STUDIES OF ROOF PANELIZATION

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Donald H. Percival

Research Report 58-2

SMALL HOMES COUNCIL
UNIVERSITY OF ILLINOIS
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The physical testing program was carried out by Donald H. Percival, Wood Technologist; Research Assistant in Forestry, Small Homes Council.

Preliminary cost studies were made by John I. Zerbe, formerly Research Assistant Professor in Forestry, Small Homes Council.

This publication was reviewed by a research committee of the Small Homes Council composed of Professor Frank M. Lescher, Professor William H. Kapple, and the authors.
ABSTRACT

A number of roofing systems for a four foot long section of a typical 24 foot span house were examined and compared to truss construction as is generally used at the present time.

The present system of roof truss construction remains the least costly when a clear span flat ceiling is desired.

Stress skin panels offer some possibility for flat roofs, or for those cases in which a sloping ceiling is desired.

The need for the development of a combined roofing-sheathing material capable of carrying loads for spans of 4 to 8 feet is stated.

The need for a ceiling material capable of spanning distances greater than 2 feet is stated.
I. PURPOSE OF THE INVESTIGATION

Expressed in broad terms, the purpose of the investigation was to examine a number of different possible roof structure systems with the intent of determining if there were possibilities of lower roof costs through better mass production or by other means.

II. METHOD OF INVESTIGATION

The method of investigation was

1) to establish the costs and characteristics of certain well known present day systems, as a base for comparison with other systems;

2) design other systems and compare them to the base design.
III. GENERAL CONSIDERATIONS

In examining roof structures for possible changes in design and methods which might result in reduction of costs, a number of related items must be considered in order to arrive at a valid answer. These items include

1. Structural soundness
2. Resistance to environment
3. Coordination of roof system with other parts of house
4. Fabrication problems
5. Distribution problems
6. Erection problems
7. Cost
8. Consumer acceptance

STRUCTURAL SOUNDNESS

In general the systems examined herein are designed to resist dead loads plus a live load of 20 pounds of snow per square foot of horizontal projection. When snow load is considered, the allowable stresses on timber are adjusted in accordance with the provisions of section 5 of Working Stresses for Stress-grade Lumber (1956) as published by the National Lumber Manufacturers Association.

Since the roof slopes considered are relatively low, wind is not considered. In any case, the permissible allowable stress increase under wind loads would probably result in smaller sections.

RESISTANCE TO ENVIRONMENT

The adaptability of the system to insulation and moisture control is considered. Also problems of weather proofing are discussed where pertinent.
COORDINATION OF ROOF SYSTEMS WITH OTHER PARTS OF HOUSE

Many systems which have advantages in certain respects may be less acceptable when considered in relation to other parts of the house. A particular example is the type of ceiling that the roof system makes possible. A system which produces a flat, uninterrupted ceiling without interior supporting walls, has the distinct advantage of allowing all interior partitions to be of one height, and to be of identical non-load-bearing construction.

Systems with flat ceilings and a single central load-bearing partition are second choice in this respect.

Systems resulting in a sloping ceiling create problems in the fabrication of interior partitions as these are of variable height. This results in more labor costs in layout, fabrication and erection of the partitions, as well as more material wastage. It is difficult to assess the exact cost of these items, but it is obvious that there is a cost differential. It is probably less important in larger projects where the layout and scheduling costs may be spread over a larger number of houses.

FABRICATION PROBLEMS

Roof systems that may be assembled by nailing offer no problem to the small producer. Nail-gluing procedures require a shop and storage space with controlled temperature, but with little other special equipment. Where gluing is to be done under pressure without nailing, large presses or other means of pressure application will be required. The employment of such equipment is usually beyond the scope of operations of the small individual manufacturer supplying only a local market. As any roof system
developed by this project would presumably be primarily used by individual lumber dealers, systems requiring excessive expenditures for machinery were ruled out.

DISTRIBUTION PROBLEMS
The space required for storage of manufactured elements as well as the space and equipment required for transportation of the elements to the construction site are considered.

ERECTION PROBLEMS
Without a series of field studies of actual erection procedures, it is impossible to present an accurate picture of the relative merits of different roof systems; nevertheless, a rational consideration is given to these problems.

COST
Material costs of different roof systems can be estimated reasonably accurately, but a precise estimate of labor costs requires information from a series of actual operations.

In this study costs are based only on the roof and ceiling component of the house, and have not been related to span, perimeter wall costs, etc., except that all designs are based on a 24 foot house dimension
which was shown to be an economical span in a preliminary study of present roof trusses and conventional flat roof framing*.

CONSUMER ACCEPTANCE

Consumer acceptance varies widely with time and with location. Only opinions can be offered in this connection. It is interesting to note, however, that manufacturers of stress skin panels have abandoned them due to the non-acceptability of the joints between the plywood panels on the ceiling.

*-The study actually showed the roof structure of a 28 foot span to be approximately $2.00 cheaper than a 24 foot span, but 24 feet was selected as being more representative.
IV. BASE DESIGN

The nail-glued clear span roof truss of 2/12 spaced at 2'-0" centers with plywood sheathing, asphalt shingles, and gypsum board ceiling, has been shown to be the lowest cost roof structure. The 4/12 slope truss is equally inexpensive at a span of 28 feet (the most economical span for a 1500 sq. ft. house), and only slightly more expensive ($1.00 per square foot of floor area) at a 24 foot span.

Since 24 feet is a more common truss span, and 4/12 a common slope, a roof of these characteristics was chosen as a base for the comparisons to be made. The base roof system was designed for 25 pound live load and a 15 pound dead load. A 4 foot section was chosen as a typical bay, and the overhang of the eave was determined by using 16 foot members in the top chord.

ESTIMATED COST OF BASE DESIGN (4/12 TRUSS)

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear span</td>
<td>24'-0&quot;</td>
</tr>
<tr>
<td>Overhang, approximately</td>
<td>3'-0&quot;</td>
</tr>
<tr>
<td>Slope</td>
<td>4/12</td>
</tr>
<tr>
<td>Width of section</td>
<td>4'-0&quot;</td>
</tr>
<tr>
<td>2 Trusses</td>
<td></td>
</tr>
<tr>
<td>material</td>
<td>2 @ 10.64 = 21.28</td>
</tr>
<tr>
<td>labor</td>
<td>2/3 hr @ 3.00 x 2 = 4.00</td>
</tr>
</tbody>
</table>

$25.28
Sheathing

128 sq. ft. 3/8" C-D plywood @ .131 = 16.77

1.28 lbs. of nails @ .13 = .17

128/100 x .75 hrs. carp. @ 3.00 = 2.88

128/100 x .225 hrs. labor @ 1.75 = .51

(Brought forward) $25.28

Roofing

128 sq. ft. shingles @ .765 = 9.80

128 sq. ft. 15-lb. felt @ .0093 = 1.19

128/100 x 1.25 lb. nails @ .20 = .32

128/100 x 1.5 hrs. labor = 5.76

8-ft metal edge @ 10 = .80

17.87

Ceiling

96 sq. ft. 1/2 gypsum board @ .1642 = 15.76

Insulation

96 sq. ft. @ .08 = 7.68

$86.92
ESTIMATED COST OF BASIC DESIGN (FLAT ROOF)

Span of interior = 24'-0"
Slope = flat
Width of section = 4'-0"

Joists
4 Roof Joists 2 x 8 x 16'-0" = 85.3 bm @ .145 = $12.37
Labor 1/6 hr. @ 3.00 = .50 $12.87

Sheathing
128 sq. ft. 1/2" C-D plywood @ .18 = 23.04
1.28 lbs. nails @ .13 = .17
128/100 x .75 hrs. carp. @ 3.00 = 2.88
128/100 x .225 hrs labor @ 1.75 = .51 26.60

Roofing
128 sq. ft. built-up roof @ .2290 = 29.31
8 ft. metal edge @ .15 = 1.20 30.51

Ceiling
96 sq. ft. 1/2" gypsum board @ 20.02 19.22

Insulation
96 sq. ft. @ .08 7.68 $96.88
V. SANDWICH ROOF PANEL

Assume a gable structure 24 feet wide spanned by two 4' x 16' sandwich panels resting on the outside walls and a structural ridge. The panel is composed of two 3/8 inch plywood skins glued to a 3-5/8 inch polystyrene foam core. The edges of the panel are protected by 1 x 4 lumber.

For purposes of simplicity in analysis, the skins will be assumed to have the dimensions of sanded 3/8" plywood although in actuality the upper skin will be unsanded material.

STRUCTURAL EVALUATION

Calculation of Moment of Inertia of Panel

\[
I_0 \text{ of plywood for 12 inch width } = 0.0461 \text{ in.}^4
\]

\[
I_0 \text{ for 2 skins 48 inches wide } = 0.3688 \text{ in.}^4
\]

Area of 1 skin = \(4 \times 2.25 = 9\) sq. in.

Distance from center of skin to neutral axis = 2 ins.

Ad\(^2\) for two skins = \(2(9 \times 2^2) = 72.00\)

Moment of Inertia \(= I = \frac{29063 \times 2.1875}{72.73} = 875 \text{ psi.}\)

which is satisfactory.
**Rolling Shear**

Shearing stresses are negligible in the plywood. It is assumed the foam is sufficiently strong to resist the shearing action.

