FULL-SCALE TESTS ON 32-FOOT HIP ROOF SYSTEM

Donald H. Percival
Quentin B. Comus

Research Report 78-1
UNIVERSITY OF ILLINOIS
SMALL HOMES COUNCIL–BUILDING RESEARCH COUNCIL
FULL SCALE TESTS ON A
32-FOOT HIP ROOF SYSTEM

Donald H. Percival, Research Professor of Wood Technology and Utilization, Small Homes Council-Building Research Council, University of Illinois at Urbana-Champaign

and

Quentin B. Comus, Wood Engineering Technologist Wood Research Laboratory, Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana

Consultants: E. T. Jauch, Director of Research and Engineering, GBH-Way Homes, Inc.
R. A. Jones, A.I.A., Director, SHC-BRC University of Illinois
Prof. S. K. Suddarth, P.E., Wood Research Laboratory, Purdue University

© 1978 by the Board of Trustees of the University of Illinois. This project was a cooperative investigation between the Small Homes Council-Building Research Council, University of Illinois at Urbana-Champaign and GBH-Way Homes, Inc., Walnut, Illinois.
INTRODUCTION

This report covers the full-scale testing of a 32-foot, 4/12 slope, hip-roof system. The program was a cooperative investigation between the Small Homes Council—Building Research Council, University of Illinois at Urbana-Champaign, and GBH-Way Homes, Inc. of Walnut, Illinois.

Full-scale testing is generally accepted as a means of determining deflection characteristics for nail-glued truss designs because the graphical methods of analysis are unreliable in calculating stresses for this type of rigid connection. The combined stresses, due to secondary bending caused by the extreme rigidity of the nail-glued joint, are not considered in graphical methods of analysis.

The objectives of this program included load tests on a full-scale hip-roof system to obtain deflection performance of the hip truss. In addition, the hip-truss was supported by a calibrated load cell at each end to determine the percentage of design load carried by the truss, and that carried by the wall. For safety reasons, the program did not include running the test to failure.

FRAMING SYSTEMS AND MATERIALS

All of the lumber for the truss and other framing was Douglas fir, graded Select Structural. The plywood gussets of the truss were 3/4 inch, exterior type, Douglas fir. The plywood roof sheathing was also Douglas fir, 1/2 inch, sheathing grade. Total span of the roof was 32 feet with a slope of 4/12. The hip truss (or carrying truss) was 32 feet in length and was placed parallel to and 16 feet from the end of the building.
The ceiling joists were 2 x 8 members, spaced 24 inches on center, and were placed perpendicular to and fastened to the hip truss (see Figure 1). They were supported at one end by the hip truss and at the other end by the end walls. The hip rafters were 2 x 10 and placed in the normal position with the outer support located at the corners of the wall framing while the peak ends met at the center of the roof and were supported by the hip truss.

Figure 1. Plan at ceiling joist level.

The jack rafters were 2 x 6 and 2 x 8 and were installed 24 inches on center in the usual manner between the hip rafters and the walls (see Figure 2).
The hip truss was a nail-glued unit designed by GBH-Way Homes, Inc. (see Figure 3).

A standard 32-foot truss was incorporated into the test setup to provide surface area for the additional one foot of the roof carried by the hip truss (see Figure 4).
Figure 3. Nail-glued hip truss with deflection gage locations.
Figure 4. Elements used in the test set-up.
DESIGN LOADS

The area of the roof under test was calculated to be 544 square feet. (This includes a one-foot x 32-foot area carried by the hip truss.) Design load included 40 psf live load and 10 psf dead load. The assumed dead load was composed of 3.35 psf for the framing, sheathing and nails. Additional assumed dead loads of 4.0 psf for drywall finish and insulation and 2.65 psf for the shingles and felt gave a total assumed dead load of 10.0 psf. At the conclusion of the test, the framing and sheathing were weighed, equaling 4.66 psf.

TEST SET-UP

The hip-roof system was designed to span 32 feet and was erected in a GBH-Way company warehouse. The roof was supported by 16-inch high wall sections constructed of single bottom and double top plates with studs 16 inches on center. Sheathing grade, 1/2-inch plywood was used to brace the corners. The roof was constructed on the walls with the hip truss spanning across the 32-foot opening (see Figure 4).

