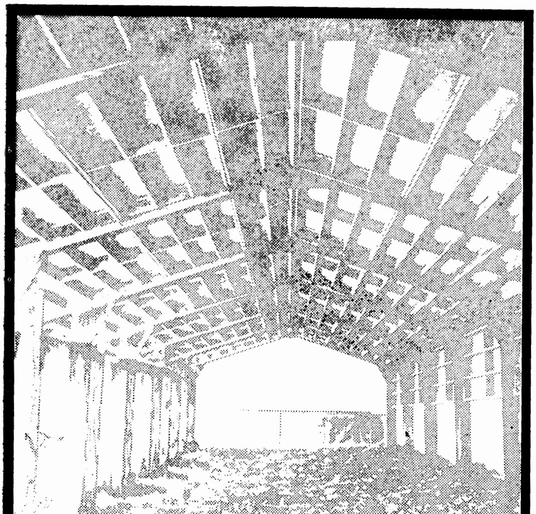
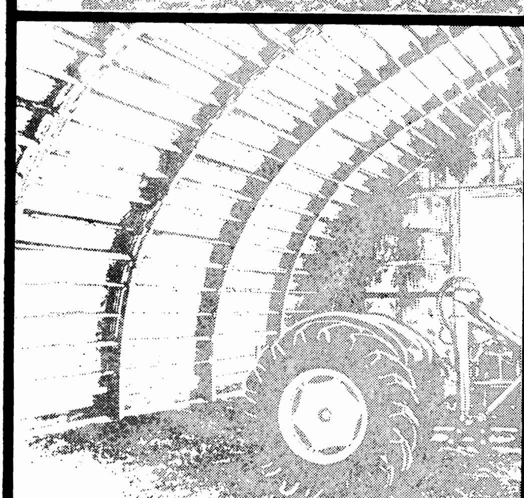
Bulletin B-615
September, 1963

Performance and Use of Single-Cover, Stressed-Skin Panels for Light Building Construction





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SCIENCE SERVING AGRICULTURE
1891
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CONTENTS

Performance and Use of Single-Cover Stressed-Skin Panels for Light Building Construction

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Studies were conducted at the Oklahoma Agricultural Experiment Station to evaluate structural performance and techniques for using selected single-cover stressed-skin panel designs in light building construction. Structural performance was evaluated with the use of prototype specimens. Construction techniques were tested and evaluated by trial erections of prototype structures at several locations on Oklahoma Agricultural Experiment Station farms in the Stillwater area, and on the Oklahoma State University Farm at Oklahoma City. This bulletin reports results of these studies.

Information derived from this research can be used by engineers and builders to design and erect single-cover stressed-skin panels for roofs on projects in which fabrication and erection costs are important factors.

Details on techniques, equipment, and analytical methods used in these experiments are presented in previous studies (Ref. 1, 2, and 3).

Description of Construction Methods

Stressed-skin panels are pre-assembled, panel-type structural units suitable for building roofs of shelters for agricultural and light industrial uses. A typical, single-cover stressed-skin panel construction project is illustrated in Figure 1. The basic parts are the cover or skin and the longitudinals to which the cover is bonded. Plywood is commonly used for the cover, but other sheet materials, such as asbestos-cement can be used. If both faces of the panel are covered, the panel is called a double-cover panel. Only single-cover panels were studied in this research.

Research reported herein was conducted under Oklahoma Station Project Number 633.

Many variations in panel configuration and design can be used. The panel design for a specific construction project should be prepared by a qualified engineer to take into account the loads to be carried by the panel, and other requirements.

A typical single-cover stressed-skin panel for roofs is 4 ft. wide. by 8 ft. long, but other sizes can be used. The cover may be ⅜ in. exterior type plywood or other weather-resistant, structural sheet material. Each panel usually has 3 or 4 longitudinals of 2 in. by 4 in., or 2 in. by 6 in., S4S lumber. Undressed 1 in. by 6 in. longitudinals can be used. The cover is glue-nailed to the longitudinals. The panels are supported at 8 ft. to 12 ft. intervals by trusses or rigid frames. If the fastening of the cover to the longitudinals is adequately reinforced at the panel ends, it can be supported by the projecting ends of the cover resting directly on the upper edge of the truss or other frame members. Note the panel being lowered into position in Figure 1.

