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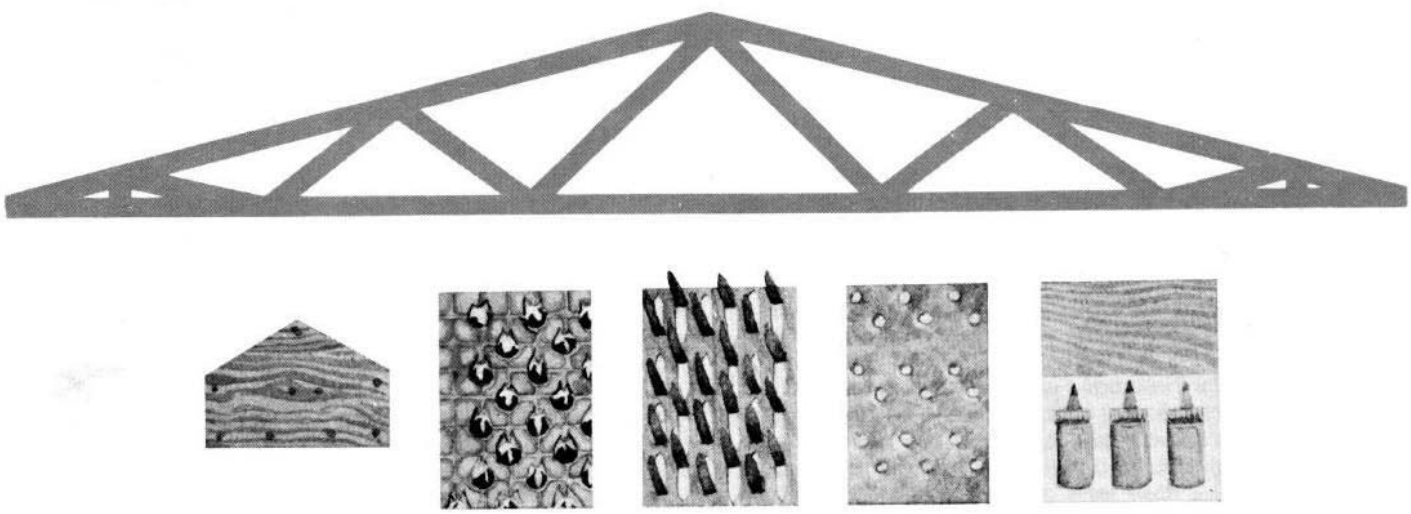
FPL 444

Longtime Performance of Trussed Rafters with Different Connection Systems

Thomas Lee Wilkinson



Abstract

Trussed rafters with seven different connecting systems were observed under load for periods of 5, 10, and 15 years. After each 5-year period, trusses were unloaded and evaluated for strength and stiffness under laboratory conditions.

At the end of 15 years, total deflection of the trusses under constant load increased about two to three times the initial deflection. Total deflection was still at an acceptable level. Creep had halted during the 15 years of observation. Trusses evaluated in the laboratory had no appreciable loss of strength or stiffness except for a 30 percent reduction in stiffness with the nailed plywood gusset trussed rafters.

Keywords: Connectors, fasteners, glue, gussets, rafters, trussed rafters.

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This paper supersedes Forest Service Research Papers FPL 93 dated 1968; FPL 204 dated 1973; and FPL 204 revised 1978.

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Longtime Performance of Trussed Rafters with Different Connection Systems

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Forest Products Laboratory, Madison, Wis.

Introduction

Wood trussed rafters have become widely used in the housing and small building industry because of their advantages over conventional rafters. These advantages include:

1. **Fast close-in.—**Trussed rafters can be erected and the sheathing applied in a minimum of time.
2. **Complete freedom of floor plan design.—**Outside walls completely support the roof load; therefore, the partition walls can be put anywhere.
3. **Less skilled labor for erection.—**There is no framing, layout, or rafter cutting done on the site.
4. **Savings in lumber.—**Interior partitions can be made lighter, since they are nonload-bearing. Nominal size 2 by 4 members are used in the trussed rafter, compared to nominal size 2 by 6 and 2 by 8 rafters and ceiling joists used in conventional systems.

After a trussed rafter is installed in a building, it is subjected to many conditions which may affect its performance. These conditions include changes in relative humidity and temperature which cause the truss members and connectors to expand and contract, and thus may loosen the connector. Conditions of loading, such as changes in the amount of live load on the roof, may cause the joint to "work" and thus result in a change in performance. A constant load, such as roofing materials, may cause continued deflection with time. These conditions in different combinations and degrees may affect the service performance of wood trussed rafters.

Service characteristics of trussed rafters or their connection systems have received little study. Trussed rafters assembled with nailed plywood gusset plates and without glue have performed satisfactorily, as indicated by their long service records. The metal plate connector has a 30-year service record with over 700 million in use. Their in-service performance has also been satisfactory.

In 1967, the Forest Products Laboratory initiated a study on the longtime performance of trussed rafters with different connection systems. The trussed rafters were loaded and exposed to sheltered outdoor conditions for 5-, 10-, and 15-year periods. After each 5-year period, one trussed rafter of each connection system was evaluated in the laboratory. Strength and stiffness was compared to a control trussed rafter tested at the program's beginning.

Results after 5 and 10 years have been reported previously (Wilkinson, 1978). This paper contains the results from all three periods.

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

Other Trussed Rafter Studies

When this study began, several studies had been conducted on full-size trussed rafters to determine their initial strength and stiffness. These included tests by Angleton (1960) on roof trusses with nailed plywood gusset plates, by Luxford and Heyer (1954) on glued and nailed roof trusses, by Pneuman (1960) on king-post trussed rafters with plywood gussets on one side, as well as many tests by Radcliffe and others (1955a, 1955b, 1955c) on nail-glued trussed rafters. Also, the manufacturers of metal plates had tested trussed rafters fabricated with their metal gusset plates. All of the more popular configurations and fastening systems were included in these studies. All the trussed rafters had adequate initial strength and stiffness.

Since this study began, tests of trussed rafters have continued. These tests have primarily been conducted to qualify new designs for code approval, or to check out new methods of analysis. Because of the special purpose of these tests, most are not reported in the general literature.

Few studies have investigated the effect of in-service conditions on the performance of trussed rafters. Luxford (1958) investigated the effect of changes in relative humidity on the strength and rigidity of trussed rafters with nail-glued joints and nailed joints. Both types of trussed rafters had ample strength and stiffness after exposure for normal service conditions, but nail-glued trussed rafters were considerably stiffer and stronger than the nailed trussed rafters.

Radcliffe and Sliker (1964) studied the effect of moisture content on trussed rafters with four connection systems (three different metal plates and nail-glued plywood gussets). One group was fabricated and tested at 10 percent moisture content, and another group was fabricated at 18 percent moisture content and tested at 6 percent. Trussed rafters fabricated at the higher moisture content lost 2 to 28 percent in ultimate strength compared to those fabricated at the lower moisture content. The loss in relative stiffness ranged from 5 to 29 percent.

Wilkinson (1966) investigated the effect of moisture cycling on the strength and rigidity of nailed wood and plywood, metal-plate, and glued plywood trussed-rafter joints fabricated at approximately 10, 17, and 25 percent moisture content. Specimens were cycled between 20 and 6 percent moisture content, after which they were tested and the results compared with those for matched uncycled specimens. Both cycled and control tension specimens (made from nominal 2- by 4-in. material) were loaded with 500 pounds during cycling. Elongation of the cycled tension specimens increased from 0 to 350 percent over the controls at a design load of 2,000 pounds. These values did not include residual elongations from the cycling. Losses in ultimate load ranged from 0 to 23 percent.

When this study began, there had been no long-time load test of trussed rafters. During the time since, Suddarth et al. (1981) have conducted long-term load tests on parallel-chord floor trusses. Trusses were loaded at half their design live load. The trusses deflected past L/360 in the second year of loading. Seasonal changes in the rate and amount of creep were observed.

Feldburg and Johansen (1976) presented the deflection data for trussed rafters subjected to alternating load during a year. During the year, the load was varied between 8 weeks of design dead load and 1 week of design dead load plus design snow load. Their study includes five different connection systems.

Specimens

W-type trussed rafters (fig. 1) with a slope of 4:12 and 28-foot span (outside to outside of bearing walls) were selected for this study. They were designed for a dead load of 10 pounds per square foot (lb/ft^2) on the bottom chord and a load of 26 lb/ft^2 on the upper chord. The 26 lb/ft^2 load was composed of 10 lb/ft^2 dead load plus 16 lb/ft^2 live load. These were the loads used by metal-plate manufacturers for their trussed rafter designs. The trusses are designed for a 2-foot spacing.

The trussed rafter members consisted of nominal 2- by 4-inch Douglas-fir (1-1/2 by 3-5/8 in.). The upper chords were a 1,500f Industrial grade; the lower chords were 1,200f Industrial grade; and the web members were Construction grade. The members were graded under 1963 WWPA grading rules. All material had a moisture content of approximately 10 percent at the time of fabrication.

Seven different connection systems were used:
(a) Nailed plywood.
(b) Nailed metal plate.
(c) Toothed metal plate.
(d) Barbed metal plate.
(e) Casein glue with plywood gussets.
(f) Phenol-resorcinol glue "A" with plywood gussets.
(g) Phenol-resorcinol glue "B" with plywood gussets.

All plywood gussets were 1/2-inch, exterior grade Douglas-fir. Sixpenny common nails were used for the nailed plywood trussed rafters and fourpenny common were used for the nail-glued trussed rafters. The metal truss plates were selected as being representative of three general classifications: (1) Those which rely on nails alone to carry loads transmitted through the joint, (2) those which rely on barbs and also some nails to carry the load, and (3) those which depend solely upon teeth punched in the plate to carry the load. The plates selected for this study from each of the three groups are shown in figure 2. A 1-1/2-inch-long annular-grooved nail, as recommended by the manufacturer, was used with the nailed metal plate.

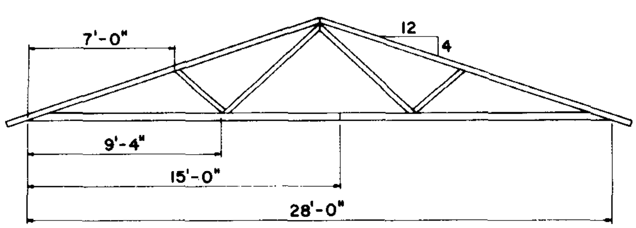

Figure 1.—Details of truss member location. All members are nominal 2 by 4's. (M140987)

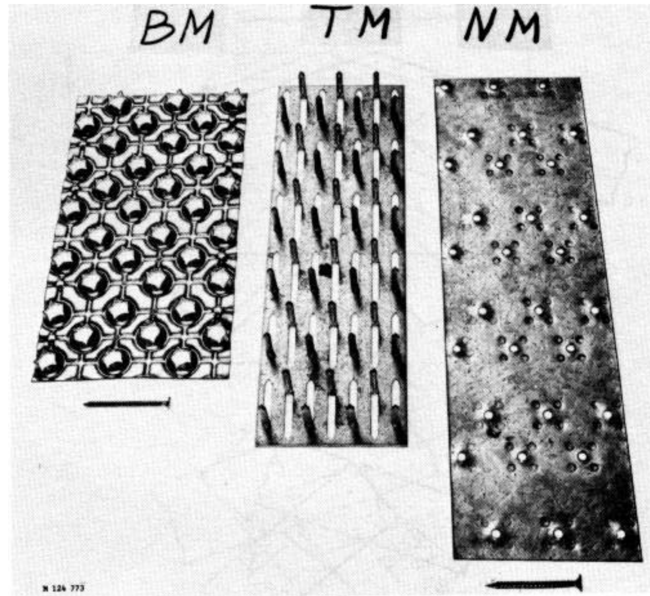

Figure 2.—Three types of metal plates selected for the longtime performance study. Left, barbed metal plate (20-gage); center, toothed plate (18-gage); and right, nailed metal plate (20-gage). (M 124773)

The casein glue that was used was water and mold resistant. Phenol-resorcinol "A" was a type of glue that has been used since about 1950 and has earned an excellent reputation for performance in glued-laminated white oak produced for the Navy and in heavy glued-laminated members for building construction. Phenol-resorcinol "B" was a faster setting glue developed in the 1960's.