**Deflection**

Allowable deflection \(1/240 \times 12.5 \times 12 = .625 \text{ ins.}\)

Maximum deflection \[
\frac{5 \times Wl^3}{384 \times E1} \]

\[
\frac{5 \times 1550 \times (12.5)^3 \times 1728}{384 \times 1600000 \times 72.73} = .59 \text{ ins.}
\]

satisfactory

**ESTIMATE OF COST**

128 sq. ft. 3/8" C-D plywood sheathing @ .13 = $16.64
128 sq. ft. 3/8" A-D plywood sheathing @ .21 = $26.88
128 sq. ft. x 2/3 lb. foamed polystyrene @ .40 = $34.20
256 sq. ft. of glue line @ .03 = $7.68
80 lf. 1 x 4 edge 27 bd. ft. @ .14 = $3.78
128 sq. ft. of asphalt shingles, 15 lb. felt, nails, labor, and 8 ft. of metal edge = $17.87

Estimated labor of fabrication and erection = $107.05

TOTAL COST = $113.05

This cost is considerably higher than the truss construction standard.

**COMMENTS**

These panels require a press for manufacture unless self-adhering polyurethane foam is used at approximately double the cost of polystyrene foam. The requirement for a press of this size will prohibit the small manufacturer from making this panel.

Central ridge support is required and the structure has a sloping ceiling.

The panel is reasonably light in weight (approximately 200 lbs.) but would be difficult to handle in the wind. Some type of spline connection between adjacent panels will be required.
The same panel may be adapted to flat roof construction.

In those areas where a plywood ceiling is unacceptable, a lower grade plywood may be used on the inside surface over which a second surface may be applied.

Thermal characteristics compare to those of truss construction. In effect, the foam core establishes its own vapor barrier.

**EVALUATION**

This system is not competitive to truss construction under present day prices. It is more nearly competitive to conventional flat roof construction.

**VI. STRESSED SKIN ROOF PANEL**

Assume a panel of dimensions similar to the sandwich panel with two 3/8 plywood skins and four 2 x 4 rafters per panel.

**STRUCTURAL EVALUATION**

**Calculation of Moment of Inertia**

Moment of inertia of skins as before \( 72.37 \text{ in.}^4 \)

Moment of inertia of four 1 x 4 = \( 12.40 \)

Moment of inertia of panel = \( I = 84.77 \text{ in.}^4 \)

**Rolling Shear**

Allowable rolling shear stress in plywood = 68 psi. x .75 = 51 psi.

Dead load = 12 psf.
Live Load = 25 psf.
Total load = 37 psf.

Maximum Shear = \( V = \frac{35 \times 4 \times 12.65}{2} = 886 \text{ lbs.} \)

Area for static moment = \( 48 \times 3/32 = 4.5 \text{ sq. in.} \)

Arm for moment = 2.14 ins.

Static moment of area above shear plane = \( Q = 9.63 \)

Shearing stress = \( \frac{VQ}{Ib} = \frac{886 \times 9.63}{84.77 \times 3} = 33.6 \text{ psi.} \)

Shearing stress is satisfactory
Horizontal Shear

Area for additional static moment = 1.812 \times 3 = 5.436 \text{ sq. in.} \\
Arm for moment = .906 \\
Additional static moment = 4.92 \\
Total static moment = 4.92 + 9.63 = 14.55 \\
Shearing stress = \frac{VQ}{Ib} \frac{886 \times 14.55}{84.77 \times 3} = 51 \text{ psi.} \\
Shearing stress is satisfactory.

Fiber Stress

Basic allowable fiber stress = 1875 \text{ psi.} \\
Actual spacing \frac{14.25}{14.25} = 1 \gtrsim .50 \\
use 67\% of basic stress \\
allowable stress = .67 \times 1875 = 1250 \text{ psi.} \\
Total load = W = 35 \times 12.5 \times 4 = 1750 \text{ lbs.} \\
Maximum moment = \frac{WL}{8} = \frac{1750 \times 12.5 \times 12}{8} = 33,600 \text{ in. lbs.} \\
Fiber stress = \frac{Mc}{l} = \frac{33,600 \times 2.1875}{84.77} = 846 \text{ psi.} \\
Fiber stress is satisfactory.

ESTIMATE OF COST

128 \text{ sq. ft.} 3/8 \text{ inch C-D plywood sheathing @ .13 = } $16.64 \\
128 \text{ sq. ft.} 3/8 \text{ inch A-D plywood sheathing @ .21 = } 26.88 \\
8 \text{ pcs.} 1 \times 4 \times 16'-'0"') \\
4 \text{ pcs.} 1 \times 4 \times 4'-'0"') = 51 \text{ bm. @ .14} \\
104 \text{ sq. ft.} of mineral wool insulation @ .06 = 8.32 \\
Glue \\
128 \text{ sq. ft. of roofing, etc.} \\
Estimated labor of fabrication and erection \\
\hline \\
128.85 \\
6.00 \\
\hline \\
85.85

COMMENTS

Essentially the same comments made on the sandwich panel are applicable here excepting that costs are very close to standard truss construction. However the disadvantage of the sloping ceiling must not be overlooked.

By using 2 x 4 ribs in place of 1 x 4 members, the nail-gluing technique could be used for assembly in lieu of the press method. Labor costs would probably be higher, and great care would be required in fastening the ceiling plywood to the panel.

EVALUATION

If actual time studies of fabrication and erection processes verify the assumed costs, the panel has merit for certain uses, particularly for flat roofs or for houses.
VII. FOLDED PLATE ROOF STRUCTURES

A folded plate roof structure is a type of gable construction in which horizontal ties between the eave lines may be partially or completely eliminated. In order to make this possible, the sheathing is designed as a diaphragm to resist the lateral thrust of the roof. (If open side walls are desired, the plate can also be designed to resist vertical loads.)

Since the sheathing functions as a diaphragm, it is important that the roof be well nailed so as to act as a unit. The usual recommendation is that the plywood sheathing be applied horizontally with staggered joints so that maximum continuity occurs. (Nailing must be approximately doubled if joints are not staggered.) The requirement makes it more difficult to devise a panelization system that would be effective in developing this system.

The most spectacular application of the folded plate roof is the single folded plate roofing the entire house. In this application the roof appears the same from outside as a gable roof, but the interior of the house is distinguished by freedom of horizontal ties at the eave height and the absence of beams supporting the ridge.

STRUCTURAL EVALUATION

Assume a structure 48 feet long with a single horizontal tie at the center and with cross section dimensions equivalent to those previously specified. Following the procedures recommended by the Douglas Fir Plywood Association in their release of September 16, 1957, the critical stresses may be checked as follows:

Plywood Thickness

Effective length of diaphragm = $L = 24$ ft.
Half-width of building = $B = 12$ ft.
Rise of roof = $H = 4$ ft.
Uniform load on horizontal projection of roof = $W = 40$ psf.
Maximum shear = \( \frac{WBL}{4H} = \frac{40 \times 12 \times 24}{4 \times 4} = 720 \text{ lbs./ft.} \)

Assume C-D sheathing at 180 psi. allowable shearing stress

Thickness required = \( t = \frac{720}{12(180)} = .33 \text{ ins.} \) 

Use 3/8" plywood

Nail Spacing

Using 8d common nails with an allowable shear carrying value of 100 lbs. per nail, the required nail spacing is:

\( \frac{100 \times (12)}{720} = 1.5 \text{ inches} \)

If the plywood is staggered, this value may be increased 50% to 2-1/4 inches.

This spacing is required on the edge of all panels at critical points, but may be reduced to 6 inches at the center of the span of the diaphragm. Nails are spaced 6 inches on center on intermediate supports. All plywood edges must be blocked.

Rafters

Use 2 x 8 rafters spaced 24 inches on center.

Eave and Ridge Beams

Eave force = \( \frac{WBL^2}{16H} = \frac{40 \times 12 \times 24 \times 24}{16 \times 4} = 4320 \text{ lbs.} \)

Ridge force = 2 x 4320 lbs. = 8640 lbs.

A continuous 2 x 8 is satisfactory.
ESTIMATE OF COST

Framing (Use standard grade)

Material

4 - 2 x 8 x 16' rafters = 85.3 bm.
3 - 2 x 8 x 4' ridge and eave beams = 16 bm.
12 - 2 x 4 x 4' blocking = 32 bm.

133.3 bm. @ $1.35  $18.00

Labor  1 hr. @ 3.00  3.00  21.00

Sheathing

128 sq. ft.  20.33

Roofing

128 sq. ft.  17.87

Ceiling

104 sq. ft. @ .2002 = 20.80

Insulation

104 sq. ft. @ .08 = 8.32

$ 88.32

COMMENTS

The use of the plywood sheathing in the horizontal position makes field
application necessary and eliminates any possibilities of panelization.

Additional studies on the use of vertical applied sheathing in diaphragms might
make a panelization system feasible.