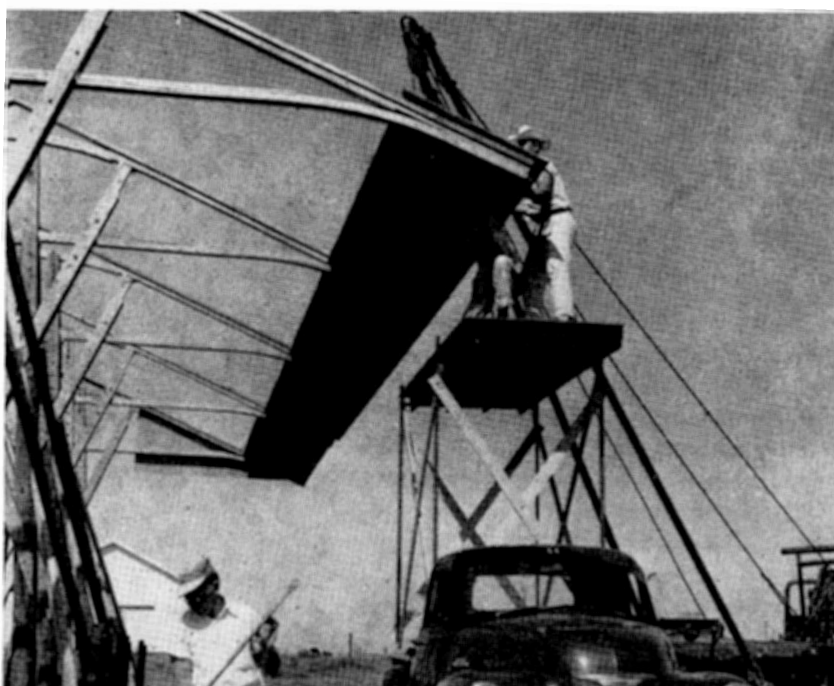

Figure 1. Erection of a 4 ft. by 12 ft. stressed-skin panel for a utility shelter roof. Panel is being lowered into position between main roof frames. Panel is supported by plywood lip at ends.

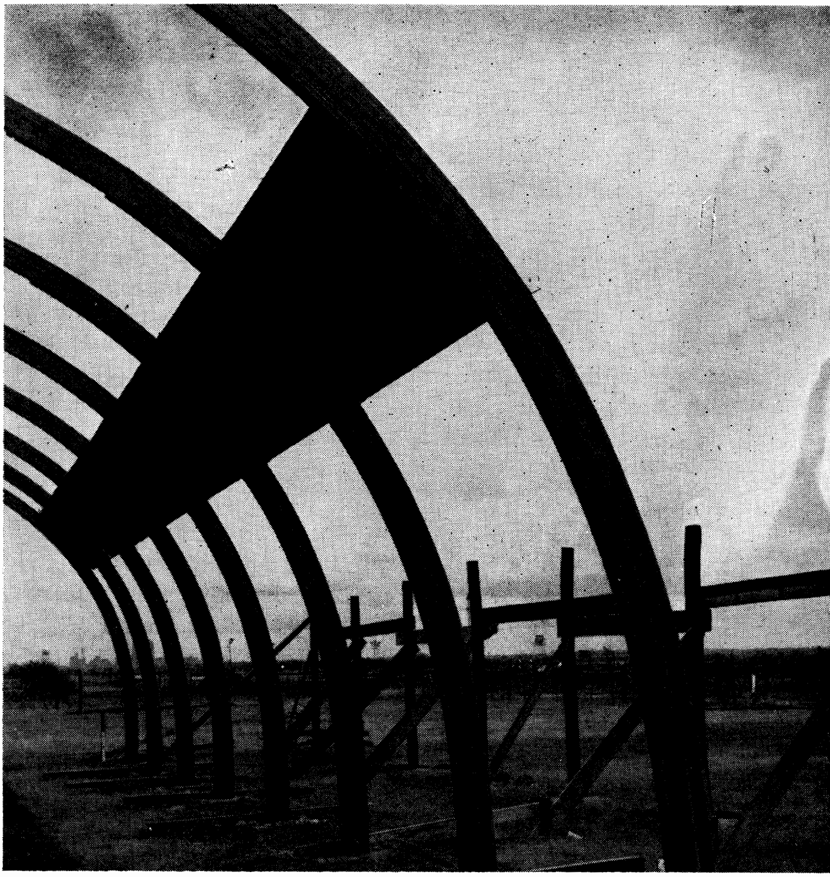

Figure 2. Self-indexing of stressed-skin panels with respect to main frame elements. Panel longitudinal ends fit between main frames.

Advantages of Stressed-Skin Panels

Stressed-skin panels can be pre-assembled in a shop, then rapidly installed in the roof. This helps to obtain fast roof construction and reduces weather hazards and delays. Stressed-skin panels can be self-indexing with respect to the main roof frame elements, thus eliminating some measuring and adjusting otherwise needed to position the panel on the roof. Figure 2 illustrates this self-indexing characteristic.

Stressed-skin panels are economical because they replace the usual purlins, deck, and roof covering used in conventional roof construction. If minor leaks are tolerable, such as in a livestock shelter, no other covering is needed to complete the roof, since the panel is the combined deck and cover.