The hip truss reactions were instrumented by inserting two calibrated load cells at the ends of the truss. To insert the load cells, the truss was raised and a section of one of the top plates of the wall at each end was removed at the truss bearing point. The rings were then positioned on supports and the truss lowered into position (see Figure 5).
Figure 5. Load cell located under each end of the hip truss.

A braided nylon line and scale-mirror arrangement were attached to the truss to measure deflection during the test (see Figure 6). Deflection readings were taken at three points along the bottom chord, N, M, and S (see Figure 3 and 6):

Figure 6. Deflection gage arrangement.
TEST PROCEDURES

Shingle bundles averaging 77 pounds each were used as the loading elements. The roof was sectioned off to facilitate placement of the bundles. The roof area was laid out in 3 ft. x 3 ft. sections (horizontal plane) and the bundles were positioned as far as practicable without touching, therefore eliminating an arching action.

LOADING

The assumed dead load of the drywall and insulation (4.0 psf) was placed on the ceiling joists and the assumed dead load of shingles and felt (2.65 psf) was placed on the roof. At this point, the gages and load cells were read for dead load deflection. The design live load was then applied at predetermined locations on the roof in increments of 10 psf until a live load of 40 psf was reached. After each increment, each gage and load cell was read. This load was allowed to remain on the test set-up for seven days. After this period, the system was dismantled and the individual elements weighed, totaling 2535 pounds or 4.66 pounds per square foot for the framing used in the test set-up. Total dead load plus total live load, placed on the test set-up, is listed in Table 1.

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead load = 2.65 psf = shingles and felt</td>
</tr>
<tr>
<td>= 4.66 psf = actual weight of framing and sheathing</td>
</tr>
<tr>
<td>= 4.00 psf = insulation and drywall</td>
</tr>
<tr>
<td>= 11.31 psf = total dead load</td>
</tr>
<tr>
<td>Live load = 40.00 psf = total live load</td>
</tr>
</tbody>
</table>

A total load of 51.31 psf was used in the test.

Figure 7 shows area of roof .544 sq. ft., loaded in the test.
Figure 7. Loaded area of the roof.

Table 2 lists the loads applied to the roof system.

TABLE 2

<table>
<thead>
<tr>
<th>LOADS</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Live load</strong></td>
<td></td>
</tr>
<tr>
<td>Weight of shingles and felt</td>
<td>2.65 psf x 544 sq. ft.</td>
</tr>
<tr>
<td><strong>Simulated load of insulation and drywall</strong></td>
<td>4.00 psf x 544 sq. ft.</td>
</tr>
<tr>
<td><strong>Weight of framing and sheathing</strong></td>
<td>4.66 psf x 544 sq. ft.</td>
</tr>
<tr>
<td><strong>Total load on roof</strong></td>
<td></td>
</tr>
</tbody>
</table>
Table 3 shows the test data. Refer to figure 3 for gage locations.

### TABLE 3. GAGE LOCATIONS AND TEST RESULTS

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>LOAD (psf.)</th>
<th>RING Y</th>
<th>GAGE N</th>
<th>GAGE M</th>
<th>GAGE S</th>
<th>RING X</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-28-77</td>
<td>13:30</td>
<td>0</td>
<td>.0011</td>
<td>4.1</td>
<td>4.0</td>
<td>5.2</td>
<td>.0014</td>
</tr>
<tr>
<td></td>
<td>13:45</td>
<td>ceiling d.l.</td>
<td>.0032</td>
<td>5.2</td>
<td>5.0</td>
<td>7.0</td>
<td>.0034</td>
</tr>
<tr>
<td></td>
<td>14:30</td>
<td>Total d.l.</td>
<td>.0048</td>
<td>7.0</td>
<td>6.2</td>
<td>8.0</td>
<td>.0046</td>
</tr>
<tr>
<td>12-29-77</td>
<td>9:00</td>
<td>Total d.l.</td>
<td>.0046</td>
<td>7.2</td>
<td>6.0</td>
<td>7.9</td>
<td>.0047</td>
</tr>
<tr>
<td></td>
<td>10:05</td>
<td>d.l.+10</td>
<td>.0090</td>
<td>10.0</td>
<td>.11</td>
<td>8.8</td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td>10:40</td>
<td>d.l.+20</td>
<td>.0133</td>
<td>13.2</td>
<td>.24</td>
<td>12.5</td>
<td>.26</td>
</tr>
<tr>
<td></td>
<td>11:35</td>
<td>d.l.+30</td>
<td>.0181</td>
<td>17.5</td>
<td>.41</td>
<td>17.0</td>
<td>.43</td>
</tr>
<tr>
<td></td>
<td>12:15</td>
<td>d.l.+40</td>
<td>.0220</td>
<td>21.0</td>
<td>.54</td>
<td>20.3</td>
<td>.56</td>
</tr>
<tr>
<td></td>
<td>14:15</td>
<td>d.l.+40</td>
<td>.0219</td>
<td>20.5</td>
<td>.52</td>
<td>20.3</td>
<td>.56</td>
</tr>
</tbody>
</table>