Detailed layouts of joints, giving the size of gussets, number of nails, and locations of members, are shown in figures 3 through 7. Metal plate sizes were selected from trussed-rafter plans developed by the plate manufacturers. Gusset sizes for the glued trusses were determined using a shear stress of 50 pounds per square inch (lb/in.^{2}) and a shear load equal to the axial forces in the members.

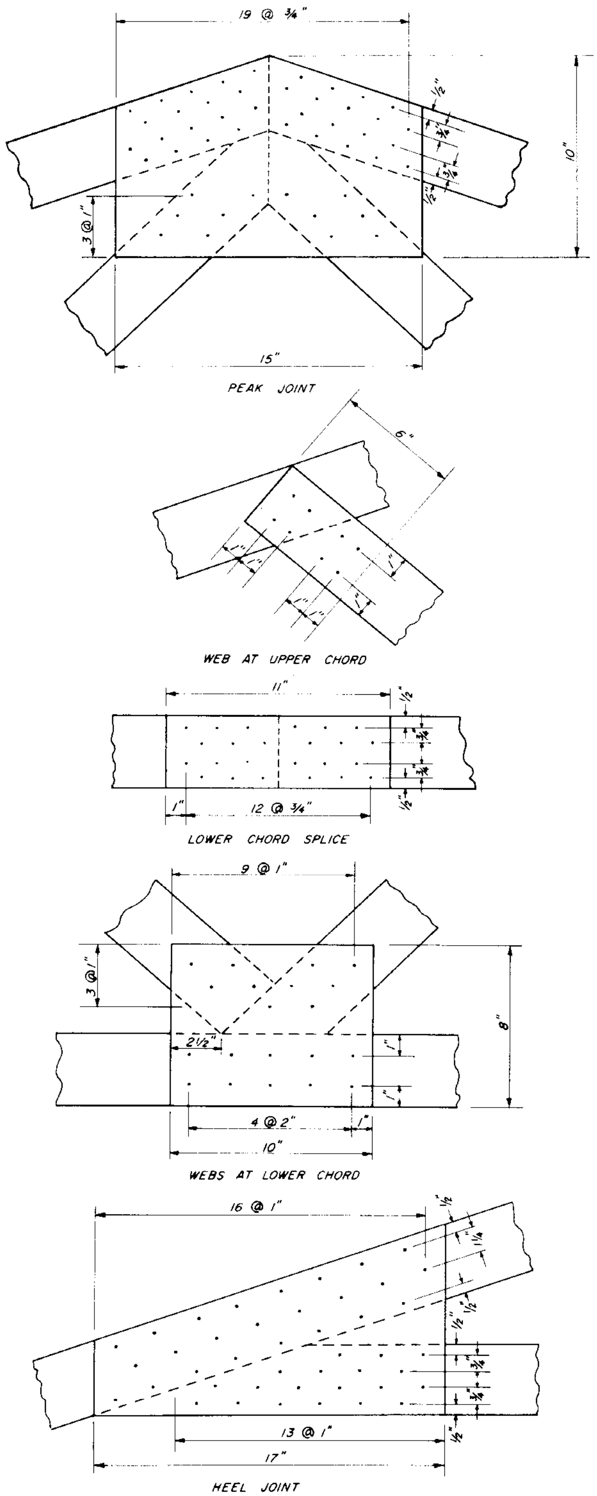

Figure 3.—Joint details for nailed plywood trussed rafters. All gussets were 1/2-inch, exterior grade, Douglas-fir. The grain direction ran the long dimension of each gusset. All nails were sixpenny common. (M 134833)

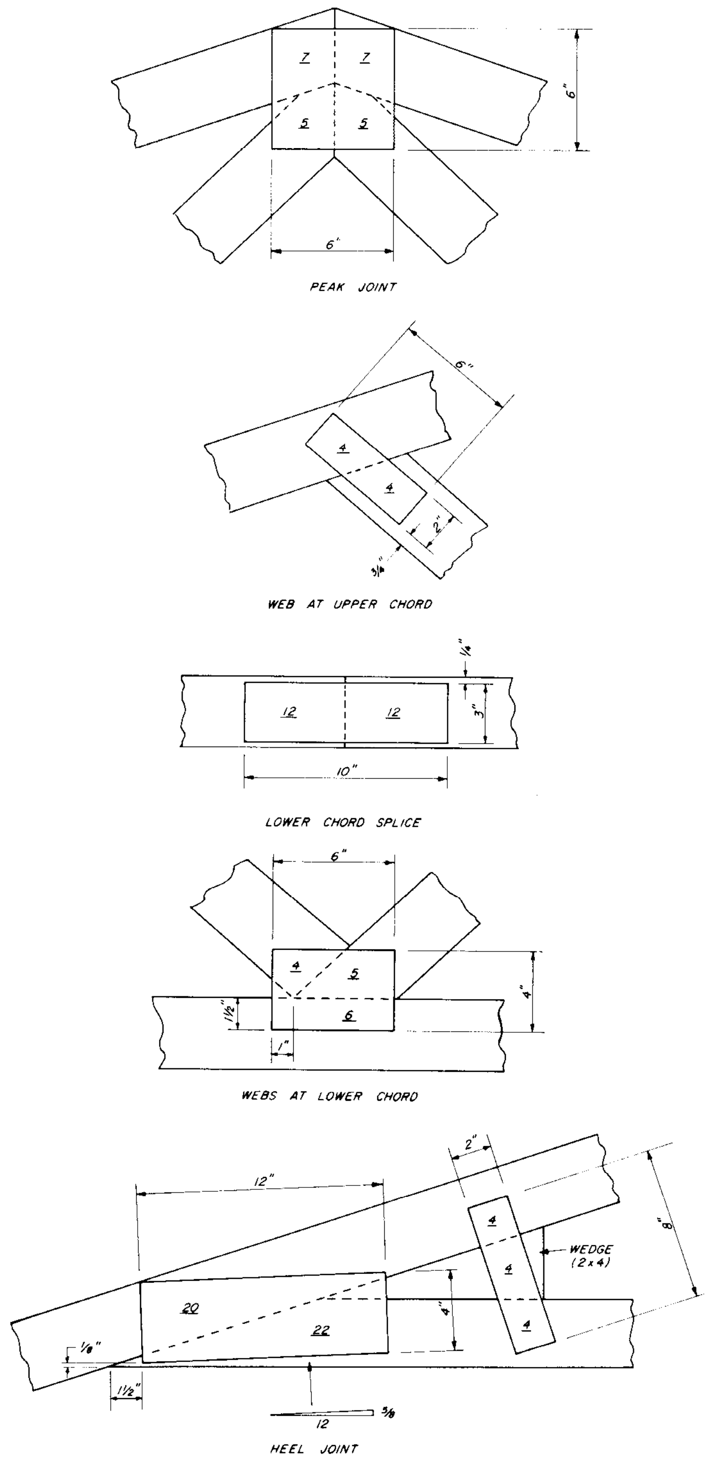

Figure 4.—Joint details for nailed metal plate trussed rafters. Numbers on gussets refer to the number of nails used. Nails were 1-1/2-inch-long annular grooved. Gussets were 20-gage galvanized sheet metal with punched holes. (M134836)

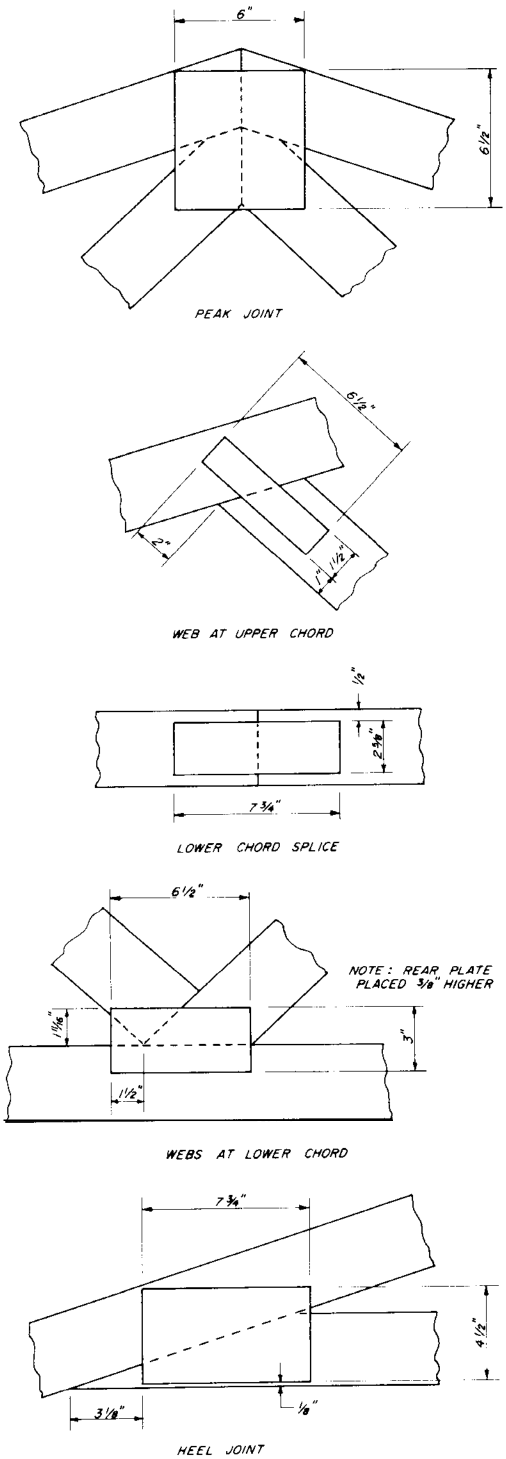

Figure 5.—Joint details for toothed metal plate trussed rafters. Plates were 18-gage galvanized sheet metal with 3/4-inch-long teeth. (M134835)