The composite or Tee-beam action developed in stressed-skin panels produces greater strength and stiffness from construction materials, compared to conventional construction. This leads to savings in construction to carry specified loads.

Construction Requirements and Techniques

The basic requirement that must be fulfilled in a stressed-skin panel is bonding or fastening the cover securely to the longitudinals to form a composite structural unit which acts as a Tee-beam. The cover is structurally similar to the upper or flange part, and the longitudinals are similar to the stem or web of a Tee-beam. This Tee-beam action produces more strength and stiffness than is obtained in conventional roof construction. To develop fully this Tee-beam action and obtain maximum strength and stiffness, the cover must be glue-nailed or otherwise bonded to the longitudinals. When nails alone are used, slippage can occur between the cover and the longitudinals, reducing the strength and stiffness. If moisture from humidity in the building, or leakage through the cover possibly can penetrate to the glue line between the longitudinal and the cover, waterproof resorcinol-resin or other waterproof adhesive should be used.

Shop facilities are needed to precut the panel parts accurately to close dimensional tolerances and to assemble them in a jig.

Lifting equipment such as a truck mounted derrick is often needed to install the panels without creating extra hazard to workers. For buildings with low eaves and roofs with relatively flat slopes the panels can be manhandled into position.

Construction studies revealed that installing a first row of panels along each edge of the roof as illustrated in Figure 3 automatically registers the roof frame, such as trusses or rigid frames, with the panels. This eliminates some measuring and adjusting. These rows of panels also provide a platform on which workmen can stand while installing additional panels to complete the roof. After all of the panels have been installed and temporarily fastened in place, they can be nailed down permanently to the main roof frame.

Reinforced, contact-type tape and mastic systems have been used to seal the seam between the panel ends shown in Figure 4 where they meet over the truss or rigid frame. Experience with these indicates that

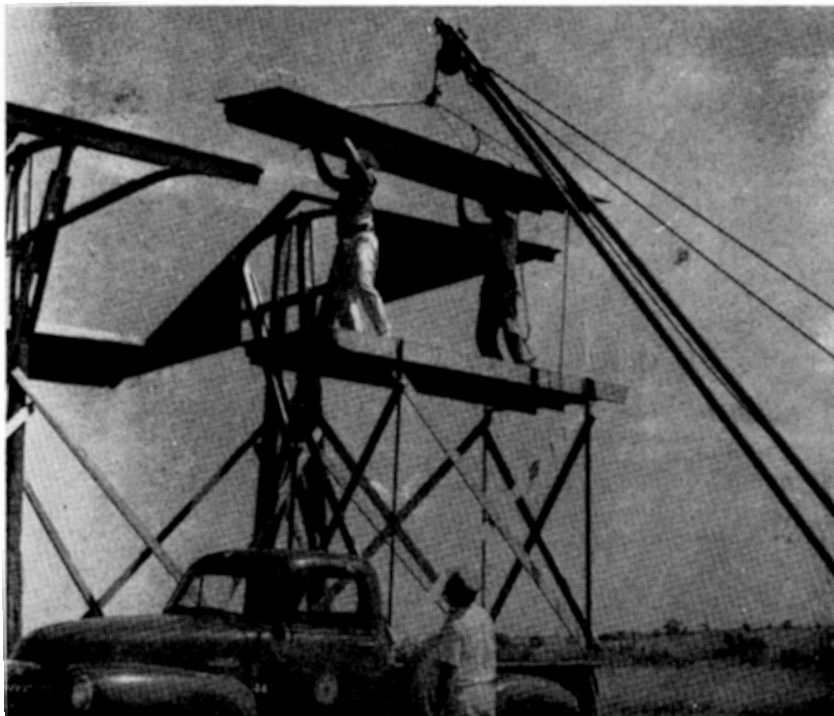

Figure 3. Automatic alignment of main roof frame by installing row of stressed-skin panels along each edge of roof.

they maintain watertight integrity for only two or three years. After two or three years of exposure, the tape and mastic systems begin to deteriorate and tear from weathering and dimensional changes in the roof caused by temperature and moisture variations. Regular maintenance is needed to preserve the watertight integrity of the tape and mastic systems. For additional protection, wooden or plywood batten strips can be installed over the seams.

The longitudinal joint between the long edges of adjoining panels can be made watertight on sloping roofs by lapping the edge of the upper panel 3 or 4 inches over the lower adjoining panel to produce a shingle effect as illustrated in Figure 4.

The longitudinal edge under the overlap can be supported by a 1 in. strip nailed to the longitudinal to form a slot to receive the edge. If a conventional roof cover is to be used over the panels, overlapping of the longitudinal joints is unnecessary.

