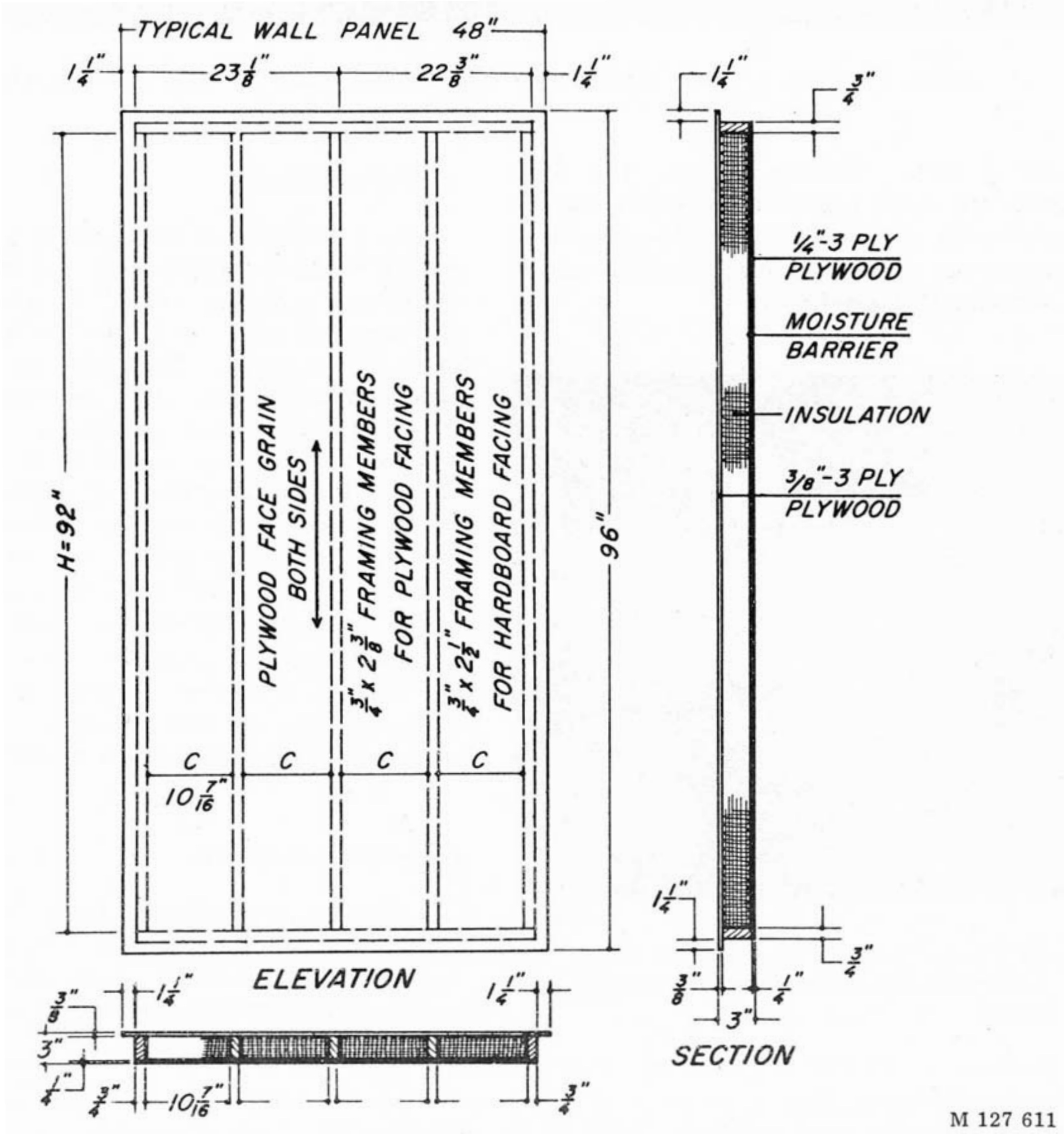

Figure 6.--Construction details of replacement panel. One panel utilized 1/4-inch plywood as the interior facing and 3/8-inch plywood as the exterior facing. The other panel utilized 1/4-inch hardboard as interior and exterior facings.