Normal erection procedure for the single folded plate roof would involve
the temporary support of the central ridge of the plate until such time as
the sheathing is fully nailed so as to insure diaphragm action of the roof
surface. With this procedure the erection difficulties would appear to be
considerable.
A series of smaller folded plates may be used to span the structure in the 24 foot dimension, but these plates would be of such dimension as to require handling by crane. Also the waterproofing of the valleys resulting from the system would be a serious problem.

**VIII. TRUSSES SPACED AT 4'-0"

One possible solution to panelization of roof systems is the use of trusses spaced more widely with panelized roof sheathing and ceiling construction. The difficulty herein lies in finding suitable low-cost panels for spanning the distance between trusses.

A panel system was developed for sheathing this truss system. (see Appendix A). Several designs were proposed and tested. All of these designs were predicated on the idea of a stiffened panel which could be dropped between or over the trusses without requiring fastening other than through the plywood. A nail-glued panel with 2 x 4 stiffeners and designed to be placed across the trusses proved most satisfactory.

No panel system was devised for the ceiling.

The truss designed for 4 foot spacing was based on a modified Howe design using 2 x 6 chord members and 2 x 4 struts and diagonals. Gusset plates were made of 1/2" C-D plywood sheathing, interior type.

**STRUCTURAL EVALUATION**

The system was found to be satisfactory by test. (See Appendix A).
ESTIMATE OF COST

Truss

2 top chords 2 x 6 x 16' = 32.0 bm.
1 bottom chord 2 x 6 x 14' ) = 26.0 bm.
1 bottom chord 2 x 6 x 12' )
1 center strut 2 x 4 x 4' )
2 struts 2 x 4 x 2' )
2 diagonals 2 x 4 x 6' )

= 71.3 bm. @ $ .145 = $10.34

1/2 plywood gussets 44 sq. ft. @ $ .18 = 7.92
Glue
Nails 2 lbs. @ .13 = .26
Labor 1 hour = 3.00

$23.02

Sheathing

Plywood 128 sq. ft. (includes labor) = 20.33
Blocking 17 pcs. 2 x 4 x 4' = 45.3 bm. @ .135 = 6.12
Glue

.75

27.20

Roofing

128 sq. ft.

17.87

Ceiling

Gypsum bd. 96 sq. ft. @ $ .1642 = 15.76
Blocking 13 pcs. 2 x 4 x 4' = 34.67 bm. @ .135 = 4.68
Labor 1/2 hour @ $3.00 = 1.50
Nails 1 lb. @ .13 = .13

22.07

Insulation

96 sq. ft. @ .08 = 7.68

97.84
COMMENTS

This system is more costly in both labor and materials than the basic truss system. Some gain would be made in the amount of space required for the storage and moving of trusses, but a corresponding loss would occur in the storage of the sheathing panels.

Material costs for a single truss of this design were greater than for two trusses of conventional design. As the truss was designed for a longer span and flatter slope (2/12), it is possible that the amount of material in the truss could be reduced for the 24 foot span with a slope of 4 in 12.

The greatest advantage of the large truss might be found when trusses are spaced at 8 feet. In this case the 2 x 4 blocking would be structurally utilized more fully, and truss costs should be considerably lower than those of other truss systems.

Since the ceiling drywall finish is fastened to blocking between the trusses as well as the trusses themselves, gypsum board may be placed parallel to the trusses. This will result in the reduction of end joints in many cases.

EVALUATION

This system, designed for trusses at 4 foot centers, is less economical than conventional truss systems and, therefore, offers no advantages.
IX. CONCLUSIONS AND RECOMMENDATIONS

Nail-glued trusses spaced 2 feet on center with plywood sheathing and gypsum board ceiling remains the lowest cost method of building a sloping roof with a flat ceiling.

Conventional framing with 2 x 3 joists at 2 foot centers and plywood sheathing and gypsum board ceiling is the lowest cost flat roof framing, although the stress skin panel with built-up roofing approaches the cost of conventional construction very closely.

For structures with sloping ceilings supported at the ridge and walls, the stress skin panel is the least costly.

Wider spacing of trusses may result in economies once some roof sheathing and ceiling finish cheaper than plywood and gypsum board are found.

Further investigation should be undertaken in order to develop a combination roofing and sheathing material capable of sustaining loads for spans of from four to eight feet.

Similarly, a ceiling material (possibly combining acoustical treatment and insulation) should be developed for the spans greater than two feet.
APPENDIX
PANEL TESTS

A number of different stiffened panels designed to span between trusses 4'-0" on center were tested. Tests were performed for uniform load and for impact loading.

Uniform Loading

A live load of 25 pounds per square foot, representing snow, and a dead load of 8 pounds per square foot representing roofing were applied in increments and released after each increment. Deflections under loads and residual deflection after each load increment were recorded. Overloads were not applied.

Uniform Loading - Acceptable Performance

Under live load, maximum deflection shall not exceed 1/180 of the span for panel without finish below. Since the panels are to span 4'-0", the maximum deflection allowable is .267 inches.

Impact Loading

10-inch diameter sand bag weighing 60 pounds dropped on upper surface at weakest point of element. As the joint between the plywood and the stiffening ribs was the most critical point, the sand bag was dropped over these ribs.

Impact Loading - Acceptable Performance

(a) Under 1-1/2 foot drop - no residual deflection

(b) Under 3 foot drop

25% maximum residual deflection and no break in covering.
PANEL TYPE 1

Description of Panel: 3/8" x 4' x 8' C-D interior type plywood sheathing (nailed with 8d common nails)

5 - 2 x 4 x 4'-0" cross ribs

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins. Dials</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
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<tr>
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<td>26.4</td>
<td>Failure--Nails Pulled Through Plywood</td>
<td>Unacceptable</td>
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<td>Failure--Nails Pulled Through Plywood</td>
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</tr>
<tr>
<td>33.0</td>
<td>Failure--Nails Pulled Through Plywood</td>
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</tr>
<tr>
<td></td>
<td>Load of 22.2 psf caused failure of nail pull out</td>
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</table>

Performance, Impact Loading:

<table>
<thead>
<tr>
<th>Height 1-1/2'</th>
<th>Deflection 1-3/4&quot;</th>
<th>Residual Deflection 1/4&quot;</th>
<th>Unacceptable 4 nails pulled through the plywood.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3'</td>
<td></td>
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<td>2 nails were pulled from the rib.</td>
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</table>
### Description of Panel:

1/2" x 4' x 8' C-D interior type plywood sheathing
(nailed with 8d common nails)

5 - 2 x 4 x 4'-0" cross ribs

### Performance, Uniform Loading:

<table>
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<th>Load in psf</th>
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<tr>
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### Performance, Impact Loading

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<th>Deflection</th>
<th>Residual Deflection</th>
<th>Nails pulled out of center rib</th>
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<tbody>
<tr>
<td>1-1/2'</td>
<td>1-1/8&quot;</td>
<td>3/8&quot;</td>
<td>unacceptable</td>
</tr>
<tr>
<td>3'</td>
<td>not performed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Description of Panel: 1/2" x 4' x 8' C-D interior type plywood sheathing (nailed with 2" ring shank nails)

5 - 2 x 4 x 4'-0" cross ribs

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dials</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
</tr>
<tr>
<td>6.6</td>
<td>.026</td>
</tr>
<tr>
<td>13.2</td>
<td>.045</td>
</tr>
<tr>
<td>19.8</td>
<td>.063</td>
</tr>
<tr>
<td>26.4</td>
<td>.093</td>
</tr>
<tr>
<td>33.0</td>
<td>.200</td>
</tr>
<tr>
<td>0.0</td>
<td>.017</td>
</tr>
</tbody>
</table>

Performance, Impact Loading:

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection</th>
<th>Residual Deflection</th>
<th>Nail pulled out at one end of center rib</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2&quot;</td>
<td>11/16&quot;</td>
<td>1/16&quot;</td>
<td>unacceptable</td>
</tr>
<tr>
<td>3'</td>
<td>5/16&quot;</td>
<td>1/4&quot;</td>
<td>Several additional nails pulled out</td>
</tr>
</tbody>
</table>

Acceptable: < 0.100

Unacceptable: > 0.100
PANEL TYPE 4

Description of Panel: 3/8" x 4' x 8' C-D interior type plywood sheathing
(nail-glued with 4d common nails)
5 – 2 x 4 x 4'-0" cross ribs

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dials</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
</tr>
<tr>
<td>6.6</td>
<td>.030</td>
</tr>
<tr>
<td>13.2</td>
<td>.055</td>
</tr>
<tr>
<td>0.0</td>
<td>.013</td>
</tr>
<tr>
<td>19.8</td>
<td>.194</td>
</tr>
<tr>
<td>0.0</td>
<td>.019</td>
</tr>
<tr>
<td>26.4</td>
<td>.213</td>
</tr>
<tr>
<td>33.0</td>
<td>.220</td>
</tr>
<tr>
<td>0.0</td>
<td>.019</td>
</tr>
</tbody>
</table>

Performance, Impact Loading:

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection</th>
<th>Residual Deflection</th>
<th>Nails pulled loose at one end</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2'</td>
<td>11/16&quot;</td>
<td>1/8&quot;</td>
<td>unacceptable</td>
</tr>
<tr>
<td>3'</td>
<td>1-1/2&quot;</td>
<td>3/8&quot;</td>
<td></td>
</tr>
</tbody>
</table>
PANEL TYPE 5