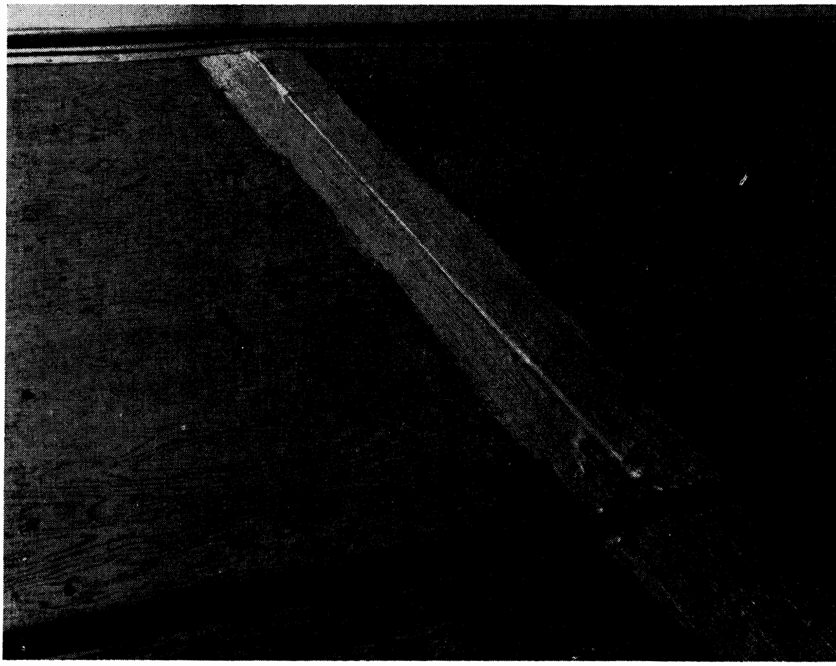

Figure 4. Joint treatment in exposed stressed-skin panel roof. Longitudinal joint formed by overlapping edge of upper panel on lower panel. End joint is sealed with a fabric tape and mastic system.

Construction Time Analyses

Single-covered stressed-skin roof panels have been used at the Oklahoma Agricultural Experiment Station for an umbrella-frame hay shelter, an arch-frame utility building, an umbrella-frame livestock shade, a large rigid-frame building for swine and a trussed roof utility building. Four of these structures are illustrated on Figures 5 through 8.

A summary of the time and labor requirements for construction and placement of the panels in four structures of different sizes and design is given in Table 1. The data in Table 1 do not take into account time needed for pre-cutting the longitudinals and other pieces needed. If undressed 1" x 6" 's are used for the longitudinals, the upper edge of each longitudinal which contacts the plywood cover should be dressed to help obtain a sound adhesive bond with the plywood. The pre-cutting and dressing operations are estimated to require approximately one man hour per 100 sq. ft. of panel surface.

Figure 5. Shelter building erected with 4 ft. by 12 ft. plywood stressed-skin panels on sandwich trusses. (A) Exterior appearance (B) Appearance under the roof.

An analysis of erection time for the roof framing and covering system used in the building illustrated in Figure 5 revealed that the complete roof, including the trusses and stressed-skin panels, could be erected for approximately 2½ man hours per 100 sq. ft., compared with approximately 5½ man hours per 100 sq. ft. for a roof of galvanized corrugated metal on purlins supported by trussed rafters 3 ft. on center; and approximately 8 man hours per 100 sq. ft. for asphalt shingles on a 1 in. by 6 in. solid roof deck on trussed rafters spaced at 20 inches.

Structural Performance Tests

Laboratory load-testing experiments were used to measure the stiffness and strength of various panel configurations. These tests were done with gravity loads or a special hydraulically-actuated test stand. Each panel type was replicated at least three and usually four times. Some of the tests were done with 1 ft. by 8 ft. test specimens consisting of a 1 ft. by 8 ft. sheet of ⅜ in. plywood bonded to one 2 in. by 4 in., S4S,