**LOAD ON HIP TRUSS**

Calculated load on hip truss: state of the art reveals that various methods of calculations have been used to determine design loads to be carried by a hip truss. For example, the design method used in this study assumes that half the load on each jack rafter is transferred to the hip rafter, and that the hip rafter supports this load as a simple beam, then, of the total loaded area supported by the hip rafter, an area of 154 sq. ft. is transferred to the carrying truss at its center, area A (see Figure 8). The truss would also carry 64 sq. ft. directly on its top chord, area B and 16 sq. ft. from the central rafter of the hip, area C. According to these calculations, the roof area carried by the hip truss would be 234 sq. ft. Loaded at 51.3 psf (includes the dead load), the load on the truss would be calculated to be 12,004 pounds.
ALLOWABLE DEFLECTION

Under the usual code regulations, the allowable deflection of the truss would be as follows:

\[ \frac{L}{360} = \frac{32' \times 12''}{360} = 1.07 \text{ inches} \]

\[ \frac{L}{240} = \frac{32' \times 12''}{240} = 1.60 \text{ inches} \]

\[ \frac{L}{180} = \frac{32' \times 12''}{180} = 2.13 \text{ inches} \]

ACTUAL DEFLECTIONS

Deflection at the three gage locations at completion of the tests were:

\[ N = 0.52'' \quad M = 0.56'' \quad S = 0.51'' \]

After the full load was applied, the set-up was allowed to remain for an additional seven days. These deflections are shown in Table 4 and the gage locations are shown in Figure 3.

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>LOAD</th>
<th>RING Y</th>
<th>M.M. (IN.)</th>
<th>M.M. (IN.)</th>
<th>M.M. (IN.)</th>
<th>RING X</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-30-77</td>
<td>835</td>
<td>d.l.+40</td>
<td>.0218</td>
<td>21.0</td>
<td>.54</td>
<td>20.3</td>
<td>.51</td>
</tr>
<tr>
<td>1-3-78</td>
<td>1600</td>
<td>d.l.+40</td>
<td>.0218</td>
<td>25.0</td>
<td>.70</td>
<td>24.5</td>
<td>.73</td>
</tr>
<tr>
<td>1-4-78</td>
<td>1600</td>
<td>d.l.+40</td>
<td>.0218</td>
<td>25.5</td>
<td>.72</td>
<td>24.5</td>
<td>.73</td>
</tr>
<tr>
<td>1-5-78</td>
<td>745</td>
<td>d.l.+40</td>
<td>.0218</td>
<td>25.5</td>
<td>.72</td>
<td>24.5</td>
<td>.73</td>
</tr>
<tr>
<td>1-5-78</td>
<td>1400</td>
<td>d.l.+40</td>
<td>.0218</td>
<td>25.5</td>
<td>.72</td>
<td>24.5</td>
<td>.73</td>
</tr>
<tr>
<td>1-6-78</td>
<td>730</td>
<td>d.l.+40</td>
<td>.0218</td>
<td>25.5</td>
<td>.72</td>
<td>24.5</td>
<td>.73</td>
</tr>
</tbody>
</table>

Even under the full design load for the additional seven days, deflections did not reach the allowable.
MEASURED LOAD ON THE HIP TRUSS

Observations from the load cells indicated that all of the assumed design load did not go to the hip truss. The total load (including materials and loading elements), was 27,913 pounds. The load cells indicated only 8600 pounds were carried by the hip truss. See Table 5 for the actual loads recorded at the various load levels.