Description of Panel: 1/2" x 4' x 8' C-D interior type plywood sheathing (nailed with 4d common nails at 3" o.c.)
5 - 2 x 4 x 4'-0" cross ribs nail-glued

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dials</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
</tr>
<tr>
<td>6.6</td>
<td>.013</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
</tr>
<tr>
<td>13.2</td>
<td>.042</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
</tr>
<tr>
<td>19.8</td>
<td>.064</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
</tr>
<tr>
<td>26.4</td>
<td>.080</td>
</tr>
<tr>
<td>0.0</td>
<td>.110</td>
</tr>
<tr>
<td>33.0</td>
<td>.004</td>
</tr>
</tbody>
</table>

Performance, Impact Loading

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection</th>
<th>Residual Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2'</td>
<td>15/32&quot;</td>
<td>1/32&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Several nails pulled loose. unacceptable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wood failure of ribs at glue joint. No glue failure.</td>
</tr>
<tr>
<td>3'</td>
<td>1-7/8&quot;</td>
<td>1/2&quot;</td>
</tr>
</tbody>
</table>

Recommendation: Nail-glue using 2" ring shank nails for greater clamping pressure.
PANEL TYPE 6

Description of Panel: 1/2" x 4' x 8' C-D interior type plywood sheathing (nail-glued with 2" ring shank nails)

1 - 2 x 2 longitudinal rib on each edge (see drawing page A-8)

1 - 2 x 4 longitudinal flat rib at center

Performances, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Dials</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>6.6</td>
<td>.007</td>
<td>.012</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>13.2</td>
<td>.030</td>
<td>.027</td>
</tr>
<tr>
<td>0.0</td>
<td>.002</td>
<td>.000</td>
</tr>
<tr>
<td>19.8</td>
<td>.037</td>
<td>.040</td>
</tr>
<tr>
<td>0.0</td>
<td>.001</td>
<td>.000</td>
</tr>
<tr>
<td>26.4</td>
<td>.053</td>
<td>.057</td>
</tr>
<tr>
<td>0.0</td>
<td>.001</td>
<td>.000</td>
</tr>
<tr>
<td>33.0</td>
<td>.073</td>
<td>.081</td>
</tr>
<tr>
<td>0.0</td>
<td>.055</td>
<td>.004</td>
</tr>
</tbody>
</table>

Performance, Impact Load

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection</th>
<th>Residual Deflection</th>
<th>No glue failure or wood failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2&quot;</td>
<td>5/16&quot;</td>
<td>0</td>
<td>acceptable</td>
</tr>
<tr>
<td>3'</td>
<td>13/16&quot;</td>
<td>0</td>
<td>acceptable</td>
</tr>
</tbody>
</table>
PANEL TYPE 7
(Layout of Panel Type 6 similar)

Panel as tested

Panel as installed on truss
PANEL TYPE 7

Description of Panels: 3/8" x 4' x 8' C-D interior type plywood sheathing (nail-glued with 4d common nails)

1 - 2 x 2 longitudinal rib on each edge (see drawing page A-8)

1 - 2 x 4 longitudinal rib at center

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dials</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
</tr>
<tr>
<td>6.6</td>
<td>.064</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
</tr>
<tr>
<td>13.2</td>
<td>.091</td>
</tr>
<tr>
<td>0.0</td>
<td>.005</td>
</tr>
<tr>
<td>19.3</td>
<td>.104</td>
</tr>
<tr>
<td>0.0</td>
<td>.008</td>
</tr>
<tr>
<td>26.4</td>
<td>.115</td>
</tr>
<tr>
<td>0.0</td>
<td>.016</td>
</tr>
<tr>
<td>33.0</td>
<td>.120</td>
</tr>
<tr>
<td>0.0</td>
<td>.020</td>
</tr>
<tr>
<td>39.6</td>
<td>.169</td>
</tr>
<tr>
<td>0.0</td>
<td>.022</td>
</tr>
</tbody>
</table>

Performance, Impact Loading:

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection</th>
<th>Residual Deflection</th>
<th>Glue joint did not fail. (Larger glue area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2'</td>
<td>3/4&quot;</td>
<td>1/16&quot;</td>
<td>acceptable</td>
</tr>
<tr>
<td>3'</td>
<td>1-7/8&quot;</td>
<td>1/8&quot;</td>
<td>Recommend setting up trusses with panels in place. (Load for test)</td>
</tr>
</tbody>
</table>

acceptable
TRUSS TEST

Three trusses were set up and sheathed with ribbed panels of type 7. Tests were made for uniform loading.

Uniform Loading

Trusses were tested for a design load of 25 pounds per square foot snow load and 15 pounds per square foot dead load. Loads of 20, 30, 40, and 100 pounds per square foot were applied, deflection measured, loads removed and residual deflection measured on the center truss of the three trusses. Loading was applied so as to simulate loading conditions when a series of trusses are loaded simultaneously. (The load of 100 pounds per square foot is in excess of the overload designated by the HHFA performance standards which is specified as 1-1/4 dead load plus 2-1/4 live load, or in this case 75 pounds per sq. ft.)

Uniform Loading, acceptable performance

Under live load, maximum deflection not to exceed L/360 for plaster ceilings: 0.98 ins.

or L/240 for drywall ceilings: 1.40 ins.

Under overload - Sustain the load

Maximum residual deflection: 25%
TRUSS TYPE 1

Description of Truss

Type: Modified Howe.
Span: 28'-8" outside to outside.
Spacing: 4'-0" on center.
Material

Chords: 2 x 6 "standard" grade Douglas fir.
Struts and ties: 2" x 4" standard grade Douglas fir and hemlock.

(Moisture content of lumber: 22%)

Gusset plates: 1/2" C-D unsanded plywood, interior type.

Roof Sheathing

3/8" sheathing (interior type) plywood panels with 2 x 4 nail-glued flat to panels as stiffeners.

Condition of Trusses Immediately Before Testing:

1) Noticeable warpage, checking and splitting due to shrinkage and loss in moisture content.
2) Excess glue squeeze at gussets had dissolved and softened from excessive moisture under the tarpaulin.
3) Nail-popping had occurred in a large percentage of the gusset plates (some could be pulled with claw hammers).
4) Dimensional changes in the chord from shrinkage.

Performance

<table>
<thead>
<tr>
<th>No. of Blocks</th>
<th>Load</th>
<th>Load (psf)</th>
<th>Deflection (in.)</th>
<th>Residual Deflection (in.)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>1565</td>
<td>20</td>
<td>0.187</td>
<td>0</td>
<td>Center Truss</td>
</tr>
<tr>
<td>110</td>
<td>4780</td>
<td>30</td>
<td>0.344</td>
<td>0</td>
<td>Data Loading</td>
</tr>
<tr>
<td>192</td>
<td>8350</td>
<td>40</td>
<td>0.875</td>
<td>0.187</td>
<td>Applied to Compensate for Support</td>
</tr>
<tr>
<td>432</td>
<td>18,787</td>
<td>100</td>
<td>1.440</td>
<td>0.218</td>
<td>Derived From Adjoining Trusses</td>
</tr>
</tbody>
</table>
Illustrations
(on following page)

Left to Right, Top to Bottom

1. Trusses, 4 feet on center, 28 foot span
2. Placing stiffened panels as roof sheathing
3. View of trusses partially sheathed
4. Trusses sheathed and covered with 15 lb. felt
5. Load test
6. Load test
STUDIES OF ROOF PANELIZATION

Rudard A. Jones

Donald H. Percival

Research Report 58-2

SMALL HOMES COUNCIL
UNIVERSITY OF ILLINOIS
This study is the report of an investigation made by the Small Homes Council under a research grant given to the University of Illinois by the Lumber Dealers Research Council.

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Price: $1.50.
ACKNOWLEDGMENTS

The arrangements for this research contract were made by Professor James T. Lendrum, Director of the Small Homes Council prior to October 12, 1957. Studies were completed under the direction of Professor Rudard A. Jones, Director, Small Homes Council; Research Professor of Architecture.

The physical testing program was carried out by Donald H. Percival, Wood Technologist; Research Assistant in Forestry, Small Homes Council.

Preliminary cost studies were made by John I. Zerbe, formerly Research Assistant Professor in Forestry, Small Homes Council.

This publication was reviewed by a research committee of the Small Homes Council composed of Professor Frank M. Lescher, Professor William H. Kapple, and the authors.
ABSTRACT

A number of roofing systems for a four foot long section of a typical 24 foot span house were examined and compared to truss construction as is generally used at the present time.

The present system of roof truss construction remains the least costly when a clear span flat ceiling is desired.

Stress skin panels offer some possibility for flat roofs, or for those cases in which a sloping ceiling is desired.

The need for the development of a combined roofing-sheathing material capable of carrying loads for spans of 4 to 8 feet is stated.

The need for a ceiling material capable of spanning distances greater than 2 feet is stated.
I. PURPOSE OF THE INVESTIGATION

Expressed in broad terms, the purpose of the investigation was to examine a number of different possible roof structure systems with the intent of determining if there were possibilities of lower roof costs through better mass production or by other means.