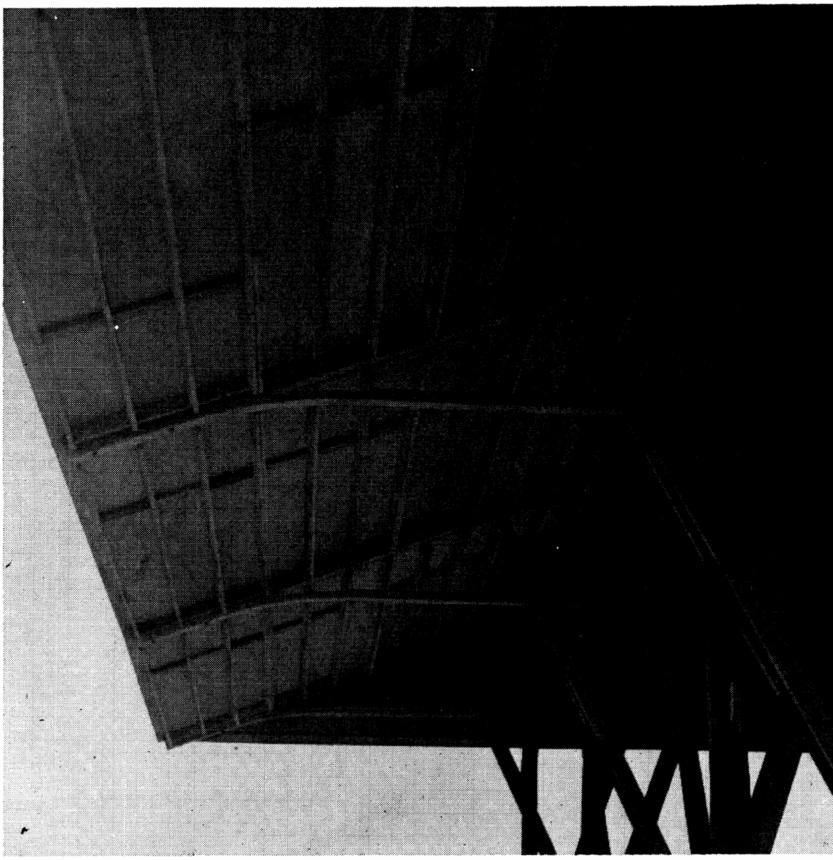

Figure 6. Hay storage erected with 4 ft. by 12 ft. plywood stressed-skin panels on glue-laminated umbrella-type frame supported by pole bipods.

longitudinal. Others were full size panels, either 4 ft. by 8 ft. or 4 ft. by 12 ft. with two or more longitudinals.

Gluing Versus Nailing—Experiments were conducted to evaluate panel bending stiffness as affected by method of attaching the cover to the longitudinals. The two methods tested were: (1) glue-nailing to obtain a continuous adhesive bond between the cover and the longitudinals, and (2) nailing alone, with a nailing pattern designed to resist horizontal shear between the cover and longitudinals without exceeding the allowable lateral load on the nails. The experiments were done with 4 ft. by 12 ft. single-cover stressed-skin panels consisting of ⅜ inch plywood on either four 2 in. by 4 in. or four 1 in. by 6 in. longitudinals. The results

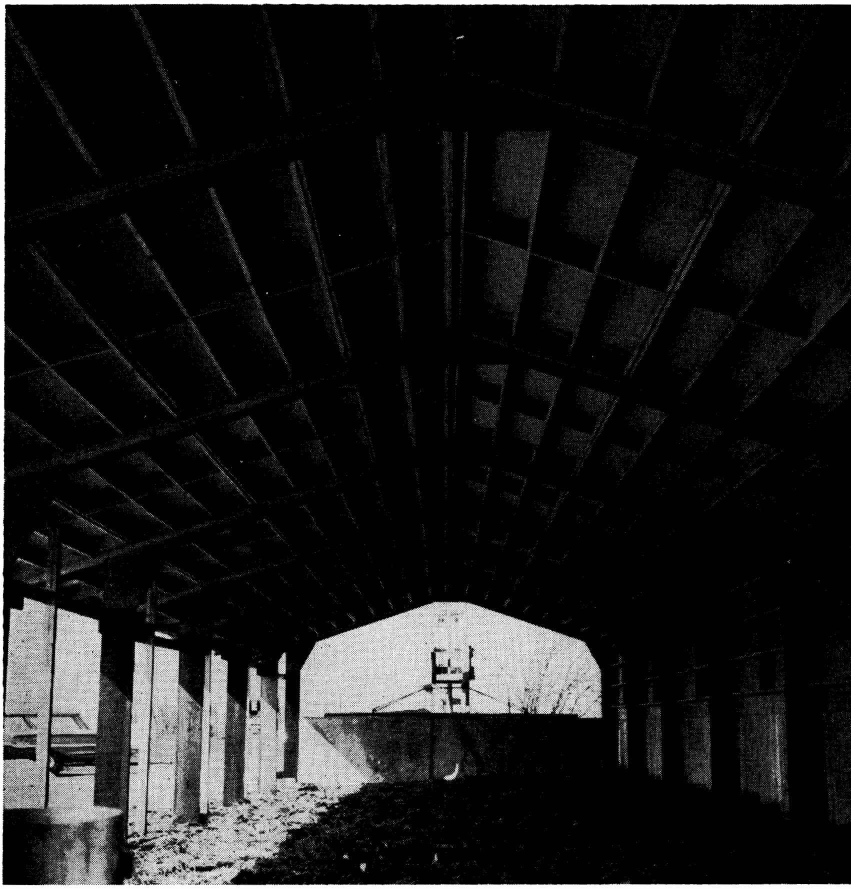

Figure 7. Swine rearing building erected with 4 ft. by 12 ft. asbestos cement stressed-skin panels on hingeless rigid frames.

revealed that glue-nailing significantly increased the stiffness of the panel compared to only nailing the cover to the longitudinals. The ratio of the stiffness of the glue-nailed compared with the nailed panels ranged from 1.25 to 1.34 with an average ratio of 1.28.