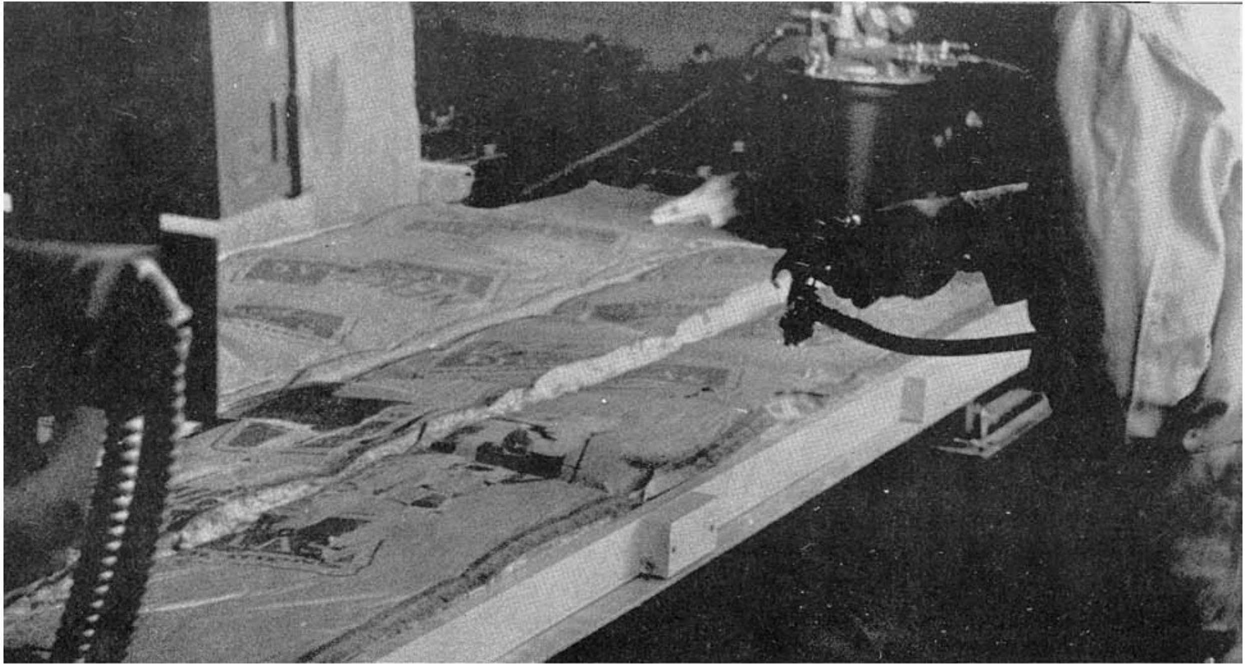

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Figure 7.--Spraying contact adhesive on the framing members of the replacement panels.

provide a better bonding surface. The other panel in the north wall had 3/8-inch three-ply plywood on the exterior face and 1/4-inch three-ply plywood on the interior face. The plywoodwas exterior-type Douglas-fir.

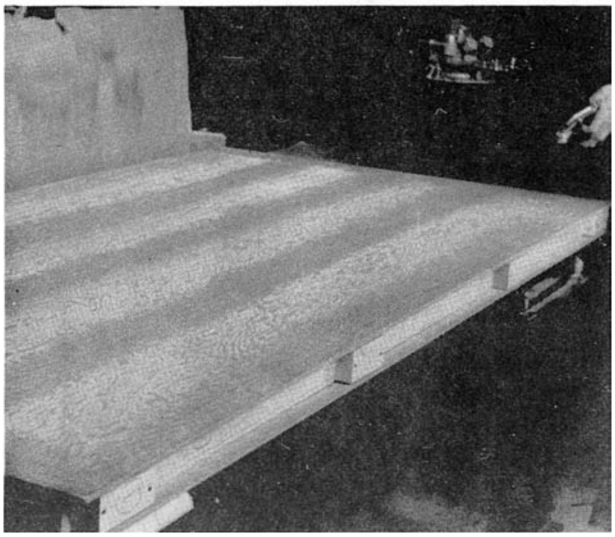

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Figure 8.--Spraying the back face of the plywood facing with contact adhesive at the framing member location.