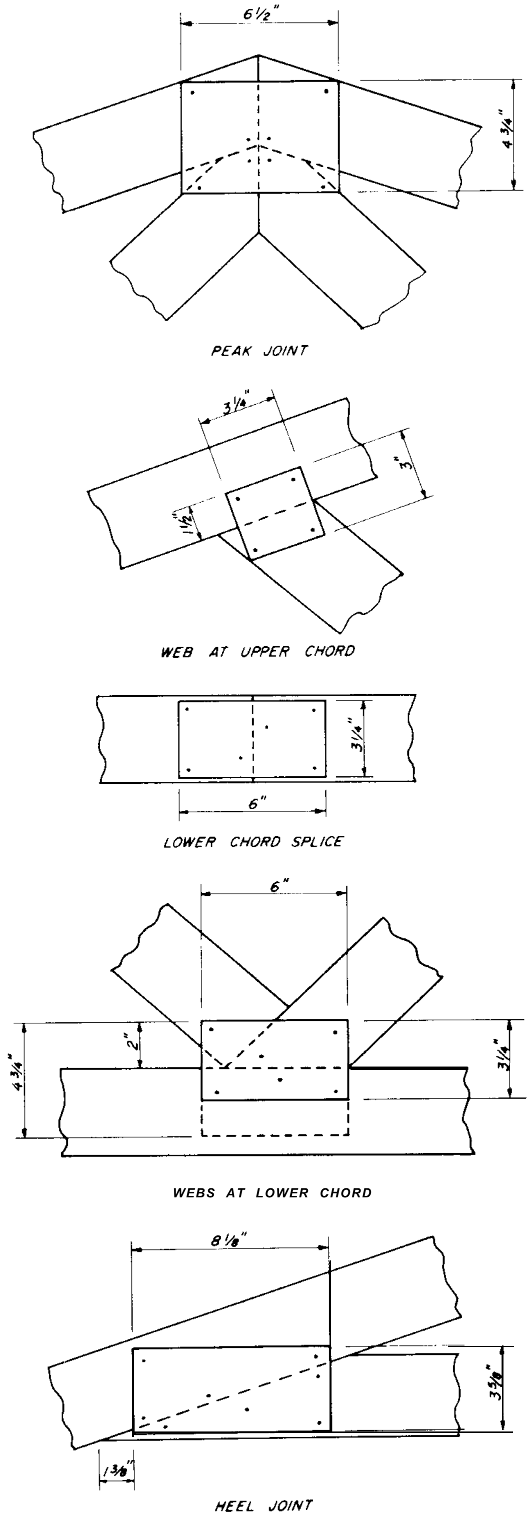

Figure 6.—Joint details for barbed metal plate trussed rafters. Plates were 20-gage galvanized sheet metal. Positioning nails were 1-1/2-inch-long annular-grooved nails. (M134832)

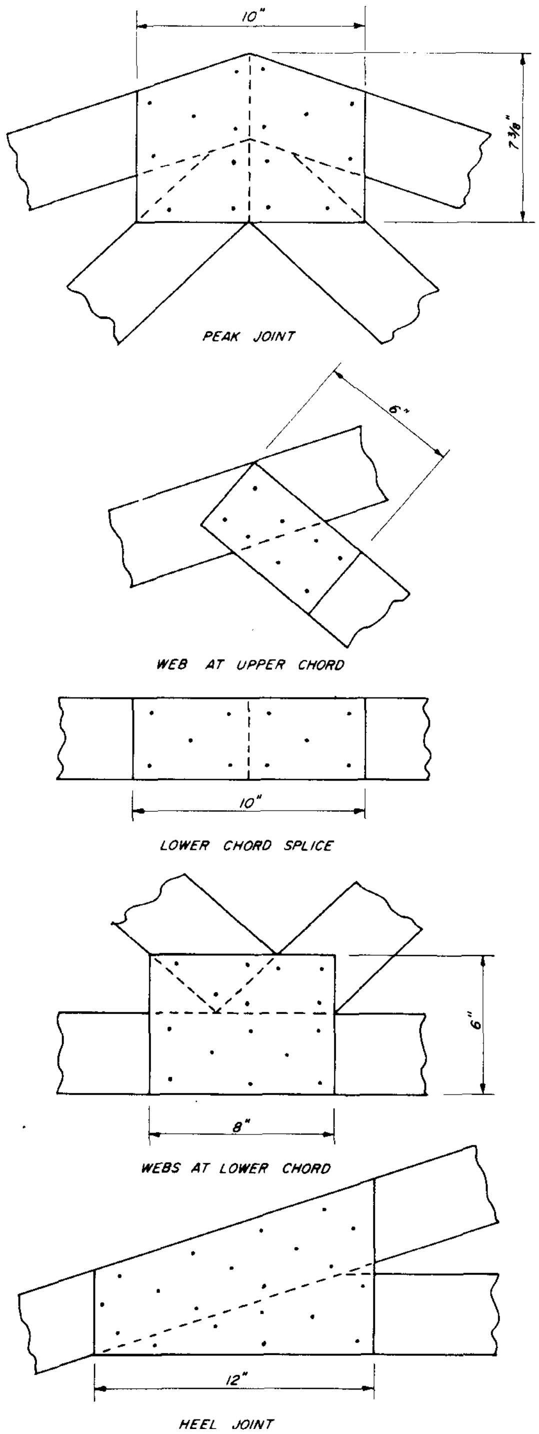

Figure 7.—Joint details for all nail-glued trussed rafters. All gussets were 1/2-inch, exterior grade, Douglas-fir plywood. Grain direction ran the long dimension of the gusset. Fourpenny common nails were used to apply pressure. Glues were: (1) Casein, (2) phenol-resorcinol "A," and (3) phenol-resorcinol "B." (M 134834)

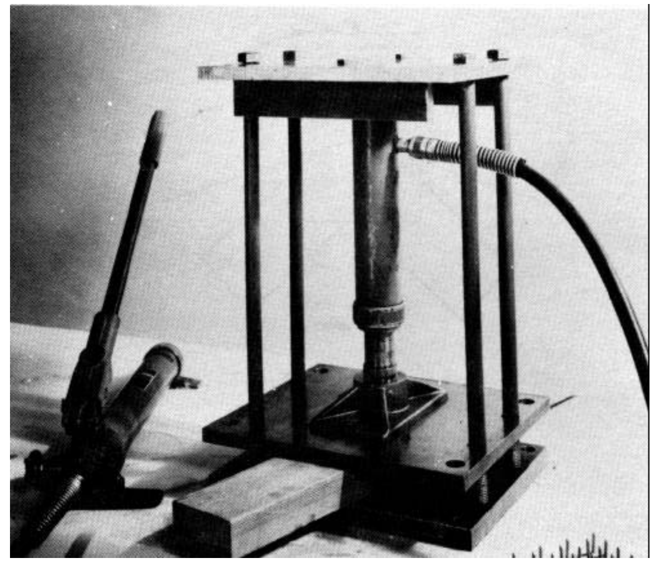

Figure 8.—Portable hydraulic jacking system used to apply toothed and barbed metal plates. (M 132794)

The trussed rafters were carefully assembled in the Forest Products Laboratory shop. The barbed and toothed metal plates were applied with a portable hydraulic jack (fig. 8). Plates were applied to one side of the trussed rafter; then it was turned over and plates applied to the opposite side. For the nail-glued trusses, gussets were applied to one side and allowed to set for at least 3 hours. They were then turned over and gussets applied to the other side. Room temperature during the gluing was 78° ± 4°F.

Before the trussed rafters were assembled, the bending stiffness (product of modulus of elasticity and moment of inertia of the cross section) from quarter-point loading on edge was determined for the 2 by 4's to be used for the chord members. This was done so that all trusses with the same connection systems could be fabricated with chords of similar bending stiffness. Thus, the results obtained after 5-, 10-, and 15-year periods were directly comparable on an initial stiffness basis. Cross-sectional dimensions, modulus of elasticity values, and initial moisture contents of the chord members are presented in table 1.

Table 1.—Dimensions, modulus of elasticity, and initial moisture content

Trussed rafter connection system	Years to be observed	Dimensions								Modulus of elasticity values				Initial moisture content[1]			
		Upper chords				Lower chords				Upper chords		Lower chords		Upper chords		Lower chords	
		Left side of truss[2]		Right side of truss[2]		Left side of truss[2]		Right side of truss[2]		Left side[2]	Right side[2]	Left side[2]	Right side[2]	Left side[2]	Right side[2]	Left side[2]	Right side[2]
		Width	Depth	Width	Depth	Width	Depth	Width	Depth								
		In								1,000 Lb/in.^{2}				Pct			
Nailed plywood gussets	0	1.49	3.62	1.49	3.58	1.48	3.57	1.47	3.56	1,800	1,860	2,050	2,120	12	10	9	10
	5	1.49	3.62	1.47	3.60	1.46	3.52	1.47	3.57	1,810	1,860	2,180	2,050	10	10	11	10
	10	1.49	3.62	1.48	3.61	1.48	3.56	1.43	3.56	1,780	1,790	2,100	2,270	10	10	10	12
	15	1.49	3.61	1.47	3.62	1.48	3.57	1.46	3.55	1,780	1,790	2,100	2,270	10	10	7	11
Nailed metal-plate gussets	0	1.48	3.61	1.47	3.57	1.49	3.58	1.48	3.57	2,310	2,400	1,520	1,540	10	11	9	10
	5	1.48	3.60	1.47	3.58	1.48	3.60	1.46	3.57	2,360	2,420	1,480	1,510	11	12	10	12
	10	1.47	3.57	1.49	3.62	1.48	3.59	1.47	3.59	2,420	2,300	1,510	1,500	12	11	10	9
	15	1.48	3.59	1.48	3.55	1.48	3.57	1.47	3.50	2,310	2,440	1,630	1,650	11	8	6	11
Toothed metal-plate gussets	0	1.48	3.53	1.47	3.60	1.46	3.53	1.45	3.52	2,060	1,960	2,100	2,110	10	12	10	10
	5	1.49	3.60	1.47	3.50	1.47	3.60	1.46	3.46	1,860	2,100	2,000	2,280	10	11	10	12
	10	1.49	3.60	1.48	3.49	1.47	3.60	1.47	3.55	1,980	2,220	1,950	1,980	11	10	10	12
	15	1.48	3.56	1.49	3.62	1.48	3.55	1.48	3.58	2,080	1,940	2,030	1,780	12	9	10	10
Barbed metal-plate gussets	0	1.47	3.58	1.49	3.59	1.47	3.56	1.47	3.49	2,200	2,150	1,820	1,760	10	10	12	10
	5	1.48	3.55	1.46	3.54	1.48	3.58	1.47	3.60	2,380	2,440	1,640	1,520	10	11	10	10
	10	1.47	3.56	1.47	3.59	1.47	3.56	1.48	3.59	2,320	2,300	1,690	1,530	10	11	8	9
	15	1.48	3.62	1.46	3.59	1.48	3.56	1.46	3.55	2,140	2,200	1,760	1,630	10	10	10	10
Nail-glued gussets, casein glue	0	1.46	3.53	1.47	3.61	1.49	3.59	1.47	3.58	2,310	2,150	1,770	1,630	10	11	9	11
	5	1.46	3.60	1.48	3.60	1.48	3.56	1.48	3.60	2,160	2,110	1,670	1,820	10	10	10	10
	10	1.47	3.54	1.49	3.60	1.47	3.59	1.48	3.58	2,220	2,080	1,890	1,710	10	10	9	10
	15	1.48	3.60	1.48	3.57	1.46	3.55	1.48	3.58	2.120	2,170	1,735	1,870	11	9	9	10
Nail-glued plywood gussets, phenol-resorcinol glue "A"	0	1.48	3.58	1.48	3.53	1.50	3.59	1.46	3.54	2,080	2,170	1,920	1,870	10	11	10	10
	5	1.49	3.61	1.48	3.58	1.47	3.55	1.52	3.52	2,060	2,120	1,990	1,750	11	10	11	10
	10	1.49	3.59	1.48	3.60	1.47	3.59	1.48	3.59	2,060	2,040	1,760	1,920	11	10	11	10
	15	1.47	3.60	1.47	3.60	1.48	3.56	1.44	3.53	2,110	2,090	1,960	1,830	11	10	10	10
Nail-glued plywood gussets, phenol-resorcinol glue "B"	0	1.47	3.59	1.46	3.52	1.49	3.60	1.45	3.55	2,480	2,620	1,460	1,520	10	11	9	10
	5	1.48	3.59	1.49	3.61	1.47	3.48	1.49	3.57	2,490	2,420	1,590	1,500	10	11	7	8
	10	1.47	3.60	1.45	3.57	1.47	3.57	1.48	3.56	2,570	2,640	1,370	1,370	10	10	9	9
	15	1.48	3.57	1.46	3.60	1.48	3.59	1.48	3.58	2,540	2,500	1,360	1,470	8	10	10	10

[1] Moisture contents were determined with an electric moisture meter.

