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Duration of Load on Bolted Joints

A Pilot Study

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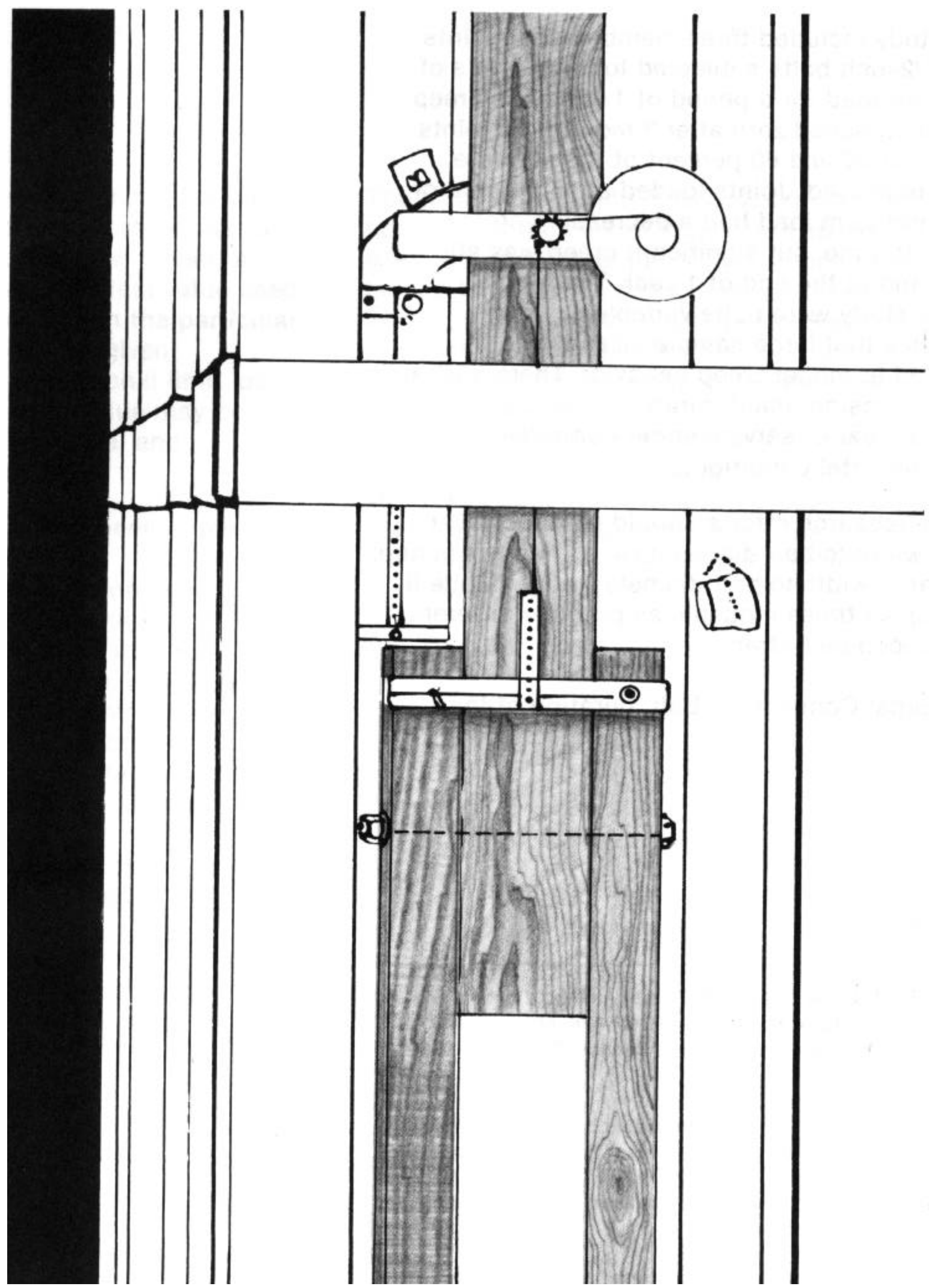

Abstract

Design values for bolted joints are adjusted for the effect of duration of load by using an arbitrary factor based on bending tests of small clear wood beams. Designers of timber structures need a more realistic factor. This report describes an initial effort to determine the effect of time under load on bolted joints. This is the first such study in the United States.