Contact Adhesive

The hardboard and the plywood facings were bonded to the framing members with a new type of contact adhesive which, in 1962, was an experimental material but is now being developed commercially. This new adhesive was based on a synthetic elastomer (not neoprene) in an organic solvent system. It required the addition of a separate curing agent at the time of use. Preliminary tests of small specimens of the same construction had indicated that this adhesive system withstood the six-cycle test of ASTM D 1037-60T[3] quite well, considerably better than did conventional neoprene contact cements. The entire adhesive bonding process was done in a commercial plant by Laboratory staff members and some members of the technical staff of the adhesive manufacturer.

Preparation of Panels

Each panel was prepared by spraying several coats of the contact adhesive on the framing member and also on the facing material (figs. 7 and 8). After a short open assembly time at room

[3]American Society for Testing and Materials. Tentative methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM Designation D 1037-60T. Philadelphia, 1961.

conditions to remove volatile solvents, the facing was assembled to the framing on one side and then run through a nip roll ontwopasses (through the roller and immediately back again). The panel was then turned and the adhesive applied similarly to the framing and the other facing material, and then after another short assembly time this facing assembly was run through the roller and back. Thus, one skin was bonded at a time.

PANEL EVALUATION

Panel Stiffness

Stiffness tests were made on the two 4- by 8-foot replacement panels (panels 5 and 6, table 1). A panel of a construction similar to each of the replacement panels was tested to establish both stiffness and strength values (panels 3 and 4, table 1). Table 1 also gives the stiffness of the half-width of the 4-foot original panels removed from the experimental prefabricated house.

Bending Strength

Bending strength tests were also made on one-half of the width of each of the 4-foot panels removed from the experimental house (panels 1 and 2, table 1). The half-width panels were 23 inches wide and approximately 8 feet in length and 3 inches thick. The other half width of the panel was used to evaluate the quality of the glue bonds in the plywood and between the plywood and the framing members.

The panels were evaluated under static bending in a mechanical testing machine over a span of 90 inches with a load applied at the quarter points. The rate at which the loading device descended was 0.04 inch per minute. Midspan deflections were measured to 0.01 inch with a steel scale mounted at the midspan relative to a taut wire fastened at points above the reactions. Deflections were read at 100-pound increments of load. Figure 9 shows a panel in the testing machine after failure. It also shows the standard method of testing the panel with the load applied at the quarter point of the span. By means of these deflections, the panel deflections under uniformly distributed load were computed and are given in column 8 of table 1.

Loads to Failure

The replacement panels were loaded only to the equivalent design load of 20 pounds per square foot. Panels of a construction similar to the replacement panels were also tested to failure. Equivalent uniformly distributed maximum loads were computed and are given in column 10 of table 1.

Original experiments conducted in 1937 indicated that panels of a construction similar to the ones removed from the one-story prefabricated house, when tested as a beam, required a load of more than 200 pounds per square foot to cause failure. A 60-mile-per-hour wind has a pressure of approximately 12 pounds per square foot, which would be about one-seventeenth of the load to break the panel.

Figure 9.--Final failure of half panel removed from northeast corner of the experimental prefabricated house. Failure consists of a tension failure of framing member and horizontal shear maximum load was 284 pounds per square foot. This is a standard method of testing wall panels with load applied at the quarter point of the span.