II. METHOD OF INVESTIGATION

The method of investigation was

1) to establish the costs and characteristics of certain well known present day systems, as a base for comparison with other systems;

2) design other systems and compare them to the base design.
III. GENERAL CONSIDERATIONS

In examining roof structures for possible changes in design and methods which might result in reduction of costs, a number of related items must be considered in order to arrive at a valid answer. These items include

1. Structural soundness
2. Resistance to environment
3. Coordination of roof system with other parts of house
4. Fabrication problems
5. Distribution problems
6. Erection problems
7. Cost
8. Consumer acceptance

STRUCTURAL SOUNDNESS

In general the systems examined herein are designed to resist dead loads plus a live load of 20 pounds of snow per square foot of horizontal projection. When snow load is considered, the allowable stresses on timber are adjusted in accordance with the provisions of section 5 of Working Stresses for Stress-grade Lumber (1956) as published by the National Lumber Manufacturers Association.

Since the roof slopes considered are relatively low, wind is not considered. In any case, the permissible allowable stress increase under wind loads would probably result in smaller sections.

RESISTANCE TO ENVIRONMENT

The adaptability of the system to insulation and moisture control is considered. Also problems of weather proofing are discussed where pertinent.
COORDINATION OF ROOF SYSTEMS WITH OTHER PARTS OF HOUSE

Many systems which have advantages in certain respects may be less acceptable when considered in relation to other parts of the house. A particular example is the type of ceiling that the roof system makes possible. A system which produces a flat, uninterrupted ceiling without interior supporting walls, has the distinct advantage of allowing all interior partitions to be of one height, and to be of identical non-load-bearing construction.

Systems with flat ceilings and a single central load-bearing partition are second choice in this respect.

Systems resulting in a sloping ceiling create problems in the fabrication of interior partitions as these are of variable height. This results in more labor costs in layout, fabrication and erection of the partitions, as well as more material wastage. It is difficult to assess the exact cost of these items, but it is obvious that there is a cost differential. It is probably less important in larger projects where the layout and scheduling costs may be spread over a larger number of houses.

FABRICATION PROBLEMS

Roof systems that may be assembled by nailing offer no problem to the small producer. Nail-gluing procedures require a shop and storage space with controlled temperature, but with little other special equipment. Where gluing is to be done under pressure without nailing, large presses or other means of pressure application will be required. The employment of such equipment is usually beyond the scope of operations of the small individual manufacturer supplying only a local market. As any roof system
developed by this project would presumably be primarily used by individual lumber dealers, systems requiring excessive expenditures for machinery were ruled out.

DISTRIBUTION PROBLEMS
The space required for storage of manufactured elements as well as the space and equipment required for transportation of the elements to the construction site are considered.

ERECTION PROBLEMS
Without a series of field studies of actual erection procedures, it is impossible to present an accurate picture of the relative merits of different roof systems; nevertheless, a rational consideration is given to these problems.

COST
Material costs of different roof systems can be estimated reasonably accurately, but a precise estimate of labor costs requires information from a series of actual operations.

In this study costs are based only on the roof and ceiling component of the house, and have not been related to span, perimeter wall costs, etc., except that all designs are based on a 24 foot house dimension
which was shown to be an economical span in a preliminary study of present roof trusses and conventional flat roof framing*.

CONSUMER ACCEPTANCE

Consumer acceptance varies widely with time and with location. Only opinions can be offered in this connection. It is interesting to note, however, that manufacturers of stress skin panels have abandoned them due to the non-acceptability of the joints between the plywood panels on the ceiling.

*The study actually showed the roof structure of a 28 foot span to be approximately $2.00 cheaper than a 24 foot span, but 24 feet was selected as being more representative.
IV. BASE DESIGN

The nail-glued clear span roof truss of 2/12 spaced at 2'-0" centers with plywood sheathing, asphalt shingles, and gypsum board ceiling, has been shown to be the lowest cost roof structure. The 4/12 slope truss is equally inexpensive at a span of 28 feet (the most economical span for a 1500 sq. ft. house), and only slightly more expensive ($1.00 per square foot of floor area) at a 24 foot span.

Since 24 feet is a more common truss span, and 4/12 a common slope, a roof of these characteristics was chosen as a base for the comparisons to be made. The base roof system was designed for 25 pound live load and a 15 pound dead load. A 4 foot section was chosen as a typical bay, and the overhang of the eave was determined by using 16 foot members in the top chord.

ESTIMATED COST OF BASE DESIGN (4/12 TRUSS)

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear span</td>
<td>24'-0&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhang, approximately</td>
<td>3'-0&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td>4/12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width of section</td>
<td>4'-0&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Trusses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>material</td>
<td>2 @ 10.64</td>
<td></td>
<td>21.28</td>
</tr>
<tr>
<td>labor</td>
<td>2/3 hr @ 3.00 x 2</td>
<td></td>
<td>4.00</td>
</tr>
</tbody>
</table>

$25.28
Sheathing

128 sq. ft. 3/8" C-D plywood @ .131 = 16.77
1.28 lbs. of nails @ .13 = .17
128/100 x .75 hrs. carp. @ 3.00 = 2.88
128/100 x .225 hrs. labor @ 1.75 = .51

(Brought forward) $25.28

Roofing

128 sq. ft. shingles @ .765 = 9.80
128 sq. ft. 15-lb. felt @ .0093 = 1.19
128/100 x 1.25 lb. nails @ .20 = .32
128/100 x 1.5 hrs. labor = 5.75
8-ft metal edge @ 10 = .80

17.87

Ceiling

96 sq. ft. 1/2 gypsum board @ .1642 = 15.76

Insulation

96 sq. ft. @ .08 = 7.68

$86.92
ESTIMATED COST OF BASIC DESIGN (FLAT ROOF)

Span of interior = 24'-0"
Slope = flat
Width of section = 4'-0"

Joists
4 Roof Joists 2 x 8 x 16'-0" = 85.3 bm @ .145 = $12.37
Labor 1/6 hr. @ 3.00 = .50

Sheathing
128 sq. ft. 1/2" C-D plywood @ .18 = 23.04
1.28 lbs. nails @ .13 = .17
128/100 x,75 hrs. carp. @ 3.00 = 2.88
128/100 x,225 hrs labor @ 1.75 = .51 26.60

Roofing
128 sq. ft. built-up roof @ .2290 = 29.31
8 ft. metal edge @ .15 = 1.20 30.51

Ceiling
96 sq. ft. 1/2" gypsum board @ 20.02 = 19.22

Insulation
96 sq. ft. @ .08 = 7.68 $96.88
V. SANDWICH ROOF PANEL

Assume a gable structure 24 feet wide spanned by two 4' x 16' sandwich panels resting on the outside walls and a structural ridge. The panel is composed of two 3/8 inch plywood skins glued to a 3-5/8 inch polystyrene foam core. The edges of the panel are protected by 1 x 4 lumber.

For purposes of simplicity in analysis, the skins will be assumed to have the dimensions of sanded 3/8" plywood although in actuality the upper skin will be unsanded material.

STRUCTURAL EVALUATION

Calculation of Moment of Inertia of Panel

\[ I_o \text{ of plywood for 12 inch width} = 0.0461 \text{ in.}^4 \]

\[ I_o \text{ for 2 skins 48 inches wide} = 0.3688 \text{ in.}^4 \]

Area of 1 skin = 4 x 2.25 = 9 sq. in.

Distance from center of skin to neutral axis = 2 ins.

\[ A \text{d}^2 \text{ for two skins} = 2(9 \times 2^2) = 72.00 \]

Moment of Inertia = \[ I = \frac{72.00}{72.37 \text{ in.}^4} \]

Fiber Stress in Bending

Live load = 25 psf.

Dead load = 6 psf.

Total load = 31 psf.

Clear span on slope = \[ l = 12.5 \text{ ft.} \]

Width of panel = 4'-0"

Total load, \[ W = 31 \text{ psf.} \times 12.5' \times 4' = 1550 \text{ lbs.} \]

Maximum moment = \[ \frac{Wl}{8} = \frac{1550 \times 12.5 \times 12}{8} = 29062.5 \text{ in. lb.} \]

Maximum fiber stress = \[ \frac{MC}{I} = \frac{29063 \times 2.1875}{72.73} = 875 \text{ psi.} \]

which is satisfactory.
Rolling Shear

Shearing stresses are negligible in the plywood. It is assumed the foam is sufficiently strong to resist the shearing action.

Deflection

Allowable deflection $1/240 \times 12.5 \times 12 = .625$ ins.

Maximum deflection \( \frac{5 \times W1^3}{384 \times EI} \)

\[
\frac{5 \times 1550 \times (12.5)^3 \times 1728}{384 \times 1600000 \times 72.73} = .59 \text{ ins.}
\]

Satisfactory

ESTIMATE OF COST

128 sq. ft. 3/8" C-D plywood sheathing @ .13 = $16.64
128 sq. ft. 3/8" A-D plywood sheathing @ .21 = 26.88
128 sq. ft. x 2/3 lb. foamed polystyrene @ .40 = 34.20
256 sq. ft. of glue line @ .03 = 7.68
80 lf. 1 x 4 edge 27 bd. ft. @ .14 = 3.78
128 sq. ft. of asphalt shingles, 15 lb. felt, nails, labor, and 8 ft. of metal edge = 17.87

Estimated labor of fabrication and erection = 6.00

TOTAL COST = $113.05

This cost is considerably higher than the truss construction standard.