Longitudinal Spacing—Experiments on longitudinal spacing were conducted with 4 ft. by 8 ft. panels consisting of 3/8 in. plywood glue-nailed to 2 in. by 4 in. S4S longitudinals, and with longitudinal spacings in the test panels of 8 inches, 12 inches, 16 inches, and 24 inches. The results revealed that no reduction in stiffness due to transverse buckling of the cover occurred with the wider compared to the 8 inch longitudinal spacings. The ratio of actual stiffness as measured experimentally to the

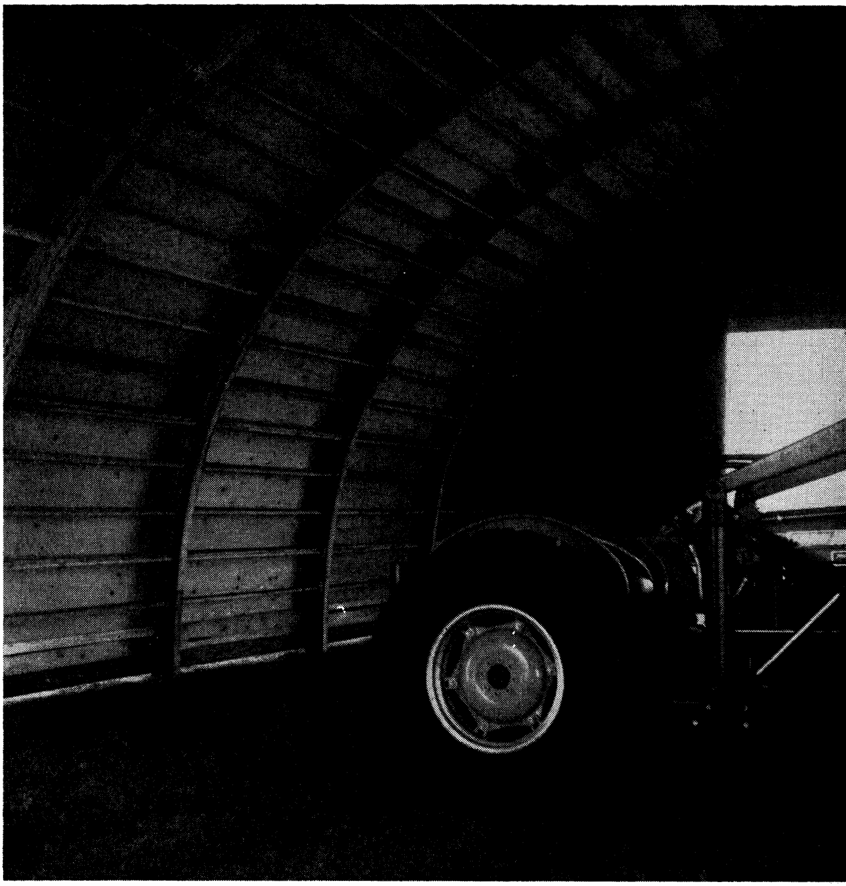

Figure 8. Utility and storage building erected with 4 ft. by 8 ft. plywood stressed-skin panels on glue-laminated arches.

stiffness, calculated on the basis of the hypothesis that no buckling of the skin occurred between the longitudinals, was not significantly affected by longitudinal spacing.

The experiments were done with concentrated, transverse line loads at the third points. Design loads are normally distributed loads. These produce transverse bending in the plywood, as well as longitudinal bending of the panel. The panel cover should be adequate to resist transverse bending between the longitudinals without excessive deflection. For wide longitudinal spacings, this may require a cover heavier than needed only to develop the necessary panel cross-section moment of inertia to resist longitudinal bending.

Bowing—When applying stressed-skin panels to a curved or arched shape main frame, the panels are bowed in a transverse direction as shown in Figure 8. For certain panel configurations, the theoretical stiffness of a panel is increased by as much as one-third when bowed to curvatures possible in light building construction, compared to a flat panel. An experimental load testing program with flat panels and panels bowed to three different radii of curvature indicated that some increase in stiffness was obtained but not as much as would be expected according to theoretical calculations. The maximum increase in stiffness obtained experimentally was approximately 10 percent.