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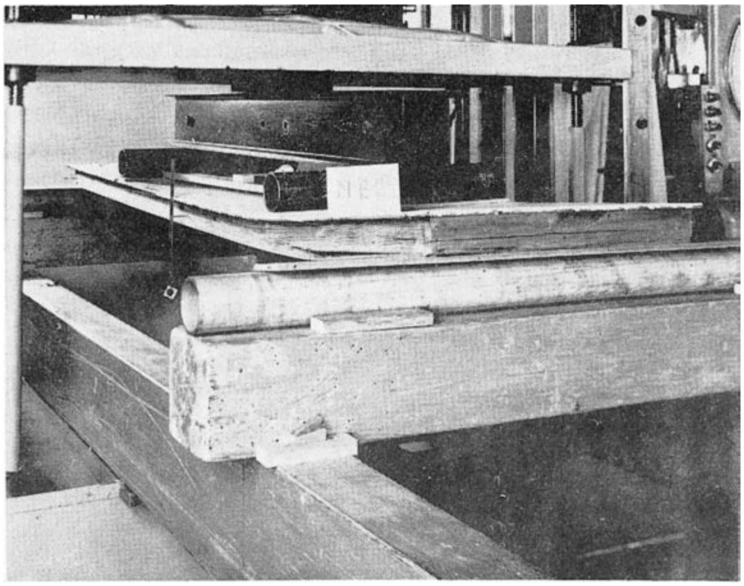

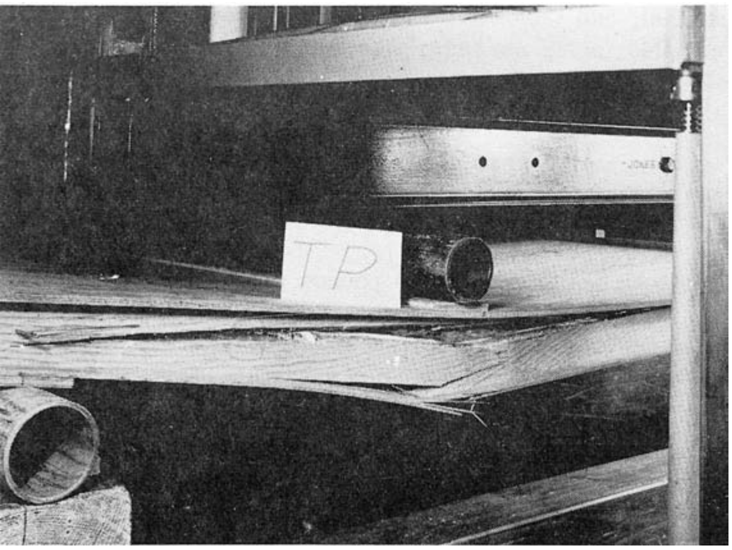

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Figure 10.--Final failure of prototype panel, similar in construction to replacement panel, using plywood facings. Failure consists of a tension failure in framing member and horizontal shearing of the framing member. Maximum load was 239 pounds per square foot.

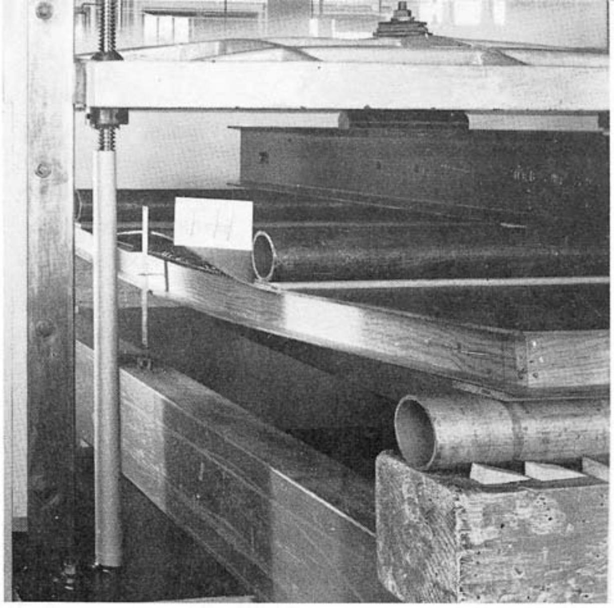

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Figure 11.--Final failure of prototype panel, similar to replacement panel, using hardboard facing. Failure consisted of buckling of compression facing. Maximum load was 247 pounds per square foot.