[2] Left and right side of trussed rafters are arbitrary designations, determined by the way one faces to make the deflection readings.

Experimental Procedure

One trussed rafter of each type of connection system was loaded to maximum load in the laboratory as a control. Three more with each type of connection system were loaded and subjected to a sheltered outdoor exposure. At the end of 5-year intervals, one truss of each construction was loaded to maximum load in the laboratory.

Laboratory Evaluation

The experimental arrangement for the laboratory loading is shown in figure 9. Twenty-five-pound weights were first suspended from the lower chord at 15-inch intervals to represent the design load of 20 pounds per foot (10 lb/ft^2 on a 2-ft spacing). Load was then applied to the upper chord at eight points through a system of cables and pulleys, spaced at 3-1/2-foot intervals. The loads were measured with electric load cells located at the reactions. A 6-inch-long bearing plate was used atop each load cell, which made the distance from center to center of reactions 27 feet 6 inches.

For the control trusses, midspan deflection was measured with a scale, and a taut wire stretched from pins located at the intersections of the reactions and the centerline of the lower chord. The midspan deflection of all other trusses was measured with a potentiometer displacement transducer mounted on a yoke which rested on pins located at the intersection of the reactions and centerline of the lower chord.

Longtime Evaluation

Trussed rafters were located in an open-sided pole building on the Forest Products Laboratory grounds in Madison, Wis. The building prevented rain or snow from falling on the trusses, while subjecting them to changes in temperature and relative humidity.

The loaded trusses are shown in figure 10. Each trussed rafter was supported and loaded independently. A load of 20 pounds per foot (design dead load of 10 lb/ft^2 for a 2-ft spacing) was applied to the lower chords, and a load of 36 pounds per foot (design dead load plus half of the design live load) was applied to the upper chords. This load represented the expected truss load during its service life. Weights were carried by cables attached to the chords at 2-foot intervals. The trussed rafters were supported on 4-1/2-inch-wide bearing areas. Load span was 28 feet from outside to outside of supports.

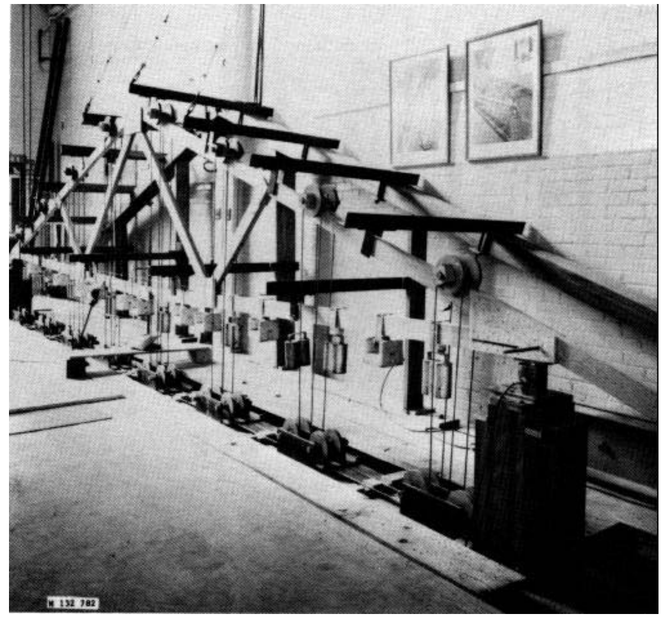

Figure 9.—Experimental arrangement for laboratory evaluation of trussed rafters. Twenty-five-pound weights were suspended at 15-inch intervals along lower chord. Loads were applied at 3-1/2-foot intervals along upper chord. The distance from center to center of load cells was 27 feet 6 inches. (M132782)

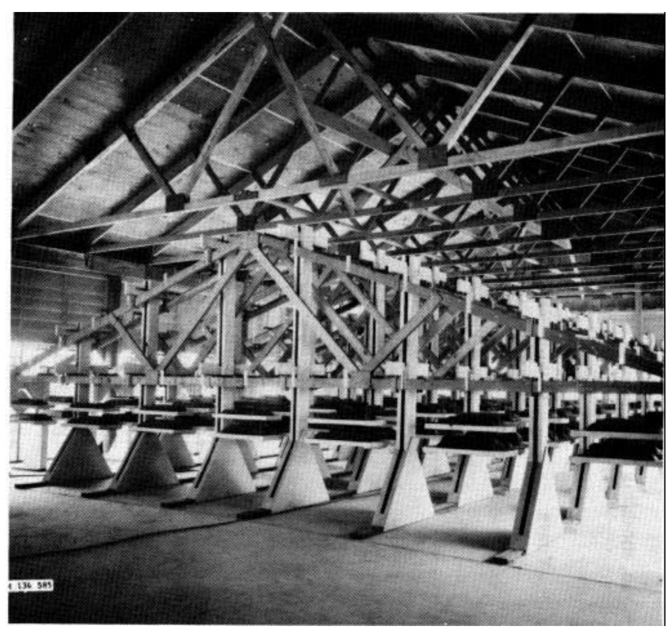

Figure 10.—Experimental arrangement for dead-loading of trussed rafters. Loads were suspended at P-foot intervals along the chords. (M 134585)

The deformed shape of the chord members was determined from deflection readings taken at 2-foot intervals along the upper and lower chords. A scale and mirror fastened at each point, and a taut line (fig. 11) were used to read the deflections. Sighting the line so that it covered its image in the mirror eliminated parallax errors. The scale was read where the line crossed. The line was stretched over pins located at the intersections of the centerlines of the upper and lower chords, which were about 1 inch outside the edge of the bearing area. The line for the upper chords was also stretched over a pin located at the centerline of upper chords at the peak. The relative movement between a scale suspended from this pin and the taut line along the lower chord gave the vertical movement of the peak.

The trusses were initially loaded in September 1967. Deflection readings were taken daily during the first week and then weekly up to 3 months. After 3 months, deflection readings were taken every 3 to 4 months for the first 5 years. For the next 5 years, deflections were read twice a year. During the last 5 years, deflections were read yearly.

Trussed rafters were randomly assigned to be tested in the laboratory at 5-year intervals. All trusses in a 5-year group were placed side by side in the pole building.

Temperature inside the pole building was recorded continuously during the first 10 years. Temperature recording was discontinued during the last 5 years because the recorder broke.

Moisture content changes were determined on 16-inch-long pieces cut from the upper chord overhang. The initial moisture content was determined from a sample cut from each piece. The initial weight was also determined. The pieces were placed with the trussed rafters in the pole building, and were weighed each time the truss deflections were taken. The moisture contents at later times were calculated from the weights and initial moisture contents.

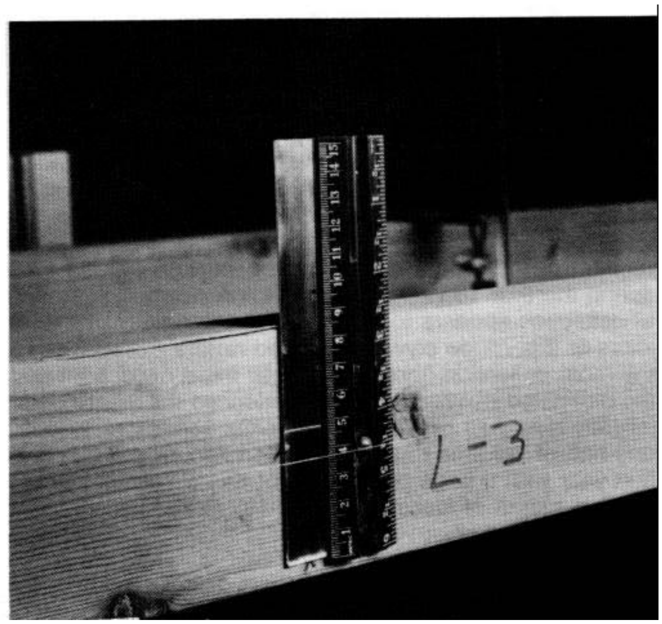

Figure 11.—Scale, mirror, and line arrangement used for measuring deflection. (M143586)

Results

Longtime Deflection Results

Figures 12 through 18 present the midspan deflection and vertical movement of the peak during the loading history of the trussed rafters. Also shown is the 1-week recovery of the seven trussed rafters which were unloaded after 5 years, and the seven which were unloaded after 10 years. Some of the deflection values are summarized in table 2.

All the trussed rafters experienced deflection with time during the 5 or 10 years of observation. The total amount of deflection appears to be related to the rigidity of the joints as the nailed plywood trussed rafters experienced the most deflection (three times their initial deflection) and the nail-glued trussed rafters experienced the least (slightly less than two times their initial deflection). About one-half of the time related deflection occurred within the first year with a large percentage of this occurring within the first month of loading (figs. 12-18). Creep halted during the 15 years of observation.

It appears that the trusses recovered deflection during the last 5 years, figures 12-18. This apparent recovery may be due to experimental error caused by either (1) creep deflection of the pins over which the lines were stretched or (2) not having the lines stretched taut enough to remove all the sag, perhaps due to slight corrosion of the pins. Because of this apparent recovery, it appears that stiffer trusses were selected for the Idyear evaluation, table 2. No attempt was made to select certain trusses for any given period. It was planned to have equal stiffness trusses for each loading period.

Using deflection criteria of span over 360[2] which yields a deflection of 0.93 inch for the 28-foot span, all of the trussed rafters are still acceptable in their performance after 15 years except the nailed plywood trussed rafters. Another assumption that is sometimes made in design of beams is that the initial deflection will double with time under permanent loading. This assumption of a factor of two appears to hold for trussed rafters with glued connections, but a factor of three appears to be more appropriate for those with mechanical fasteners.

[2] These criteria are listed in “Design Specifications for Light Metal Plate Connected Wood Trusses,” TPI-65. Truss Plate Institute.