Longitudinal Size—Theoretically, a stressed-skin panel with a ⅜ in. cover bonded to 1 in. by 6 in. (actual size) longitudinals 12 in. o.c. has a cross-section moment of inertia 2.67 times greater than for the same panel configuration but with 2 in. by 4 in. (S4S) longitudinals. Experimental results revealed that the stiffness of panels made with 1 in. by 6 in. (full size or undressed) longitudinals 12 in. o.c. was 2.49 times the stiffness of panels made with 2 in. by 4 in. longitudinals. The amount of lumber for the longitudinals in a panel made with 1 by 6's is only three-fourths of that required for panels made with 2 by 4's, based on nominal sizes. The thinner and deeper longitudinals performed satisfactorily because the top edge of each longitudinal is bonded to the skin. This helps to prevent lateral buckling of the thin longitudinals.

Theoretical and Actual Stiffness—Analysis of the test data revealed that the measured stiffness of stressed-skin panels agreed well with the stiffness predicted by theoretical calculations which neglected perpendicular plies in the plywood and used an assumed modulus of elasticity of the plywood and the longitudinals of 1.76×10^6 psi. The measured cross-section moment of inertia based on deflection data from loading tests on test specimens consisting of ⅜ in. plywood, 1 ft. by 8 ft. sheet size, glue-nailed to one 2 in. by 4 in., S4S, Select Structural Douglas Fir longitudinal was 12.76 inches^4. The calculated moment of inertia, assuming the full width of the plywood was effective, was 12.81 inches^4. The difference between the theoretical and calculated moment of inertia was less than ½ of 1 percent.

Strength—Maximum bending stress in single-skin panels of usual configurations will occur in the lower edge of the longitudinals. Tests of 1 ft. by 8 ft. stressed skin panels consisting of ⅜ in. plywood glue-nailed to 2 in. by 4 in. longitudinals gave failure loads in bending that corresponded to a calculated stress of 9,062 psi. in the lower edge or lower extreme fibers of the Select Structural Douglas Fir longitudinals. This stress was calculated by the ordinary flexure formula applied to the ultimate loads obtained in the experiments.

The panel strength measured experimentally corresponded to a ratio of ultimate load to design load of approximately 15½. This ratio is sometimes thought of as a safety factor. This safety factor is based on a reduced failure load adjusted to take into account long-term loading, and a design live load of 20 pounds per sq. ft., uniformly distributed. Failure always occurred first in the longitudinals. The longitudinals in stressed-skin panels will usually be stressed to a higher stress than the cover because the neutral axis of the cross-section is further from the bottom than from the top of the panel.

Panel End Modification—Structural loading tests were conducted to evaluate effects on strength and stiffness of several modifications of the detail for supporting panel ends on the main framing elements. A modified panel end was needed to support the panel on the main roof frame, as shown in Figure 2. This permits the panels to "nest" between, or automatically register with, the main roof frame members so the panel-roof frame system is self-aligning for fast erection.

The test results revealed that a stressed-skin panel of 4 ft. by 8 ft. by ⅜ in. plywood, glue-nailed to four, 2 in. by 4 in., S4S, longitudinals can safely support a superimposed, uniformly-distributed load of 20 pounds per sq. ft. when carried only on the two projecting end lips of ⅜ in. plywood. This arrangement is shown in Figure 1. To resist the stresses at the end tending to peel the plywood away from the longitudinals, the end must be reinforced. End reinforcement consisting of two, 10-penny, screw-shank nails driven diagonally through the plywood and into each end of the 2 by 4 longitudinals, with a 1⅛ in. square, 20-gage galvanized steel washer under each nail head, safely resisted the peeling stresses. The safety factor for peeling stress failure with this end reinforcement detail was approximately 6¼ for a uniformly distributed roof load of 20 pounds per sq. ft., a span of 8 ft., and longitudinal spacing of 12 inches. Greater strength can be achieved by adding stiffener strips to support the cover between the longitudinal ends. These strips are visible in Figure 5B where the panel meets the truss. These stiffener strips have the added avantage of preventing the panels from slipping off from the roof frame when the panels are being installed.

No significant loss in overall panel stiffness occurred due to supporting the panel on the end lip instead of on the lower edge of the longitudinals.

Summary

Construction engineering and structural load testing experiments were conducted to develop and evaluate designs for single-cover stressed-skin roof panels for light construction such as in agricultural and industrial buildings.

Observations and findings drawn from this study are summarized as follows:

1. Advantages of using single-cover stressed-skin roof panels, compared to conventional construction are: Greater economy and efficiency in use of structural materials; rapid completion of the shelter roof; and self-indexing to automatically position and align the panels with respect to the main roof frame.

2. Use of stressed-skin panels in light building construction requires adequate shop facilities for carefully controlled cutting and assembly of the panel parts, and power lifting equipment for placement of the panels in the roof.

3. The skin or cover of the panel must be glue-nailed to the longitudinals; otherwise stiffness is sacrificed. The ratio of stiffness of stressed-skin panels with the cover glue-nailed to the longitudinals compared to the stiffness of panels with the cover fastened only with a well-designed nailing pattern was 1.28.