The study included three-member wood joints with 1/2-inch bolts subjected to three levels of constant load for a period of 1 year. The creep rate approached zero after 3 months for joints loaded at 30 and 60 percent of the ultimate short-term load. Joints loaded at 85 percent of the short-term load had a decreasing creep rate with time, but significant creep was still occurring at the end of 1 year. The results of this study were quite variable, which indicates that large sample sizes would be required to model creep behavior. There appears to be an insignificant duration-of-load effect for the first year of service under controlled environmental conditions.

Future research efforts should be directed at short width-to-bolt diameter ratios (Mode I failure) and large width-to-bolt diameter ratios (Mode III failure), as these modes may produce different time-dependent effects.

Keywords: Connection, bolt, duration of load.

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Duration of Load on Bolted Joints
A Pilot Study

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Introduction

Published design values for mechanical fasteners in wood are derived by modifying test results for such effects as variability of results, moisture content, and duration of load. The test value used as a basis for design depends upon the particular fastener and may be the load at a given deformation, the apparent proportional limit load, or the ultimate load. The design value may be further modified for various physical and geometrical properties of the joint.

Arbitrary adjustment factors have been applied to fastener test values to account for duration-of-load effects. These factors are primarily based on results of bending tests of small clear wood specimens under long-term constant load. The factors have been applied to all fastener values, whether the controlling joint property is the wood property or a combination of wood and fastener properties. The factors are also applied whether the test value is an ultimate load or a load at a given deformation. Those arbitrary factors have been used because only limited data exist for time under load effects on joints.

The trend in reliability-based design concepts has pointed out the lack of knowledge about mechanical fastener joints and, in particular, the lack of knowledge on the duration-of-load effects. With the new limit states-based codes, there is a need to understand time effects on ultimate strength and on deformation at given loads.

This report describes an initial effort to determine the time effects of load on bolted joints. The study was limited to one species, one bolt diameter, and one joint geometry, as it was intended as an initial effort for determining the need for additional studies.

Literature Review

Palka (1981) has done a selective literature review on the effect of load duration upon timber fasteners. Palka's review revealed that (1) the most frequently used fasteners in light-timber constructions are nails and truss plates; (2) the most common fasteners may be considered as variants of pins or dowels; (3) both the short- and long-term behavior of timber joints can be predicted from an understanding of the behavior of five major physical components; (4) the short-term deflection of wooden structures is dominated by the lumber elements, while their long-term deflection is dominated by joint behavior; (5) both short- and long-term joint strength and stiffness can be substantially increased by gluing mechanical fasteners to, or into, wooden structural elements; and (6) a damage accumulation model developed for describing the long-term behavior of lumber can be readily adopted for describing the long-term behavior of timber joints.

Palka further states that complete theoretical and experimental evaluation of both short- and long-term behavior of timber joints would require analytical models and test data for each of the five major physical components of timber joints. These components are (1) the flexural strength and stiffness of single pins; (2) the force required for their withdrawal; (3) the bearing strength and stiffness of wood members under the pins; (4) the lateral strength and stiffness of single-pin joints; and (5) the lateral strength and stiffness of multiple-pin joints.

Based on his literature review, Palka (1982) proposed a general approach for the development of design procedures concerning the long-term behavior of timber joints. He developed appropriate testing procedures and data acquisition systems and suggested a plan for initiating load-duration experiments on truss-plate joints. Palka (1983) reported work performed on testing the short-term behavior of truss-plate joints, on modeling the short-term behavior of truss-plate joints, and on testing the long-term behavior of truss-plate joints. Palka began creep testing of 24 truss-plate joints on a small test frame built for evaluating the most economical methods of collecting long-term joint test data.

Soltis and Wilkinson (1987) have shown that the European yield theory predicts the short-term behavior of bolted connections. This yield theory assumes that the bearing capacity of a bolted connection is attained when either (a) the compressive strength of the wood beneath the bolt is exceeded (Mode I failure) or (b) one or more plastic hinges develop in the bolt (Mode II or III failure). These assumptions provide for several modes of failure, depending on connection member dimensions, member strength, and bolt strength. Because of the different failure modes, the effect of duration of load may be more important for Mode I than for Mode III failures.

No research in the United States has been done on duration of load on bolted joints.

Experimental Methods

Specimens

The specimens were three-member wood joints (fig. 1) with a single bolt. The main members were 3 inches wide and the side members were 1-1/2 inches wide. All members were 1-1/2 inches thick. All material was Douglas-fir with a moisture content of approximately 10 percent.