COMMENTS

These panels require a press for manufacture unless self-adhering polyurethane foam is used at approximately double the cost of polystyrene foam. The requirement for a press of this size will prohibit the small manufacturer from making this panel.

Central ridge support is required and the structure has a sloping ceiling.

The panel is reasonably light in weight (approximately 200 lbs.) but would be difficult to handle in the wind. Some type of spline connection between adjacent panels will be required.
The same panel may be adapted to flat roof construction.

In those areas where a plywood ceiling is unacceptable, a lower grade plywood may be used on the inside surface over which a second surface may be applied.

Thermal characteristics compare to those of truss construction. In effect, the foam core establishes its own vapor barrier.

EVALUATION

This system is not competitive to truss construction under present day prices. It is more nearly competitive to conventional flat roof construction.

VI. STRESSED SKIN ROOF PANEL

Assume a panel of dimensions similar to the sandwich panel with two 3/8 plywood skins and four 2 x 4 rafters per panel.

STRUCTURAL EVALUATION

Calculation of Moment of Inertia

Moment of inertia of skins as before \[ 72.37 \text{ in.}^4 \]

Moment of inertia of four 1 x 4 = \[ 12.40 \]

Moment of inertia of panel = \[ I = 84.77 \text{ in.}^4 \]

Rolling Shear

Allowable rolling shear stress in plywood = 68 psi. \times 0.75 = 51 psi.

Dead load = 12 psf.
Live Load = 25 psf.
Total load = 37 psf.

Maximum Shear = \[ V = 35 \times 4 \times \frac{12.65}{2} = 886 \text{ lbs.} \]

Area for static moment = \[ 48 \times \frac{3}{32} = 4.5 \text{ sq. in.} \]

Arm for moment = 2.14 ins.

Static moment of area above shear plane = \[ Q = 9.63 \]

Shearing stress = \[ \frac{VQ}{Ib} = \frac{886 \times 9.63}{84.77 \times 3} = 33.6 \text{ psi.} \]

Shearing stress is satisfactory
Horizontal Shear

Area for additional static moment = 1.812 x 3 = 5.436 sq. in.

Arm for moment = .906

Additional static moment = 4.92

Total static moment = 4.92 x 9.63 = 14.55

Shearing stress = \( \frac{VQ}{Ib} = \frac{886 \times 14.55}{84.77 \times 3} = 51 \text{ psi.} \)

Shearing stress is satisfactory.

Fiber Stress

Basic allowable fiber stress = 1875 psi.

Actual spacing = \( \frac{14.25}{14.25} = 1 \geq .50 \)

Basic spacing* = 14.25

use 67% of basic stress

allowable stress = .67 x 1875 = 1250 psi.

Total load = \( W = 35 \times 12.5 \times 4 = 1750 \text{ lbs.} \)

Maximum moment = \( \frac{Wl}{8} = \frac{1750 \times 12.5 \times 12}{8} = 33600 \text{ in. lbs.} \)

Fiber stress = \( \frac{Mc}{I} = \frac{33600 \times 2.1875}{84.77} = 846 \text{ psi.} \)

Fiber stress is satisfactory.

ESTIMATE OF COST

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>128 sq. ft. 3/8 inch C-D plywood sheathing</td>
<td>@ .13</td>
<td></td>
<td>$ 16.64</td>
</tr>
<tr>
<td>128 sq. ft. 3/8 inch A-D plywood sheathing</td>
<td>@ .21</td>
<td></td>
<td>26.88</td>
</tr>
<tr>
<td>8 pcs. 1 x 4 x 16'-0''</td>
<td></td>
<td></td>
<td>7.14</td>
</tr>
<tr>
<td>4 pcs. 1 x 4 x 4'-0''</td>
<td></td>
<td></td>
<td>8.32</td>
</tr>
<tr>
<td>104 sq. ft. of mineral wool insulation</td>
<td>@ .08</td>
<td></td>
<td>3.00</td>
</tr>
<tr>
<td>Glue</td>
<td></td>
<td></td>
<td>17.87</td>
</tr>
<tr>
<td>128 sq. ft. of roofing, etc.</td>
<td></td>
<td></td>
<td>79.85</td>
</tr>
</tbody>
</table>

Estimated labor of fabrication and erection = 6.00

\( \text{Total} = \$ 85.85 \)

Essentially the same comments made on the sandwich panel are applicable here excepting that costs are very close to standard truss construction. However the disadvantage of the sloping ceiling must not be overlooked.

By using 2 x 4 ribs in place of 1 x 4 members, the nail-gluing technique could be used for assembly in lieu of the press method. Labor costs would probably be higher, and great care would be required in fastening the ceiling plywood to the panel.

EVALUATION

If actual time studies of fabrication and erection processes verify the assumed costs, the panel has merit for certain uses, particularly for flat roofs or for houses.
VII. FOLDED PLATE ROOF STRUCTURES

A folded plate roof structure is a type of gable construction in which horizontal ties between the eave lines may be partially or completely eliminated. In order to make this possible, the sheathing is designed as a diaphragm to resist the lateral thrust of the roof. (If open side walls are desired, the plate can also be designed to resist vertical loads.)

Since the sheathing functions as a diaphragm, it is important that the roof be well nailed so as to act as a unit. The usual recommendation is that the plywood sheathing be applied horizontally with staggered joints so that maximum continuity occurs. (Nailing must be approximately doubled if joints are not staggered.) The requirement makes it more difficult to devise a panelization system that would be effective in developing this system.

The most spectacular application of the folded plate roof is the single folded plate roofing the entire house. In this application the roof appears the same from outside as a gable roof, but the interior of the house is distinguished by freedom of horizontal ties at the eave height and the absence of beams supporting the ridge.

STRUCTURAL EVALUATION

Assume a structure 48 feet long with a single horizontal tie at the center and with cross section dimensions equivalent to those previously specified. Following the procedures recommended by the Douglas Fir Plywood Association in their release of September 16, 1957, the critical stresses may be checked as follows:

- Plywood Thickness
  - Effective length of diaphragm = \( L = 24 \text{ ft.} \)
  - Half-width of building = \( B = 12 \text{ ft.} \)
  - Rise of roof = \( H = 4 \text{ ft.} \)
  - Uniform load on horizontal projection of roof = \( W = 40 \text{ psf.} \)
Maximum shear \( = \frac{WBL}{4H} = \frac{40 \times 12 \times 24}{4 \times 4} = 720 \text{ lbs./ft.} \)

Assume C-D sheathing at 180 psi. allowable shearing stress

Thickness required \( t = \frac{720}{12(180)} = .33 \text{ ins.} \)

Use 3/8" plywood

Nail Spacing

Using 8d common nails with an allowable shear carrying value of 100 lbs. per nail, the required nail spacing is:

\[
\text{Spacing} = \frac{100(12)}{720} = 1.5 \text{ inches}
\]

If the plywood is staggered, this value may be increased 50% to 2-1/4 inches.

This spacing is required on the edge of all panels at critical points, but may be reduced to 6 inches at the center of the span of the diaphragm. Nails are spaced 6 inches on center on intermediate supports. All plywood edges must be blocked.

Rafters

Use 2 x 8 rafters spaced 24 inches on center.

Eave and Ridge Beams

Eave force \( = \frac{WBL^2}{16H} = \frac{40 \times 12 \times 24 \times 24}{16 \times 4} = 4320 \text{ lbs.} \)

Ridge force \( = 2 \times 4320 \text{ lbs.} = 8640 \text{ lbs.} \)

A continuous 2 x 8 is satisfactory.
ESTIMATE OF COST

Framing (Use standard grade)

Material

- 4 - 2 x 8 x 16' rafters = 85.3 bm.
- 3 - 2 x 8 x 4' ridge and eave beams = 16 bm.
- 12 - 2 x 4 x 4' blocking = 32 bm.

133.3 bm. @ $1.35 $18.00

Labor 1 hr. @ 3.00 3.00 21.00

Sheathing

128 sq. ft. 20.33

Roofing

128 sq. ft. 17.87

Ceiling

104 sq. ft. @ .2002 = 20.80

Insulation

104 sq. ft. @ .08 = 8.32 $ 88.32

COMMENTS

The use of the plywood sheathing in the horizontal position makes field application necessary and eliminates any possibilities of panelization.

Additional studies on the use of vertical applied sheathing in diaphragms might make a panelization system feasible.

Normal erection procedure for the single folded plate roof would involve the temporary support of the central ridge of the plate until such time as the sheathing is fully nailed so as to insure diaphragm action of the roof surface. With this procedure the erection difficulties would appear to be considerable.
A series of smaller folded plates may be used to span the structure in the 24 foot dimension, but these plates would be of such dimension as to require handling by crane. Also the waterproofing of the valleys resulting from the system would be a serious problem.