4. Minor leakage through the joint where the ends of the panels meet on the supporting frame can be expected if the panels are installed with the cover exposed to the weather. This leakage can be controlled but not entirely eliminated by sealing the seam with a reinforced tape and mastic system. Improved materials and techniques of application are needed to develop a joint sealing system that has complete and prolonged watertight integrity.

5. Construction engineering studies revealed that a roof for a one-story frame building including trusses spaced 12 ft. apart and stressed-skin panels, 4 ft. by 12 ft., could be erected for approximately 2½ man hours per 100 sq. ft. of roof area. This is substantially less than the erection time for roofs of corrugated metal on purlins supported by trussed rafters.

6. Panels with longitudinal spacings up to 24 in. experienced no significant reduction in stiffness due to buckling of the cover between the longitudinals.

7. A maximum of 10 percent increase in panel stiffness was obtained by bowing the panel in a transverse direction, such as would occur with the panels applied to a curved main roof frame. The increase in stiffness was less than predicted from theoretical considerations.

8. Stressed-skin panels with ⅜ in. plywood covers and 1 in. by 6 in. full-sized or undressed longitudinals having an average spacing of 12 in. produced a panel approximately 2½ times as stiff as a panel made with 2 in. by 4 in., S4S longitudinals, at the same spacing.

9. The stiffness modulus, EI, determined by load-testing experiments agreed closely with stiffness computed for a modulus of elasticity of 1.76×10^6 psi of the Douglas Fir plywood cover and the longitudinals. Calculation of the cross-section moment of inertia was done by conventional analysis ignoring plys in the cover whose grain was perpendicular to the plane of longitudinal bending.

10. Because the lower extreme fibers in the longitudinals are stressed more highly than the extreme fibers in the plywood cover, lumber of high structural quality should be used for the longitudinals to obtain maximum panel strength and efficiency. The ultimate strength of the panel is usually limited by the maximum stress in the longitudinals instead of the cover.

11. To simplify installing stressed-skin panels, the ends can be supported on the main roof frame elements by only the projecting lips of the plywood cover at the panel ends. To prevent peeling of the cover away from the longitudinals when the end reaction is transmitted into the lip, the attachment of the cover to the panel ends must be reinforced. Reinforcement consisting of two, 10-penny screw shank nails driven diagonally through the plywood and into each end of the 2 by 4 longitudinals, with a 1⅛ in. square, 20-gage galvanized steel washer under each nail, resisted peeling effect with a safety factor of approximately 6¼ for a uniformly distributed roof load of 20 pounds per sq. ft. on an 8 ft. long panel with longitudinal spacings of 12 inches.

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Table I

Man-hours for assembly and installation of stressed-skin panels for roof construction.

No.	Building	Panel	Time Required, Man-Hours			
			Assembly	Installation	Total	
			(per panel)	(per panel)	(per panel)	(per sq. ft.)
1	28 ft. by 60 ft. baled hay storage, eaves height 14 ft. to 17 ft. Truck-mounted power hoist used to lift panels to roof-top. (Figures 1, 3, and 6)	4 ft. by 12 ft., wtih 3/8 in., exterior-type plywood on 4—1 in. by 6 in. undressed longitudinals.	1.3	1.2	2.5	0.052
2	30 ft. by 60 ft. arch-shaped utility and storage building. Panels manhandled into position by two men, starting at ground. (Figure 8)	4 ft. by 8 ft., with 3/8 in. exterior-type plywood on 4—1 in. by 6 in. undressed longitudinals.	0.8	0.5	1.3	0.041
3	14 ft. by 24 ft. livestock shade. Front end loader on tractor used to lift and p'ace panels.	4 ft. by 8 ft., with 3/16 in. asbestos cement on 4—2 in. by 4 in. S4S longitudinals. Cover reinforced by 5—1 in. by 4 in. S4S transverse stiffeners.	1.7	0.5	2.2	0.069
4	30 ft. by 72 ft. machinery shelter, eaves height approximately 10 ft. Light wagon used as working platform. Panels were manhandled onto wagon, then up to roof. (Figures 5A and 5B)	4 ft. by 12 ft., with 3/8 in. exterior-type, plywood on 4—1 in. by 6 in. undressed longitudinals.	1.6	0.6	2.2	0.046

MATERIALS AND FACILITIES used in the studies reported in this publication were supplied by the following organizations and agencies:

Douglas Fir Plywood Association
Oklahoma Lumbermen's Association
Johns-Manville Products Corporation
OSU Farm at Oklahoma City, Bill Lott, manager
Dairy Department, OSU
Poultry Science Department, OSU
Animal Husbandry Department, OSU