Results of the current evaluations show that span deflection ratios at design load, both for panels removed after 25 years of service and for recently fabricated panels, exceeded by several times the normal allowable design for walls. Failing load also exceeded design values by factors of more than 10.

Figures 9, 10, and 11 show the final failure of the 4- by 8-foot panels using the new contact adhesive.

GLUE-JOINT EVALUATION

The other half of each panel removed from the building was used for evaluations of glue-joint quality after 25 years of service. One set involved conventional plywood shear tests of specimens cut from several locations in the plywoodfrom the inner and outer facings of the north and south panels. The specimens were cut as described in ASTM D 805-52,[4] with no attention given to the orientation of lathe checks in the cores.

Groups of 20 specimens, one group for each of the inner and outer plywood facings of both the north and south walls, were tested in dry shear in approximate equilibrium at 80° F. and 65 percent relative humidity. Similarly, other groups of 20 specimens each were tested wet after the boil-cycle test normally used for exterior-type Douglas-fir plywood in Commercial Standard CS45-60.[5] The general details of cutting specimens from the house panels are shown in figure 12.

The quality of the casein-glued joints between the inner and outer plywood facings and the framing lumber was tested in dry shear tests

[4]American Society for Testing and Materials. Standard methods of testing veneer, plywood, and other glued constructions. ASTM Designation D 805-52. Philadelphia, 1961.

[5]U.S. Department of Commerce. Douglas fir plywood. Commercial Standard CS45-60. U.S. Government Printing Office. Washington, D.C., 1960. 20 pp., illus.