Table 2.—Average deflection at midspan of lower chord and vertical deflection of peak for trussed rafters under longtime loading

Connection system	Average deflection[1] of trussed rafters after-							
	0 days	300 days	600 days	1,200 days	1,800 days (5 yrs)	2,400 days	3,600 days (10 yrs)	5,400 days (15 yrs)
	in.							
MIDSPAN DEFLECTION OF LOWER CHORD								
Nailed plywood gussets	0.33	0.68	0.73	0.80	0.90	0.85	0.98	0.94
Nailed metal-plate gussets	.31	.52	.56	.59	.63	.62	.71	.69
Toothed metal-plate gussets	.25	.47	.49	.53	.60	.59	.69	.67
Barbed metal-plate gussets	.25	.49	.53	.57	.63	.60	.66	.59
Nail-glued plywood gussets, casein glue	.22	.31	.33	.32	.36	.33	.39	.28
Nail-glued plywood gussets, phenol resorcinol glue “A”	.21	.32	.34	.34	.38	.35	.39	.30
Nail-glued plywood gussets, phenol resorcinol glue “B”	.24	.36	.40	.38	.43	.45	.49	.39
VERTICAL DEFLECTION OF PEAK								
Nailed plywood gussets	.19	.39	.43	.45	.54	.47	.57	[2]—
Nailed metal-plate gussets	.16	.28	.32	.31	.34	.31	.35	
Toothed metal-plate gussets	.16	.27	.28	.29	.33	.33	.40	
Barbed metal-plate gussets	.16	.31	.35	.37	.38	.39	.43	
Nail-glued plywood gussets, casein glue	.14	.21	.23	.23	.24	.25	.29	
Nail-glued plywood gussets. phenol resorcinol glue	.13	.20	.22	.21	.24	.19	.25	
Nail-glued plywood gussets. phenol resorcinol glue “B”	.14	.26	.26	.25	.29	.31	.33	

[1] Deflection values are the average for three trussed rafters through 1,800 days, two trussed rafters through 3,600 days, and one trussed rafter for 5,400 days.

[2] Scale for measuring this deflection was broken before completion of the study.

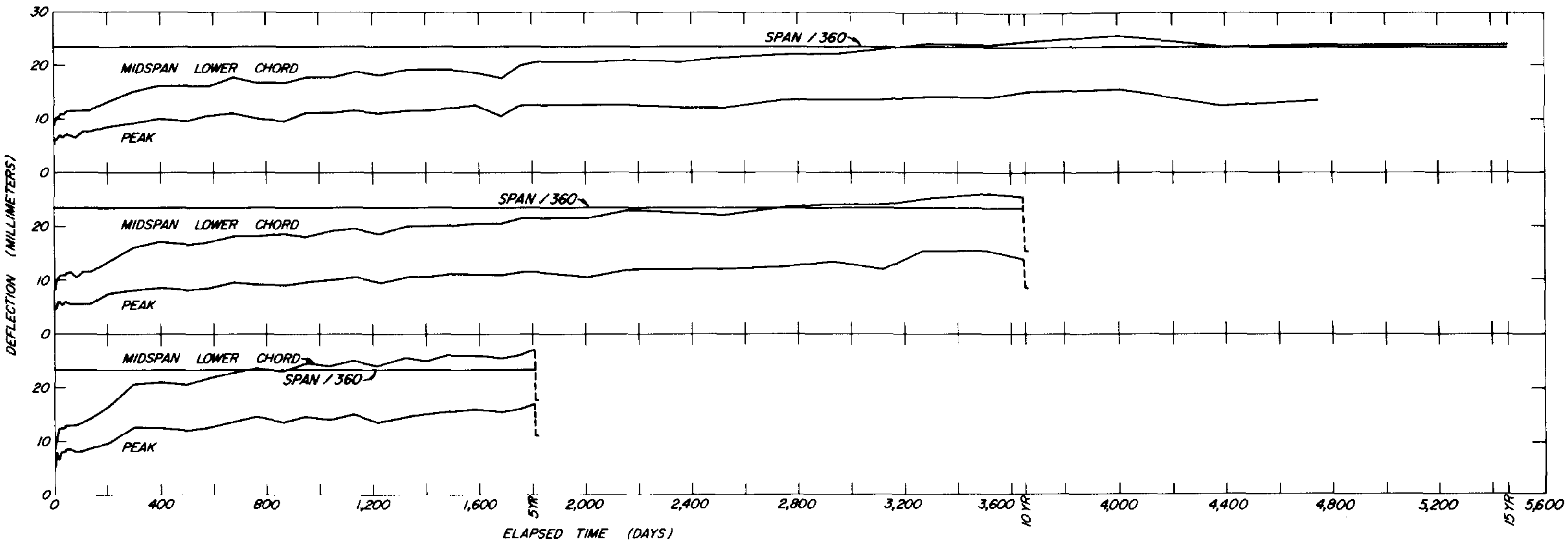

Figure 12.—Midspan deflection and movement of peak for nailed plywood gusset trussed rafters. Top, truss observed for 15 years; center, truss observed for 10 years; and bottom, truss observed for 5 years. Observation began in September 1967. (M146368)

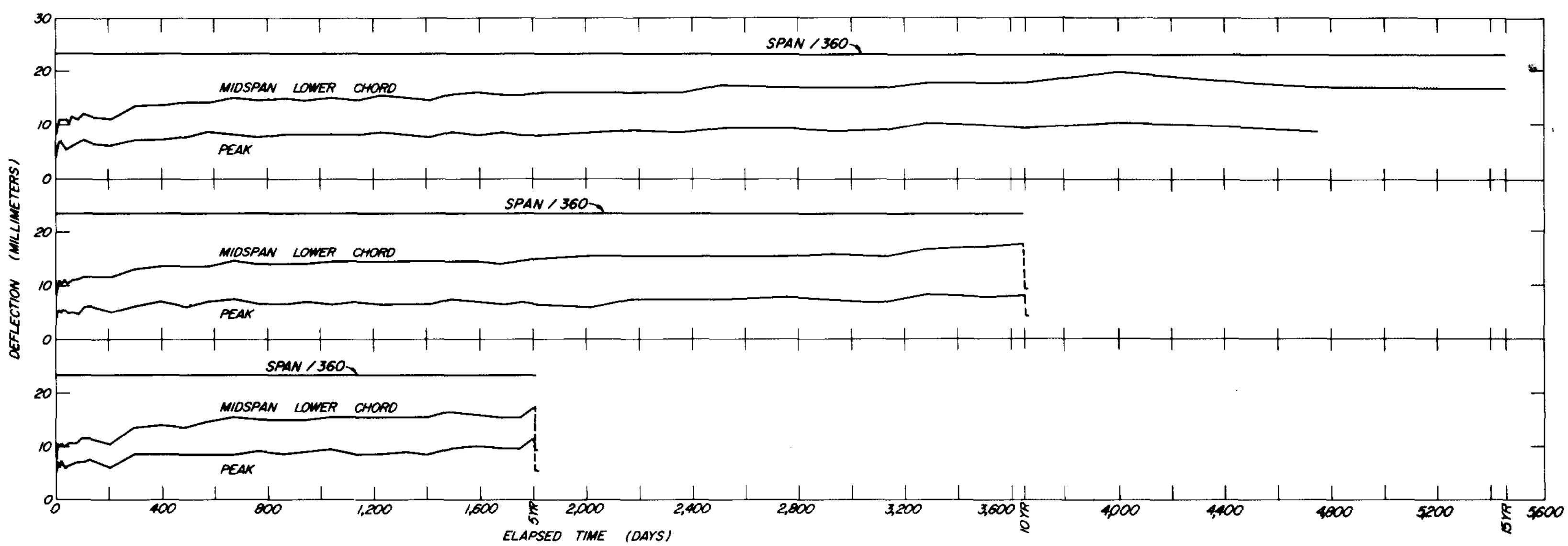

Figure 13.—Midspan deflection and movement of peak for nailed metal plate trussed rafters. Top, truss observed for 15 years; center, truss observed for 10 years; and bottom, truss observed 5 years. Observation began in September 1967. (M146367)

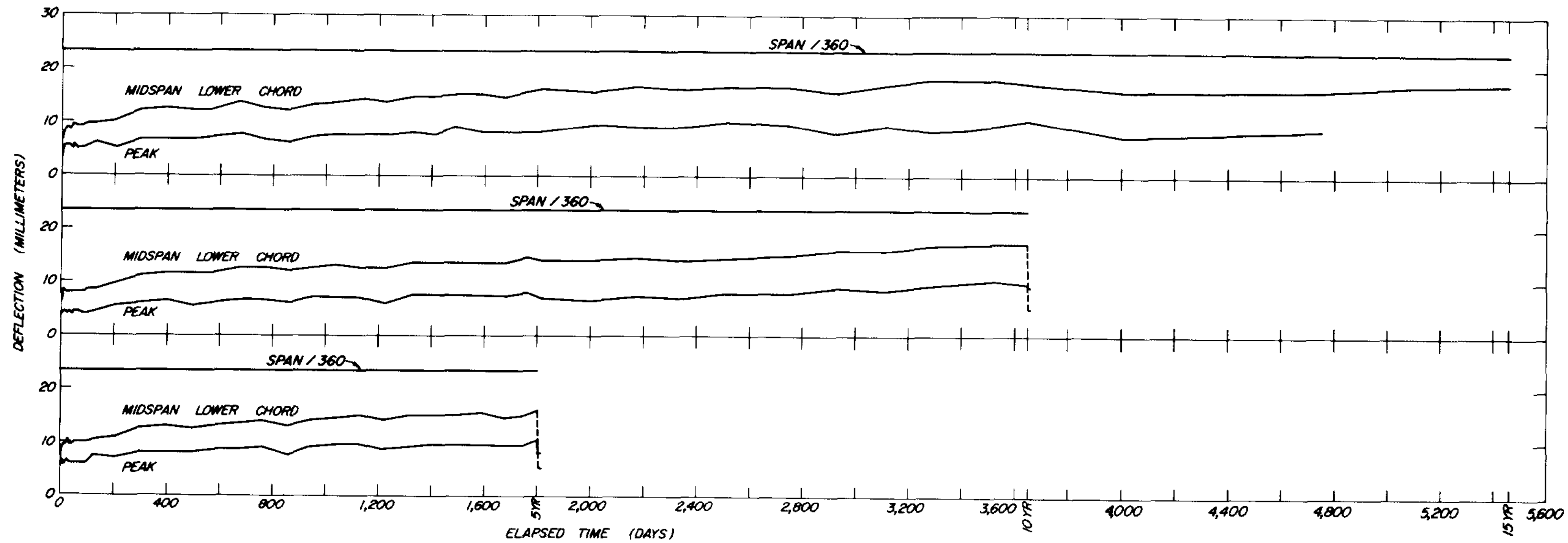

Figure 14.—Midspan deflection and movement of peak for toothed metal plate trussed rafters, Top, truss observed for 15 years; center, truss observed for 10 years; and bottom, truss observed for 5 years. Observation began in September 1967. (M146369)