VIII. TRUSSES SPACED AT 4'-0"

One possible solution to panelization of roof systems is the use of trusses spaced more widely with panelized roof sheathing and ceiling construction. The difficulty herein lies in finding suitable low-cost panels for spanning the distance between trusses.

A panel system was developed for sheathing this truss system. (see Appendix A). Several designs were proposed and tested. All of these designs were predicated on the idea of a stiffened panel which could be dropped between or over the trusses without requiring fastening other than through the plywood. A nail-glued panel with 2 x 4 stiffeners and designed to be placed across the trusses proved most satisfactory.

No panel system was devised for the ceiling.

The truss designed for 4 foot spacing was based on a modified Howe design using 2 x 6 chord members and 2 x 4 struts and diagonals. Gusset plates were made of 1/2" C-D plywood sheathing, interior type.

STRUCTURAL EVALUATION

The system was found to be satisfactory by test. (See Appendix A).
## ESTIMATE OF COST

### Truss

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost per Unit</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 top chords 2 x 6 x 16'</td>
<td>=</td>
<td>32.0</td>
<td>bm.</td>
<td>32.0</td>
</tr>
<tr>
<td>1 bottom chord 2 x 6 x 14'</td>
<td>)</td>
<td>26.0</td>
<td>bm.</td>
<td>26.0</td>
</tr>
<tr>
<td>1 bottom chord 2 x 6 x 12'</td>
<td>)</td>
<td>5.3</td>
<td>bm.</td>
<td>5.3</td>
</tr>
<tr>
<td>1 center strut 2 x 4 x 4'</td>
<td>)</td>
<td>8.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 struts 2 x 4 x 2'</td>
<td>)</td>
<td>=</td>
<td>26.0</td>
<td>bm.</td>
</tr>
<tr>
<td>2 struts 2 x 4 x 2'</td>
<td>)</td>
<td>=</td>
<td>5.3</td>
<td>bm.</td>
</tr>
<tr>
<td>2 diagonals 2 x 4 x 6'</td>
<td>)</td>
<td>=</td>
<td>71.3</td>
<td>bm.</td>
</tr>
<tr>
<td>1/2 plywood gussets 44 sq. ft. @ $ .18</td>
<td>=</td>
<td>=</td>
<td>7.92</td>
<td></td>
</tr>
<tr>
<td>Glue</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nails 2 lbs. @ .13</td>
<td>=</td>
<td>=</td>
<td>.26</td>
<td></td>
</tr>
<tr>
<td>Labor 1 hour</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>=</td>
<td>=</td>
<td><strong>$23.02</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Sheathing

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost per Unit</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plywood 128 sq. ft. (includes labor)</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td><strong>20.33</strong></td>
</tr>
<tr>
<td>Blocking 17 pcs. 2 x 4 x 4' = 45.3 bm. @ .135</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td><strong>6.12</strong></td>
</tr>
<tr>
<td>Glue</td>
<td>=</td>
<td>=</td>
<td>.75</td>
<td>=</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>=</td>
<td>=</td>
<td><strong>27.20</strong></td>
<td></td>
</tr>
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</table>

### Roofing

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost per Unit</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>128 sq. ft.</td>
<td>=</td>
<td>128</td>
<td>=</td>
<td><strong>17.87</strong></td>
</tr>
</tbody>
</table>

### Ceiling

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost per Unit</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum bd. 96 sq. ft. @ $ .1642</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td><strong>15.76</strong></td>
</tr>
<tr>
<td>Blocking 13 pcs. 2 x 4 x 4' = 34.67 bm. @ .135</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td><strong>4.68</strong></td>
</tr>
<tr>
<td>Labor 1/2 hour @ $3.00</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td><strong>1.50</strong></td>
</tr>
<tr>
<td>Nails 1 lb. @ .13</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td><strong>.13</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>=</td>
<td>=</td>
<td><strong>22.07</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Insulation

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost per Unit</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>96 sq. ft. @ .08</td>
<td>=</td>
<td>96</td>
<td>=</td>
<td><strong>7.68</strong></td>
</tr>
</tbody>
</table>

| **Total** | = | = | **97.84** | |


COMMENTS

This system is more costly in both labor and materials than the basic truss system. Some gain would be made in the amount of space required for the storage and moving of trusses, but a corresponding loss would occur in the storage of the sheathing panels.

Material costs for a single truss of this design were greater than for two trusses of conventional design. As the truss was designed for a longer span and flatter slope (2/12), it is possible that the amount of material in the truss could be reduced for the 24 foot span with a slope of 4 in 12.

The greatest advantage of the large truss might be found when trusses are spaced at 8 feet. In this case the 2 x 4 blocking would be structurally utilized more fully, and truss costs should be considerably lower than those of other truss systems.

Since the ceiling drywall finish is fastened to blocking between the trusses as well as the trusses themselves, gypsum board may be placed parallel to the trusses. This will result in the reduction of end joints in many cases.

EVALUATION

This system, designed for trusses at 4 foot centers, is less economical than conventional truss systems and, therefore, offers no advantages.
IX. CONCLUSIONS AND RECOMMENDATIONS

Nail-glued trusses spaced 2 feet on center with plywood sheathing and gypsum board ceiling remains the lowest cost method of building a sloping roof with a flat ceiling.

Conventional framing with 2 x 8 joists at 2 foot centers and plywood sheathing and gypsum board ceiling is the lowest cost flat roof framing, although the stress skin panel with built-up roofing approaches the cost of conventional construction very closely.

For structures with sloping ceilings supported at the ridge and walls, the stress skin panel is the least costly.

Wider spacing of trusses may result in economies once some roof sheathing and ceiling finish cheaper than plywood and gypsum board are found.

Further investigation should be undertaken in order to develop a combination roofing and sheathing material capable of sustaining loads for spans of from four to eight feet.

Similarly, a ceiling material (possibly combining acoustical treatment and insulation) should be developed for the spans greater than two feet.
APPENDIX
A number of different stiffened panels designed to span between trusses 4'-0" on center were tested. Tests were performed for uniform load and for impact loading.

Uniform Loading

A live load of 25 pounds per square foot, representing snow, and a dead load of 8 pounds per square foot representing roofing were applied in increments and released after each increment. Deflections under loads and residual deflection after each load increment were recorded. Overloads were not applied.

Uniform Loading - Acceptable Performance

Under live load, maximum deflection shall not exceed 1/180 of the span for panel without finish below. Since the panels are to span 4'-0", the maximum deflection allowable is .267 inches.

Impact Loading

10-inch diameter sand bag weighing 60 pounds dropped on upper surface at weakest point of element. As the joint between the plywood and the stiffening ribs was the most critical point, the sand bag was dropped over these ribs.

Impact Loading - Acceptable Performance

(a) Under 1-1/2 foot drop - no residual deflection

(b) Under 3 foot drop

25% maximum residual deflection and no break in covering.
PANEL TYPE 1

Description of Panel: 3/8" x 4' x 8' C-D interior type plywood sheathing (nailed with 8d common nails)

5 - 2 x 4 x 4'-0" cross ribs

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins.</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dials</td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>6.6</td>
<td>.047</td>
<td>.055</td>
</tr>
<tr>
<td>0.0</td>
<td>.004</td>
<td>.004</td>
</tr>
<tr>
<td>13.2</td>
<td>.094</td>
<td>.109</td>
</tr>
<tr>
<td>0.0</td>
<td>.007</td>
<td>.005</td>
</tr>
<tr>
<td>19.8</td>
<td>.126</td>
<td>.170</td>
</tr>
<tr>
<td>0.0</td>
<td>.040</td>
<td>.95</td>
</tr>
<tr>
<td>26.4</td>
<td>Failure--Nails Pulled Through Plywood</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>0.0</td>
<td>Failure--Nails Pulled Through Plywood</td>
<td></td>
</tr>
<tr>
<td>33.0</td>
<td>Failure--Nails Pulled Through Plywood</td>
<td></td>
</tr>
</tbody>
</table>

Load of 22.2 psf caused failure of nail pull out

Performance, Impact Loading:

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection 1-1/2'</th>
<th>Deflection 1-3/4&quot;</th>
<th>Residual Deflection 1/4&quot;</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>3'</td>
<td>4 nails pulled through the plywood.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2 nails were pulled from the rib.
PANEL TYPE 2

Description of Panel: 1/2" x 4' x 8' C-D interior type plywood sheathing (nailed with 8d common nails)

5 - 2 x 4 x 4'-0" cross ribs

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins. Dials</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>.000 .000 .000</td>
<td>.000</td>
</tr>
<tr>
<td>6.6</td>
<td>.030 .025 .030</td>
<td>.028</td>
</tr>
<tr>
<td>0.0</td>
<td>.000 .000 .000</td>
<td>.000</td>
</tr>
<tr>
<td>13.2</td>
<td>.058 .052 .062</td>
<td>.057</td>
</tr>
<tr>
<td>0.0</td>
<td>.006 .003 .011</td>
<td>.007</td>
</tr>
<tr>
<td>19.8</td>
<td>.092 .093 .082</td>
<td>.089</td>
</tr>
<tr>
<td>0.0</td>
<td>.015 .017 .013</td>
<td>.015</td>
</tr>
<tr>
<td>26.4</td>
<td>.142 .187 .136</td>
<td>.155</td>
</tr>
<tr>
<td>0.0</td>
<td>- - -</td>
<td>-</td>
</tr>
<tr>
<td>33.0</td>
<td>.242 .223 .242</td>
<td>.236 acceptable</td>
</tr>
<tr>
<td>0.0</td>
<td>.032 .034 .020</td>
<td>.029 acceptable</td>
</tr>
</tbody>
</table>