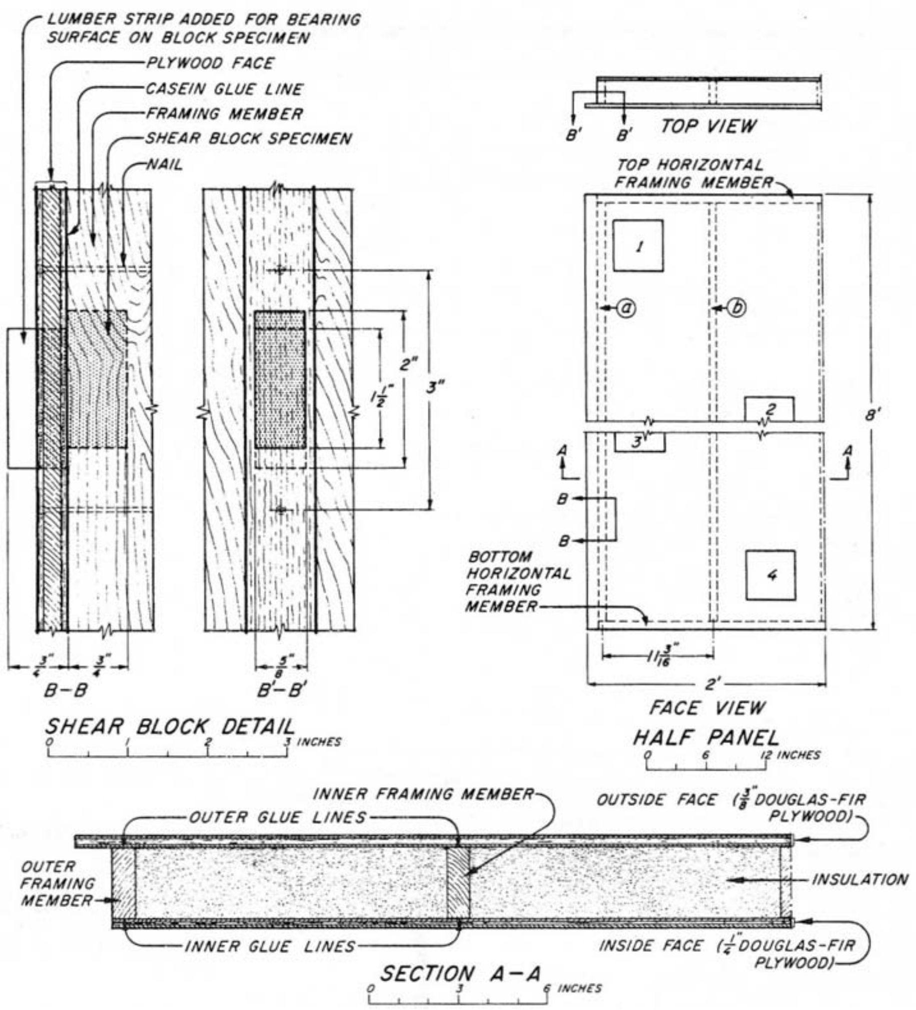

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Figure 12.--Construction details and sampling of the wall panel portion that was removed from the experimental house for evaluating the quality of the glue bonds. Numbers 1 to 4 indicate approximate locations of plywood samplings, and letters a and b indicate the framing members from which structural bond specimens were taken.

using a modification of the standard block-shear test described in ASTM D 805-52.[4] This was done by gluing strips of maple lumber to the faces of the plywood, after sanding off the remaining paint coating, so that the total thickness was 3/4 inch to the caseinglueline. Framing lumber was cut away to leave a 3/4-inch thickness on the other side of this glueline.

A room-temperature-setting urea-resin glue was used in this secondary gluing. Then shear specimens were cut to 5/8-inch widths, slightly less than the original thickness of the framing lumber. The length of the glueline in the specimen was the standard 1-1/2 inches with the usual 1/4-inch overlap at each end. These specimens were cut between the nails, up and down, for each of the two vertical members in each panel removed. The specimens were cut from both the inside and outside to check both casein gluelines. All specimens were conditioned to approximate equilibrium at 80° F. and 65 percent relative humidity and then tested in compression as in ASTM D805-52.[4]

The general details of cutting specimens from the house panels are shown in figure 12.

Results and Observations

The results of the plywood shear tests are given in table 2, and the plywood-to-framing joint data are given in table 3. Because no evaluations of joints were made on the original

Table 1.--Description of wall panels and their performance under uniformly distributed load

Panel No. and location[1]	Width of test panels	Facings: Compression	Facings: Tension	Framing members: Number	Framing members: Size	Overall depth	Deflection at 20 pounds per square foot uniformly distributed load on 96-inch span	Span deflection ratio	Maximum load[2]	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	In.				In.	In.	In.		P.s.f.	
1-NEC	24	3/8-inch plywood	1/4-inch plywood	3	3/4 x 2-3/8	3	0.101	950	284	Panel removed from FPL one-story prefabricated house October 29, 1962.
2-SEC	24	3/8-incb plywood	1/4-inch plywood	3	3/4 x 2-3/8	3	.110	870	281	Do.
3-TP	48	3/8-inch plywood	1/4-inch plywood	5	3/4 x 2-3/8	3	.142	680	239	Test panel similar to replacement panel.
4-TH	48	1/4-inch hardboard	1/4-inch hardboard	5	3/4 x 2-1/2	3.	.140	690	247	Do.
5-NECP	48	3/8-inch plywood	1/4-inch plywood	5	3/4 x 2-3/8	3	.141	690	.....	Panel set in one-story prefabricated house October 30, 1962.
6-SECH	48	1/4-inch hardboard	1/4-inch hardboard	5	3/4 x 2-1/2	3	.141	690	.....	Do.