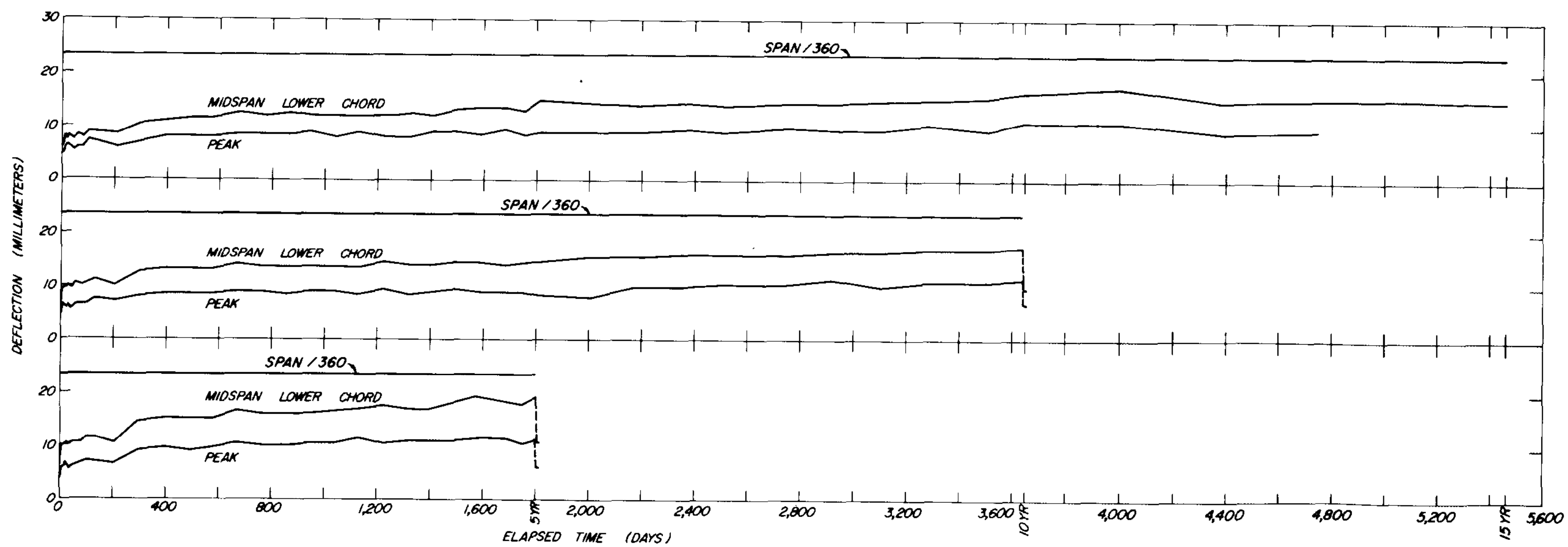

Figure 15.—Midspan deflection and movement of peak for barbed metal plate trussed rafters. Top, truss observed for 15 years; center, truss observed for 10 years; and bottom, truss observed 5 years, Observation began in September 1967. (M146370)

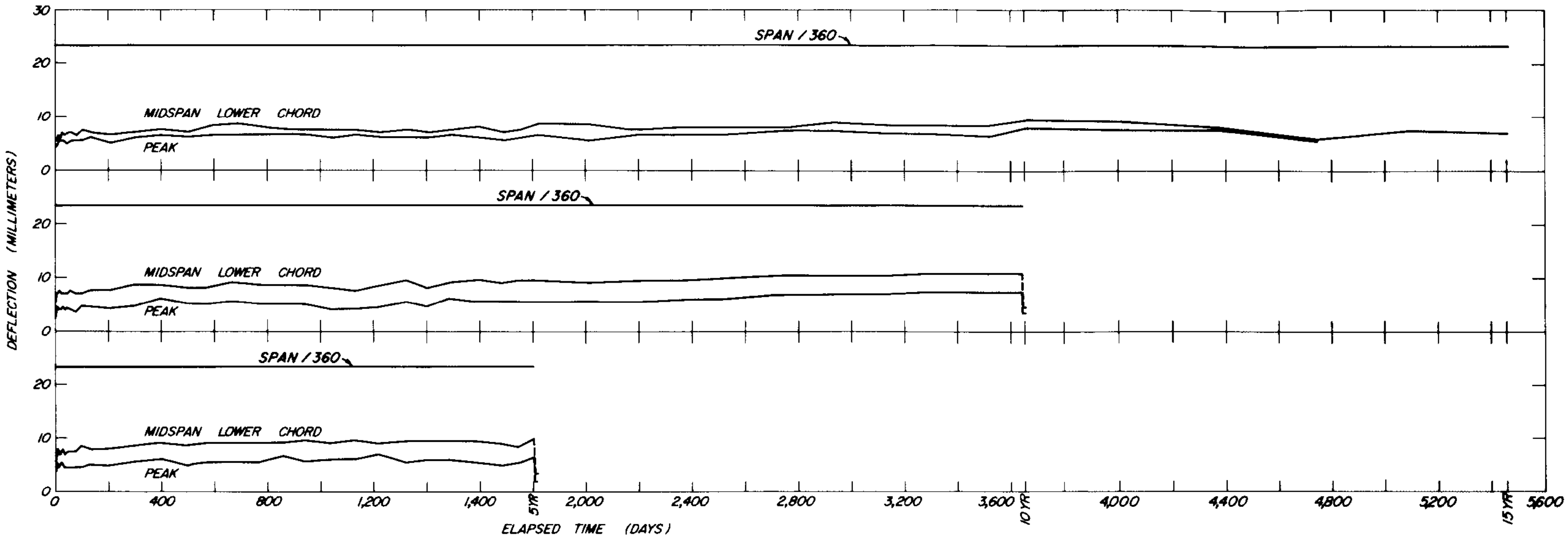

Figure 16.—Midspan deflection and movement of peak for casein-glued plywood gusseted trussed rafters. Top, truss observed for 15 years; center, truss observed for 10 years; and bottom, truss observed for 5 years. Observation began in September 1967. (M146371)

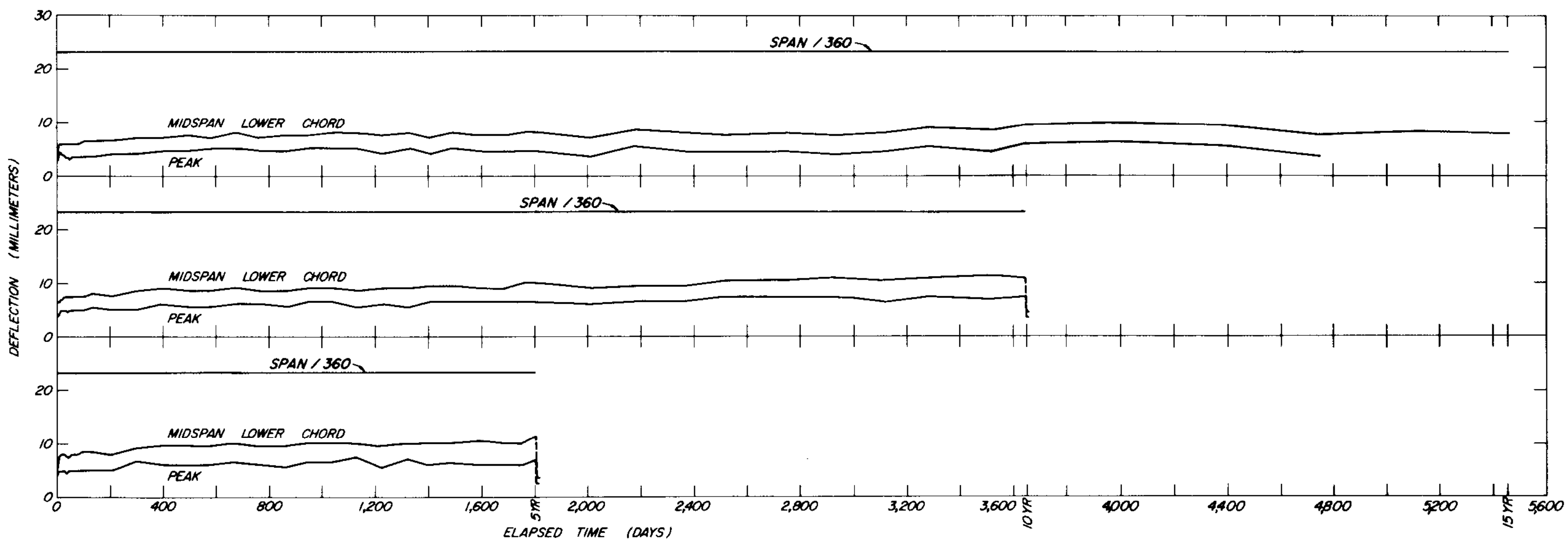

Figure 17.—Midspan deflection and movement of peak for trussed rafters with plywood gusset glued with phenol-resorcinol glue "A." Top, truss observed for 15 years; center, truss observed for 10 years; and bottom, truss observed 5 years. Observation began in September 1967. (M146373)

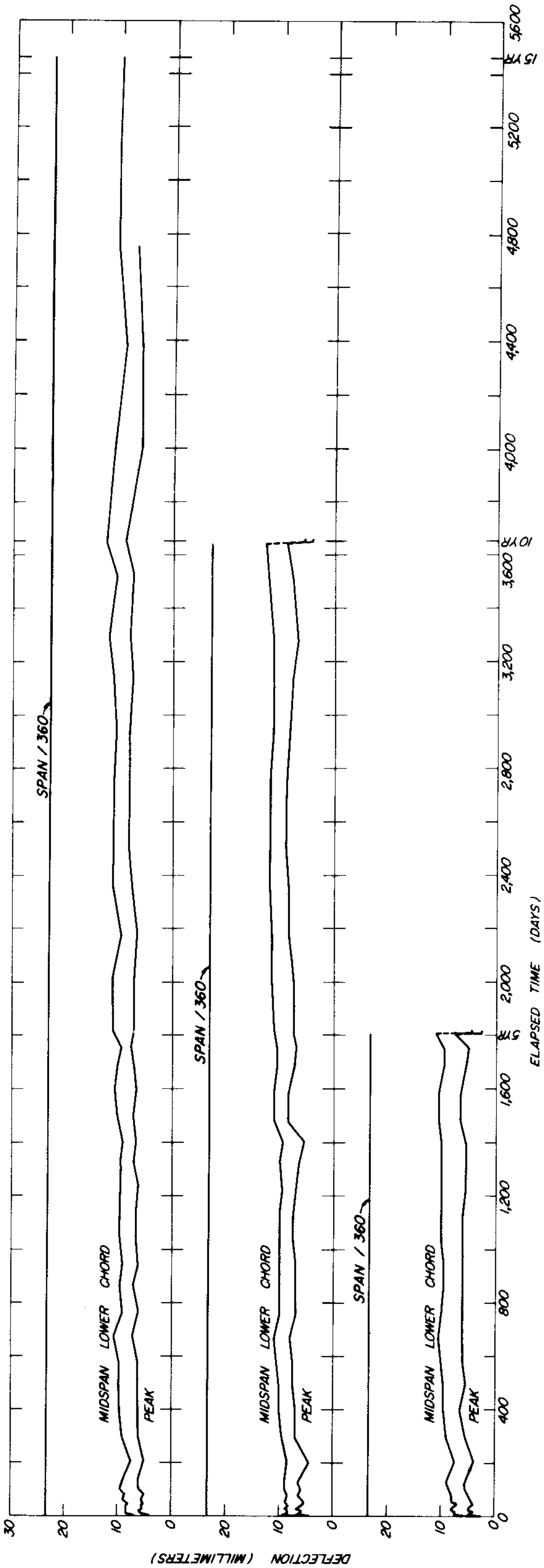

Figure 18.—Midspan deflection and movement of peak for trussed rafters with plywood gusset glued with phenol-resorcinol glue "B." Top, truss observed for 15 years; center, truss observed for 10 years; and bottom, truss observed for 5 years. Observation began in September 1967. (M146372)

Average moisture contents of the wood samples placed with the trusses during longtime loading are presented in figure 19. Moisture content fluctuated during the 15 years of observation, but gradually decreased from about 14 percent to about 12 percent. The highest observed value was 15.5 percent and the lowest was 10.6 percent. The wood samples were not weighed during the last 5 years, but only at the time the trusses were unloaded. The samples had an average moisture content of 12.4 percent after 15 years. Moisture samples from the failed trusses had moisture contents of 10 to 11 percent after 15 years.