Performance, Impact Loading

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection 1-1/8&quot;</th>
<th>Residual Deflection 3/8&quot;</th>
<th>Nails pulled out of center rib</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3'</td>
<td>not performed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Nails pulled out of center rib
**PANEL TYPE 3**

**Description of Panel:** 1/2" x 4' x 8' C-D interior type plywood sheathing  
(nailed with 2" ring shank nails)

5 - 2 x 4 x 4'-0" cross ribs

**Performance, Uniform Loading:**

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dials</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
</tr>
<tr>
<td>6.6</td>
<td>.026</td>
</tr>
<tr>
<td>0.0</td>
<td>.006</td>
</tr>
<tr>
<td>13.2</td>
<td>.045</td>
</tr>
<tr>
<td>0.0</td>
<td>.011</td>
</tr>
<tr>
<td>19.8</td>
<td>.068</td>
</tr>
<tr>
<td>0.0</td>
<td>.008</td>
</tr>
<tr>
<td>26.4</td>
<td>.095</td>
</tr>
<tr>
<td>0.0</td>
<td>.011</td>
</tr>
<tr>
<td>33.0</td>
<td>.200</td>
</tr>
<tr>
<td>0.0</td>
<td>.017</td>
</tr>
</tbody>
</table>

**Performance, Impact Loading:**

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection</th>
<th>Residual Deflection</th>
<th>Nail pulled</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2'</td>
<td>11/16&quot;</td>
<td>1/16&quot;</td>
<td>unacceptable out at one end of center rib</td>
</tr>
<tr>
<td>3'</td>
<td>5/16&quot;</td>
<td>1/4&quot;</td>
<td>Several additional nails pulled out</td>
</tr>
</tbody>
</table>
PANEL TYPE 4

Description of Panel: 3/8" x 4' x 8' C-D interior type plywood sheathing (nail-glued with 4d common nails)

5 - 2 x 4 x 4'-0" cross ribs

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins.</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dials</td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>6.6</td>
<td>.030</td>
<td>.027</td>
</tr>
<tr>
<td>0.0</td>
<td>.005</td>
<td>.000</td>
</tr>
<tr>
<td>13.2</td>
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Performance, Impact Loading:

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection</th>
<th>Residual Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2'</td>
<td>11/16&quot;</td>
<td>1/8&quot;</td>
</tr>
<tr>
<td>3'</td>
<td>1-1/2&quot;</td>
<td>3/8&quot;</td>
</tr>
</tbody>
</table>

Nails pulled loose at one end unacceptable
PANEL TYPE 5

Description of Panel: 1/2" x 4' x 8' C-D interior type plywood sheathing
(nailed with 4d common nails at 8" o.c.)
5 - 2 x 4 x 4'-0" cross ribs nail-glued

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins.</th>
<th>Dials</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
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<td>.000</td>
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<tr>
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<td>.019</td>
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<td>.000</td>
<td>.000</td>
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<tr>
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<tr>
<td>19.8</td>
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<td>.050</td>
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<tr>
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<tr>
<td>33.0</td>
<td>.004</td>
<td>.006</td>
<td>.008</td>
</tr>
</tbody>
</table>

Performance, Impact Loading

| Height  | Deflection  | Residual Deflection | Several nails pulled loose. unacceptability.
|---------|-------------|---------------------|-----------------------------------------------------|
| 1-1/2"  | 15/32"      | 1/32"               | Wood failure of ribs at glue joint. No glue failure.
| 3'      | 1-7/8"      | 1/2"                | Several nails pulled loose. unacceptability.

Recommendation: Nail-glue using 2" ring shank nails for greater clamping pressure.
PANEL TYPE 6

Description of Panel: 1/2" x 4' x 8' C-D interior type plywood sheathing (nail-glued with 2" ring shank nails)

1 - 2 x 2 longitudinal rib on each edge (see drawing page A-8)

1 - 2 x 4 longitudinal flat rib at center

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins.</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dials</td>
<td></td>
</tr>
<tr>
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<tr>
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<td>.012</td>
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<td>.000</td>
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<td>.004</td>
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</table>

Performance, Impact Load

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection</th>
<th>Residual Deflection</th>
<th>No glue failure or wood failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2'</td>
<td>5/16&quot;</td>
<td>0</td>
<td>acceptable</td>
</tr>
<tr>
<td>3'</td>
<td>13/16&quot;</td>
<td>0</td>
<td>acceptable</td>
</tr>
</tbody>
</table>
PANEL TYPE 7
(Layout of Panel Type 6 similar)

Panel as tested

Panel as installed on truss

Panel as installed on truss
PANEL TYPE 7

Description of Panels: 3/8" x 4' x 8' C-D interior type plywood sheathing (nail-glued with 4d common nails)

1 - 2 x 2 longitudinal rib on each edge (see drawing page A-8)

1 - 2 x 4 longitudinal rib at center

Performance, Uniform Loading:

<table>
<thead>
<tr>
<th>Load in psf</th>
<th>Deflection, Center of Beams, Ins.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dials</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
</tr>
<tr>
<td>6.6</td>
<td>.064</td>
</tr>
<tr>
<td>0.0</td>
<td>.000</td>
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<tr>
<td>13.2</td>
<td>.091</td>
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<tr>
<td>0.0</td>
<td>.005</td>
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<tr>
<td>19.2</td>
<td>.104</td>
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</table>

Performance, Impact Loading:

<table>
<thead>
<tr>
<th>Height</th>
<th>Deflection</th>
<th>Residual Deflection</th>
<th>Glue joint did not fail. (Larger glue area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2'</td>
<td>3/4&quot;</td>
<td>1/16&quot;</td>
<td>acceptable</td>
</tr>
<tr>
<td>3'</td>
<td>1-7/8&quot;</td>
<td>1/8&quot;</td>
<td>Recommend setting up trusses with panels in place. (Load for test)</td>
</tr>
</tbody>
</table>
TRUSS TEST

Three trusses were set up and sheathed with ribbed panels of type 7. Tests were made for uniform loading.

Uniform Loading

Trusses were tested for a design load of 25 pounds per square foot snow load and 15 pounds per square foot dead load. Loads of 20, 30, 40, and 100 pounds per square foot were applied, deflection measured, loads removed and residual deflection measured on the center truss of the three trusses. Loading was applied so as to simulate loading conditions when a series of trusses are loaded simultaneously. (The load of 100 pounds per square foot is in excess of the overload designated by the HHFA performance standards which is specified as 1-1/4 dead load plus 2-1/4 live load, or in this case 75 pounds per sq. ft.)

Uniform Loading, acceptable performance

Under live load, maximum deflection not to exceed L/360 for plaster ceilings: 0.98 ins.

or L/240 for drywall ceilings: 1.40 ins.

Under overload - Sustain the load

Maximum residual deflection: 25%
TRUSS TYPE 1

Description of Truss

Type: Modified Howe.
Span: 28'-8" outside to outside.
Spacing: 4'-0" on center.
Material

Chords: 2 x 6 "standard" grade Douglas fir.
Struts and ties: 2" x 4" standard grade Douglas fir and hemlock.

(Moisture content of lumber: 22%)
Gusset plates: 1/2" C-D unsanded plywood, interior type.

Roof Sheathing

3/8" sheathing (interior type) plywood panels with 2 x 4 nail-glued flat to panels as stiffeners.

Condition of Trusses Immediately Before Testing:

1) Noticeable warpage, checking and splitting due to shrinkage and loss in moisture content.
2) Excess glue squeeze at gussets had dissolved and softened from excessive moisture under the tarpaulin.
3) Nail-popping had occurred in a large percentage of the gusset plates (some could be pulled with claw hammers).
4) Dimensional changes in the chord from shrinkage.

Performance

<table>
<thead>
<tr>
<th>No. of Blocks</th>
<th>Load Lbs.</th>
<th>Load psf.</th>
<th>Deflection (in.)</th>
<th>Residual Deflection (in.)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>1565</td>
<td>20</td>
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<tr>
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<tr>
<td>192</td>
<td>8350</td>
<td>40</td>
<td>0.875</td>
<td>0.187</td>
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</tr>
<tr>
<td>432</td>
<td>18,787</td>
<td>100</td>
<td>1.440</td>
<td>0.218</td>
<td>Compensate for Support</td>
</tr>
</tbody>
</table>

Derived from Adjoining Trusses
Illustrations
(on following page)

Left to Right, Top to Bottom

1. Trusses, 4 feet on center, 28 foot span
2. Placing stiffened panels as roof sheathing
3. View of trusses partially sheathed
4. Trusses sheathed and covered with 15 lb. felt
5. Load test
6. Load test