![Figure 8. Load areas.](image)

**Table 5. Actual loads recorded at the various load levels.**

<table>
<thead>
<tr>
<th>LOAD (psf.)</th>
<th>LOAD CELL Y (lbs.)</th>
<th>LOAD CELL X (lbs.)</th>
<th>LOAD ON TRUSS (lbs.)</th>
<th>TOTAL LOAD ON SET UP (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>d.l. = (6.65 psf.)</td>
<td>890</td>
<td>915</td>
<td>1805</td>
<td>3617</td>
</tr>
<tr>
<td>d.l. + 10 psf.</td>
<td>1750</td>
<td>1700</td>
<td>3450</td>
<td>9057</td>
</tr>
<tr>
<td>d.l. + 20 psf.</td>
<td>2575</td>
<td>2625</td>
<td>5200</td>
<td>14497</td>
</tr>
<tr>
<td>d.l. + 30 psf.</td>
<td>3450</td>
<td>3600</td>
<td>7050</td>
<td>19937</td>
</tr>
<tr>
<td>d.l. + 40 psf.</td>
<td>4200</td>
<td>4400</td>
<td>8600</td>
<td>25377</td>
</tr>
</tbody>
</table>

Weight of Hip roof set up 2535 lbs.
Total Load = 27913 lbs.
CONCLUSIONS

The test indicated that the hip roof system designed and built as shown in this report could sustain a live load of 40 psf with deflections well below the permitted limits.

Accepted standard engineering practice would permit using shorter spans and/or higher slopes using the same hip truss design.
APPENDIX A

\[ \text{Area I} = \left( \frac{2T}{3} \right) \times \frac{\tan 45^\circ}{2} \]

\[ \text{Area II} = x \times 36 = \left( \frac{3x}{2} \right) \times \frac{\tan 60^\circ}{3} \]

\[ \text{Area III} = \frac{1}{2} \times \frac{32}{2} = \frac{32}{4} \times \frac{\tan 30^\circ}{3} \]

\[ \text{Total foot area} = 150 \text{ sq. ft.} \]

\[ \text{Cutting foot area - AREA C} = 15 \times 3 = 25 \text{ sq. ft.} \]
APPENDIX A

As a result of the tests showing that the hip truss carried only 8600 pounds of the total load, the following design assumption is suggested. The loads may be calculated as indicated. This design is suggested by Mr. E. T. Jauch, Director, Research and Engineering, GBH-Way Homes, Inc.

Truss roof load - AREA A

\[ \text{AREA A} = \frac{\text{Span}}{2} \times \left(\frac{\text{Span}}{4} - \frac{1}{2} \text{T.S.}\right) = \]

\[ = \frac{32}{2} \times \left(\frac{32}{4} - 1\right) = 16 \times 7 = 112 \text{ sq. ft.} \]

Hip rafter load - AREA B

\[ \text{AREA B} = \text{Span} \times \text{T.S.} = 32 \times 2' = 64' \]

Total roof area = 176 sq. ft.

Ceiling load - AREA C

\[ \text{AREA C} = \text{Span} \times \left(\frac{\text{Span}}{4} + \frac{\text{T.S.}}{2}\right) = 32 \times (8+1) = \]

\[ = 32 \times 9 = 288 \text{ sq. ft.} \]
176 sq. ft. x 51.3 psf. = 9029 lbs.

Total d.l. = 11.31 psf., clg. d.l. = 4.0 psf.

11.31 - 4 = 7.31 psf. = roof dead load

Total load on hip truss = clg. d.l. + roof d.l. + live load =
= 288 sq. ft. x 4 + 176 sq. ft. x (40 + 7.31) = 1152 + 8326 = 9478 lbs.

Total load on hip truss = 9478 lbs.

Actual measured load = 8600 lbs.

difference = 878 lbs.

\[
\frac{878}{8600} = 10.2\% \text{ safety factor overrun.}
\]
REFERENCE LIST