Average temperatures in the pole building during the first 5 years of trussed rafter loading are shown in figure 20. Temperatures followed a similar pattern during the second 5 years. No record was kept during the last 5 years.

Changing temperature and moisture content may explain some of the fluctuations in the deflection curves of figures 12 through 18. No attempt was made to correlate deflection changes with measured environmental conditions. It should be noted that present code requirements for energy conservation produce more severe environmental conditions than the trusses experienced in this study. These code requirements did not exist when this study was initiated.

Laboratory Evaluation

Table 3 presents the results of the laboratory evaluation of trussed rafters tested initially and those tested after 5, 10, and 15 years of observation. The midspan deflection (not including irrecoverable creep deflection) at design load was about 1/4 inch plus for all the trussed rafters, except the 5-, 10-, and 15-year-old nailed plywood gusset trussed rafters. However, even for these nailed plywood rafters, deflection was still at an acceptable level of about 0.43 inch. All the span-deflection ratios more than met the usual accepted criterion of 360. All ratios of maximum load to design load considerably exceeded the usually accepted performance criterion of 2.5.

In general, the 5, 10, and 15 years of loading and exposure did not seem to affect the stiffness or strength of the trussed rafters with the exception of the nailed plywood gusset trussed rafters, which had about a 30 percent loss in stiffness. Examination of the failure of the 5-year nailed plywood truss disclosed that the upper chord contained a l-l/e-inch diameter knot which extended across the entire width of the narrow face. The maximum permissible knot for the grade used was 7/8 inch; thus this 2 by 4 should not have been in this grade. This would account for the lower strength, but would not account for the loss in stiffness.

Most failures (21 of 28) occurred in bending in the upper chords as shown in figures 21 and 22. Other modes of failure were by failure of the joints (figs. 23, 24, 25, and 26) and by tension in the lower chord (fig. 27).

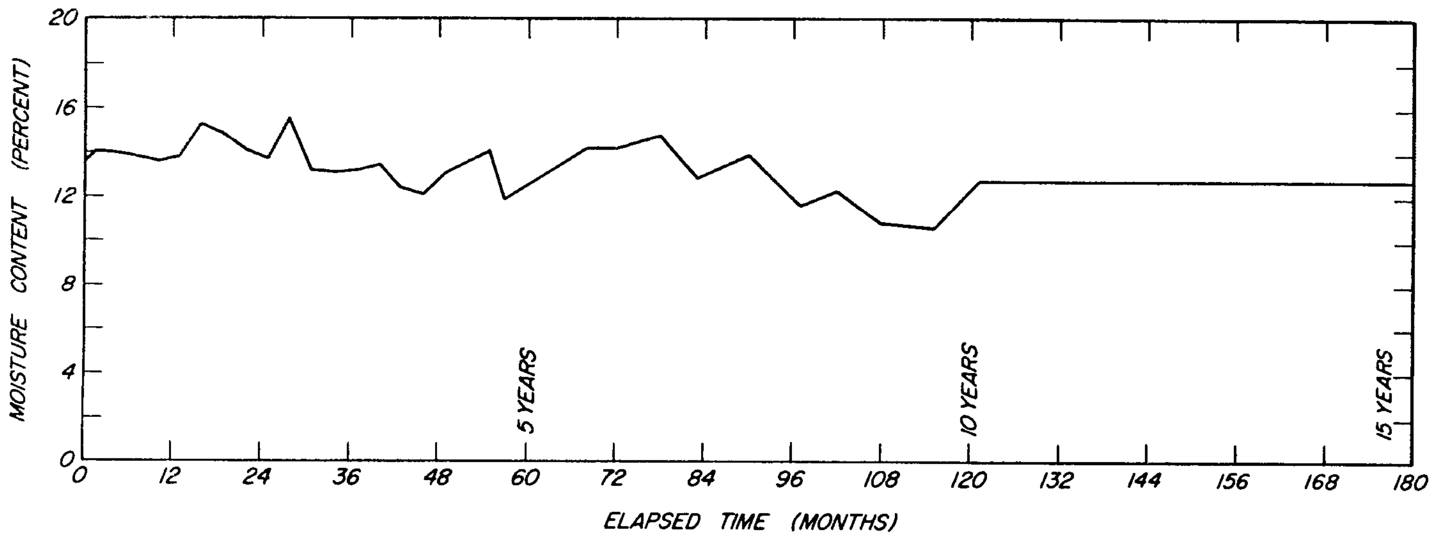

Figure 19.—Moisture content of wood samples placed with trussed rafters during longtime loading. (Samples were cut from overhang of trusses.) (M146374)

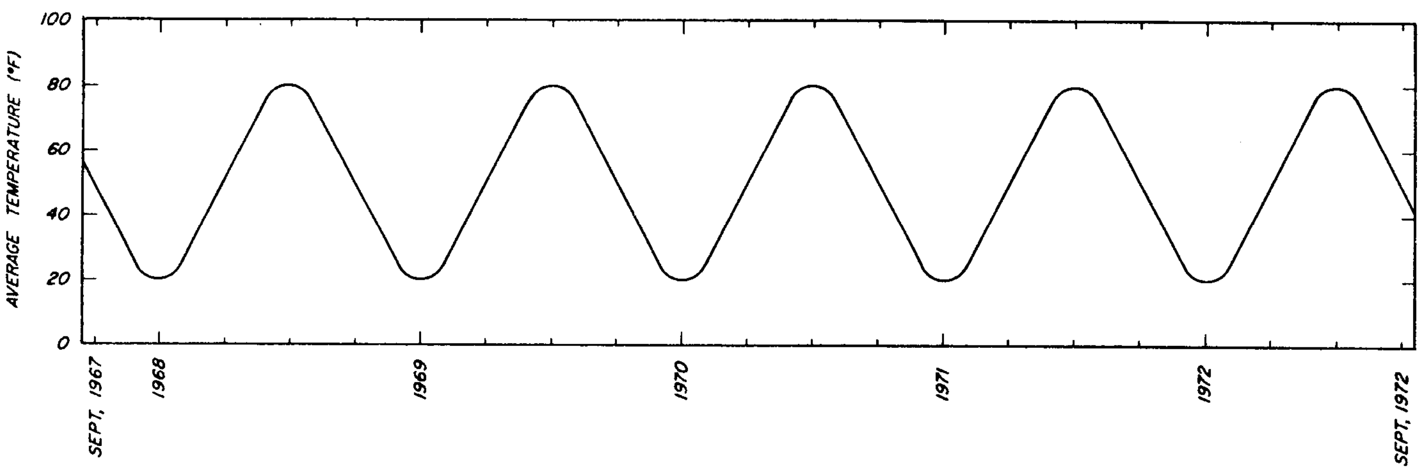

Figure 20.—Average temperatures inside the pole building during the first 5 years of trussed rafter loading. (ML835520)

Table 3.—Results of laboratory loading to maximum load of Douglas-fir trussed rafters

Gusset material	Connector	Trussed rafter age	Midspan deflection at design dead plus live load	Span deflection ratio at design load	Total load on truss at failure		Ratio of load at failure to design load	
					Lower chord	Upper chord	Lower chord	Upper chord
			In.		– – – –Lb/ft– – – –			
1/2-inch plywood, exterior grade	6d common nails	**Control**	0.29	1,160	20	256	1	4.9
		5 years	.43	780	20	[3]202	1	3.9
		10 years	.42	800	20	219	1	4.2
		15 years	.39	862	20	227	1	4.4
Galvanized sheet metal (20-gage) with punched holes	1 -1/2-inch-long annularly threaded nails	Control	.29	1,160	20	295	1	5.7
		5 years	.27	1,240	20	325	1	6.2
		10 years	.32	1,050	20	294	1	5.6
		15 years	.30	1,120	20	306	1	5.9
Toothed metal truss plate (18-gage galvanized sheet metal)	—	Control	.23	1,460	20	298	1	5.7
		5 years	.30	1,120	20	305	1	5.9
		10 years	.33	1,020	20	323	1	6.2
		15 years	.28	1,200	20	301	1	5.8
Barbed metal truss plate (20-gage galvanized sheet metal)	—	Control	.22	1,530	20	269	1	5.2
		5 years	.30	1,120	20	249	1	5.9
		10 years	.28	1,200	20	300	1	5.8
		15 years	.28	1,200	20	275	1	5.3
1/2-inch plywood, exterior grade	Casein glue and 4d nails	Control	.24	1,400	20	398	1	7.6
		5 years	.27	1,240	20	285	1	5.5
		10 years	.24	1,400	20	322	1	6.2
		15 years	.20	1.680	20	327	1	6.6
I/P-inch plywood, exterior grade	Phenol-resorcinol "A" and 4d nails	Control	.22	1,530	20	324	1	6.2
		5 years	.23	1,460	20	360	1	6.9
		10 years	.24	1,400	20	296	1	5.7
		15 years	.20	1,680	20	301	1	5.8
1/2-inch plywood, exterior grade	Phenol-resorcinol "B" and 4d nails	Control	.23	1,460	20	295	1	5.7
		5 years	.23	1,460	20	299	1	5.7
		10 years	.24	1,400	20	250	1	4.8
		15 years	.24	1,400	20	270	1	5.2

[1] Design dead load was 20 lb per lineal ft on lower and upper chords. Design live load was 32 lb per lineal ft on the top chord. The point of reference for deflection was over the center of the reactions. The distance from center to center of reactions was 27 ft 6 in. This deflection does not include any irrecoverable deflection from longtime loading.

[2] The span was 28 ft from outside to outside of bearing areas.

[3] Broke at upper chord knot which was larger than allowed by the grading rules.