[1]Location designations: NEC, northeast corner; SEC, southeast corner; TP, test panel (plywood); TH, test panel (hardboard); NECP, northeast corner (plywood); SECH, southeast corner (hardboard).
[2]The tabulated loads are unifrom load values equivalent to the applied quarter-point loads.

Table 2.--Average results of glue-joint shear tests on plywood in building panels after 25 years of service

Location of panel	Tested dry: Joint strength	Tested dry: Wood failure	Tested after boil cycle: Joint strength	Tested after boil cycle: Wood failure
	P.s.i.	Pct.	P.s.i.	Pct.
North wall, inside[1]	177	66	116	46
North wall, outside[2]	112	90	73	80
South wall, inside[1]	149	45	95	31
South wall, outside[2]	118	81	76	50
Averages,[3]				
Inside panels[1]	163	55	105	38
Outside panels[2]	115	85	74	65

[1]Interior of building (1/4-inch Douglas-fir plywood).
[2]Outside of building (3/8-inch Douglas-fir plywood).
[3]Averages of 40 specimens; all other values are averages for 20 specimens.

Table 3.--Average dry shear strength of glue joints between Douglas-fir plywood facings and framing lumber in building panels

Joint location[2]	North wall: Shear strength	North wall: Wood failure	South wall: Shear strength	South wall: Wood failure
	P.s.i.	Pct.	P.s.i.	Pct.
Inside	479	99	839	99
Outside	604	87	629	78

[1]Each value is the average of 20 specimens.
[2]Average results for joints between two vertical framing members and either the inside or outside plywood surface, as indicated.

panels when installed, no control test data are available for comparison. The present data are therefore of value primarily to indicate quality that can be expected in such joints after 25 years of exposure in a well designed and generally well maintained stressed-cover type structure.

The plywood shear strength test data indicated moderate strengths, but percentages of wood failure were somewhat variable and tended to be slightly below the levels now prescribed for exterior-type plywood in Commercial Standard CS45-60[5]. It should be recognized that at the time this plywood was made this standard did not exist and the present quality control program for exterior-type plywood by the American Plywood Association was not operating. Also, the minimum levels of wood failure in this exterior-type test have been increased substantially over the subsequent years to the present 80 percent level.

The shear strengths of the plywood were lower in the outside skins than in the inner wall facings. This difference in shear strength in the inner and outer skins might be due in part to the different thicknesses and quality of veneer in the plywood. Generally, percentages of wood failure were reasonably good, although not high by current standards. This could be due in part to inadequate or variable gluing conditions in making these early commercial panels. Thus, there is no real evidence of significant deterioration of the resin-bonded gluelines after 25 years of service, and present results are good indications of long-time serviceability of such glue joints.

The data on dry strengths of the casein-glued joints are very encouraging, since most of the failure was in the wood itself, particularly in the inside gluelines. This indicates little or no effect on the gluelines over the 25-year period. There was some evidence, on individual broken specimens, of erratic gluing conditions. It should be noted that the stressed-skin panels in this building were carefully designed with vapor barriers and tight construction to reduce moisture problems to a minimum. The building itself was generally well maintained during the 25-year period, and special attention was given to maintaining calking around the panels. This could account for the good performance of casein glues, which are known to be sensitive to high moisture conditions and to actual soaking, no evidence of which was noted in the panels removed. Since such protection cannot always be assumed in actual practice, casein glues are not currently recommended for such joints in stressed panels. The newer resorcinol-type resin glues are considered to be more suitable here.

CONCLUSIONS

Evaluations of the two panels removed from the one-story prefabricated house after 25 years of service indicate that the stressed-skin principle used in the construction of the panels and the method used in assembling the components are structurally sound. There was no visual evidence of any deterioration.

Gluelines in resin-bonded plywood panels in this structure have performed very satisfactorily over the 25-year period and show good indications of much longer service. The casein-glued joints between plywood facings and framing have also performed remarkably well and are still completely serviceable in these well designed and well maintained and protected building panels.

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:

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

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.

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