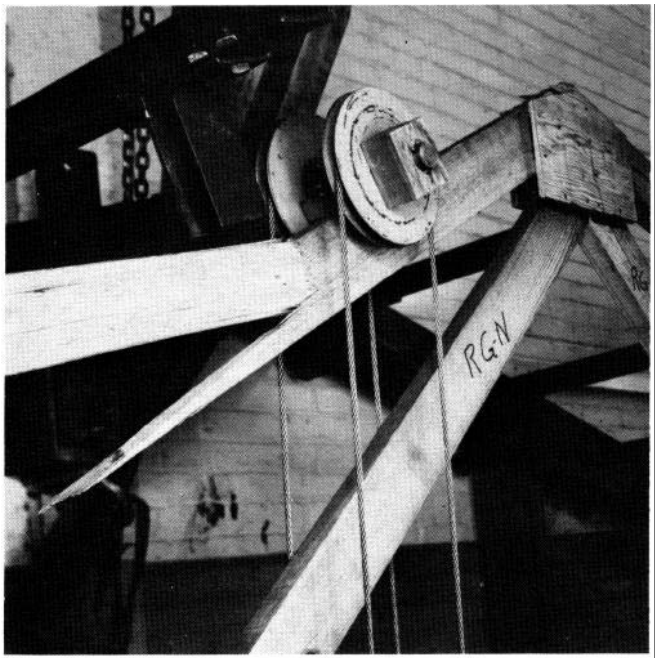

Figure PI.-Typical failure of trussed rafters in upper chord between peak and compression member. (M 132865)

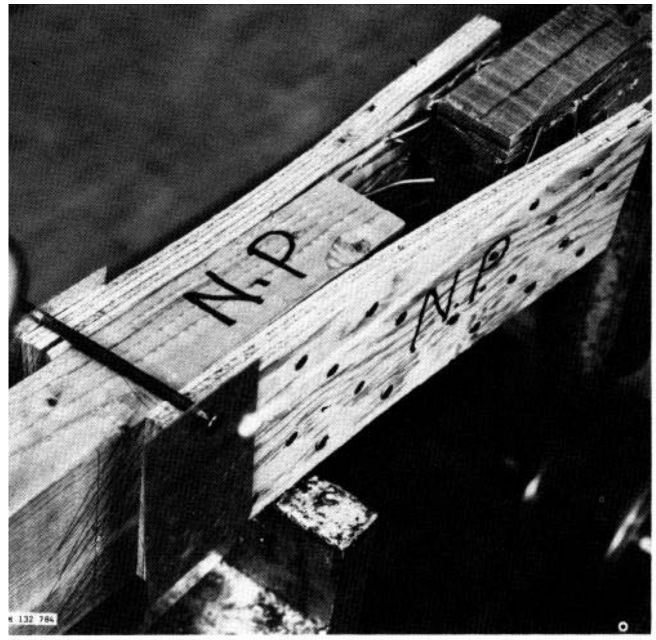

Figure 23.—Failure of control trussed rafter with nailed plywood gussets. Failure was at the lower chord splice. (M 132784)

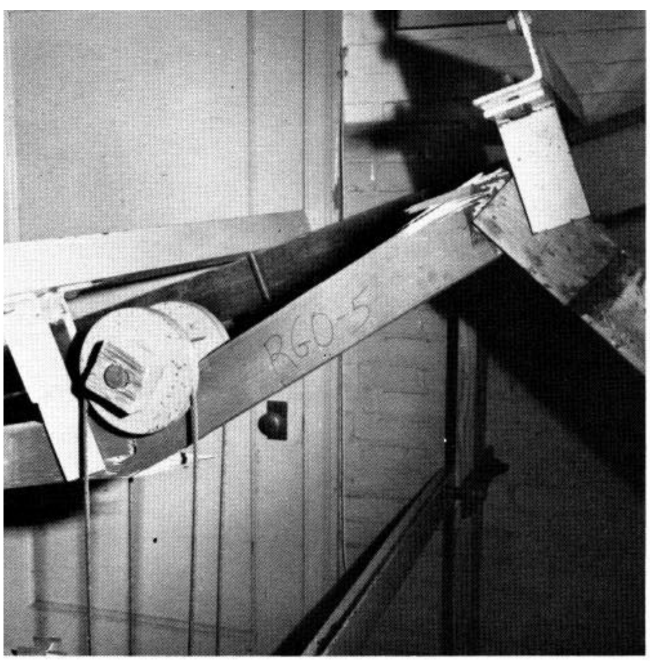

Figure 22.—Typical failure of trussed rafter in upper chord over compression member. (M140589-1)

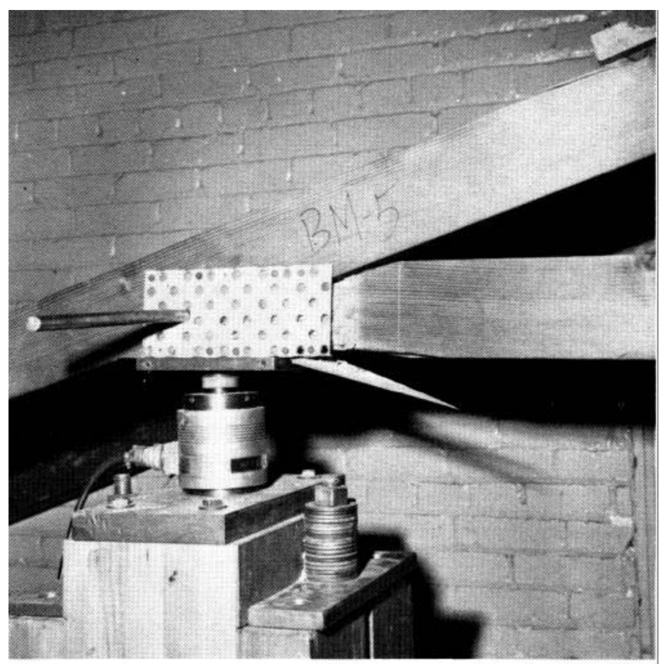

Figure 24.—Failure of 5-year-old barbed metal-plate gusset trussed rafter in heel joint. (M140589-9)

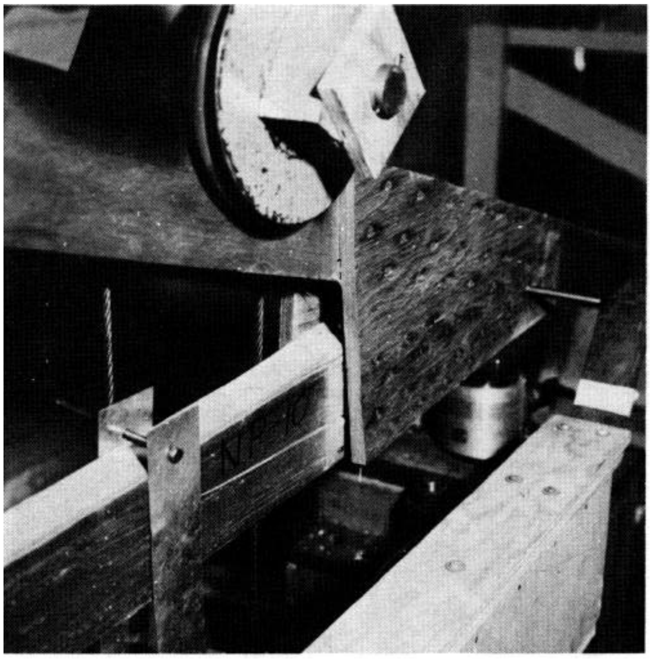

Figure 25.—Failure of 10-year-old nailed plywood gusset trussed rafter in heel joint. (M 145840-2)

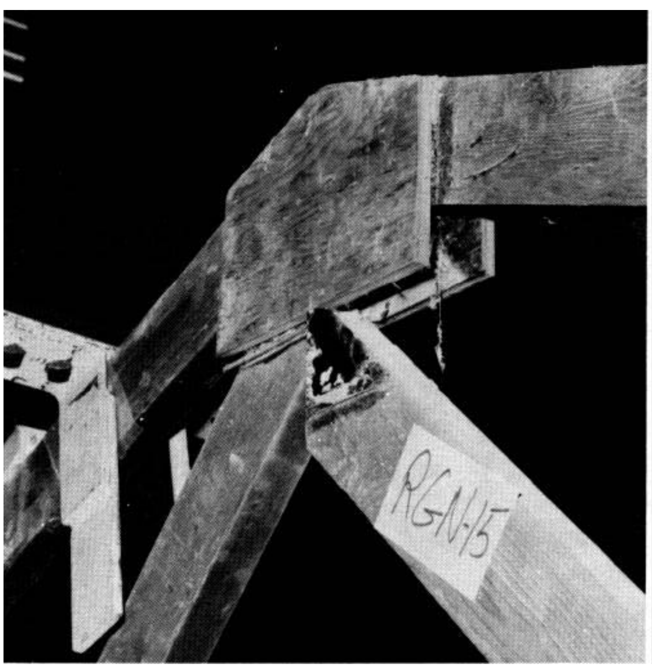

Figure 26.—Failure of 15-year-old phenol-resorcinol glued trussed rafter at the peak gusset. (M150974-7)

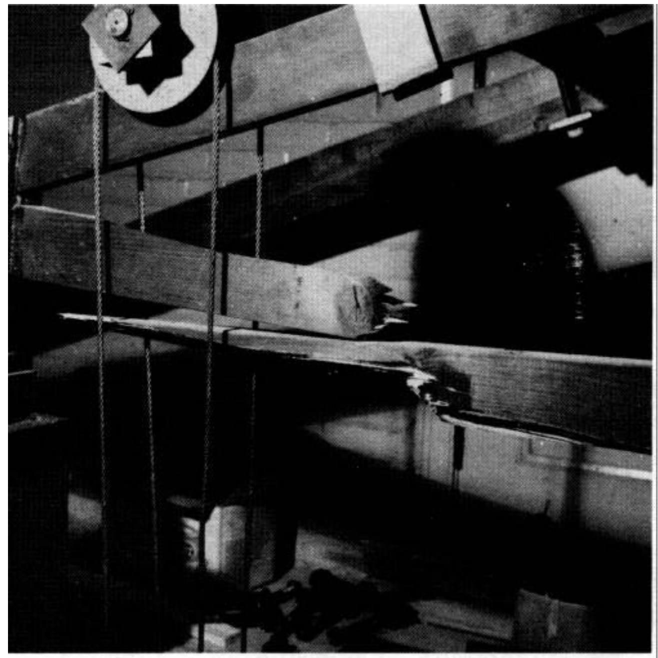

Figure 27.—Failure of lo-year-old phenol-resorcinol "B" glued plywood gusset trussed rafter in tension in the lower chord. (M145840-7)

Conclusions

The following conclusions are based on data obtained after 15 years of longtime loading of trussed rafters. One should keep in mind that environmental conditions in this study were not as severe as trusses may experience under present code requirements.

1. All the trussed rafters deflected under load with time. The amount of deflection appears to be related to the joint rigidity, with ratios of total to initial deflection of:
(a) three for the nailed plywood gusset trusses,
(b) two and one-half for the metal plate gusset trusses, and
(c) less than two for the nailed-glued gusset trusses.
Most of the creep occured during early stages of exposure. Deflection values are at an acceptable level after 15 years, based on a criterion for span divided by 360 with the exception of the nailed plywood gusset trussed rafters.

2. There appears to be no appreciable effect upon strength and stiffness as determined from laboratory evaluation after 5, 10, and 15 years of exposure, with the exception of the nailed plywood gusset trussed rafters which had a 30 percent reduction in stiffness. All the trussed rafters still meet acceptable short-time performance criteria.

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