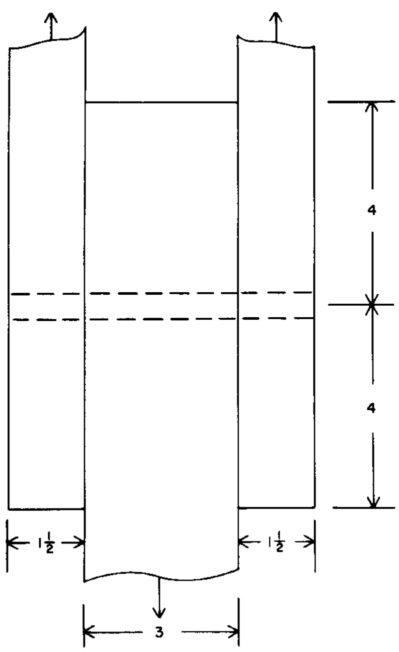

Figure 1 —Specimen geometry. Member thickness was 1-1/2 inches. (All dimensions are inches.) (ML88 5387)

Bolts were 1/2 inch in diameter and 7 inches in length. They conformed to ASTM Standard A 307 (Low Carbon Steel Externally and Internally Threaded Standard Fasteners). Washers were used under the bolt head and the nut. Nuts were finger-tight. The bolt holes were 9/16 inch in diameter.

The specimens had a ratio of main member width-to-bolt diameter of six (Mode II failure). This ratio was selected because it is commonly found in glulam construction.

End distance was 4 inches in both main and side members.

Load Conditions

For this study, four load conditions were used:

(a) Short-term ramp load (constant test machine head movement of 0.05 inch per minute).

(b) Constant load of 4,080 pounds–85 percent of the short-term mean.

(c) Constant load of 2,880 pounds–60 percent of the short-term mean.

(d) Constant load of 1,440 pounds–30 percent of the short-term mean.

All loads were applied in tension. Sixteen replications were evaluated at each load condition.

Matching

The specimen members were cut from 12-foot-long No. 2 and Better grade 2 by 4's. One piece from each 2 by 4 (fig. 2) was assigned to a joint within one of the four load conditions. No attempt was made to match side members within a joint or to match main and side members within a joint.

The area near the bolt hole was clear of knots. Some members did have rather large knots away from the bolt.

Testing Procedures

The short-term specimens were loaded in tension in a universal testing machine. Load-deformation curves were recorded to failure load. Test machine head movement was used to measure deformation.

The constant load test utilized tension test frames which were designed to load full-size structural lumber. Specimens were suspended in the frames (fig. 3) and the load applied through a system of pulleys and cables where weights were attached. The machines were located in controlled conditions which maintained the lumber at a constant moisture content of. 10 percent.

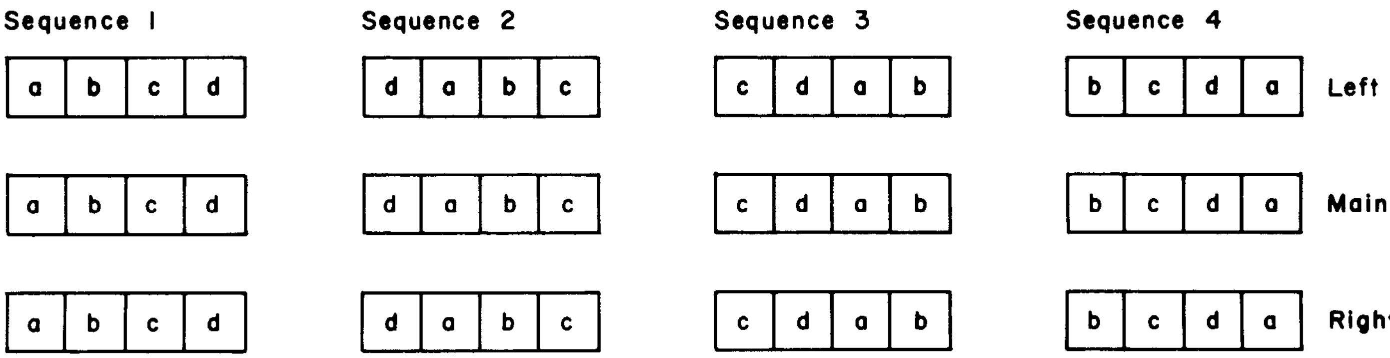

Figure P-Scheme for matching specimens between the four load conditions (a, *b, c, or d) for left, main, and right-side member. Each sequence* was *repeated 4 times to obtain 16 replications. (ML88 5386)*

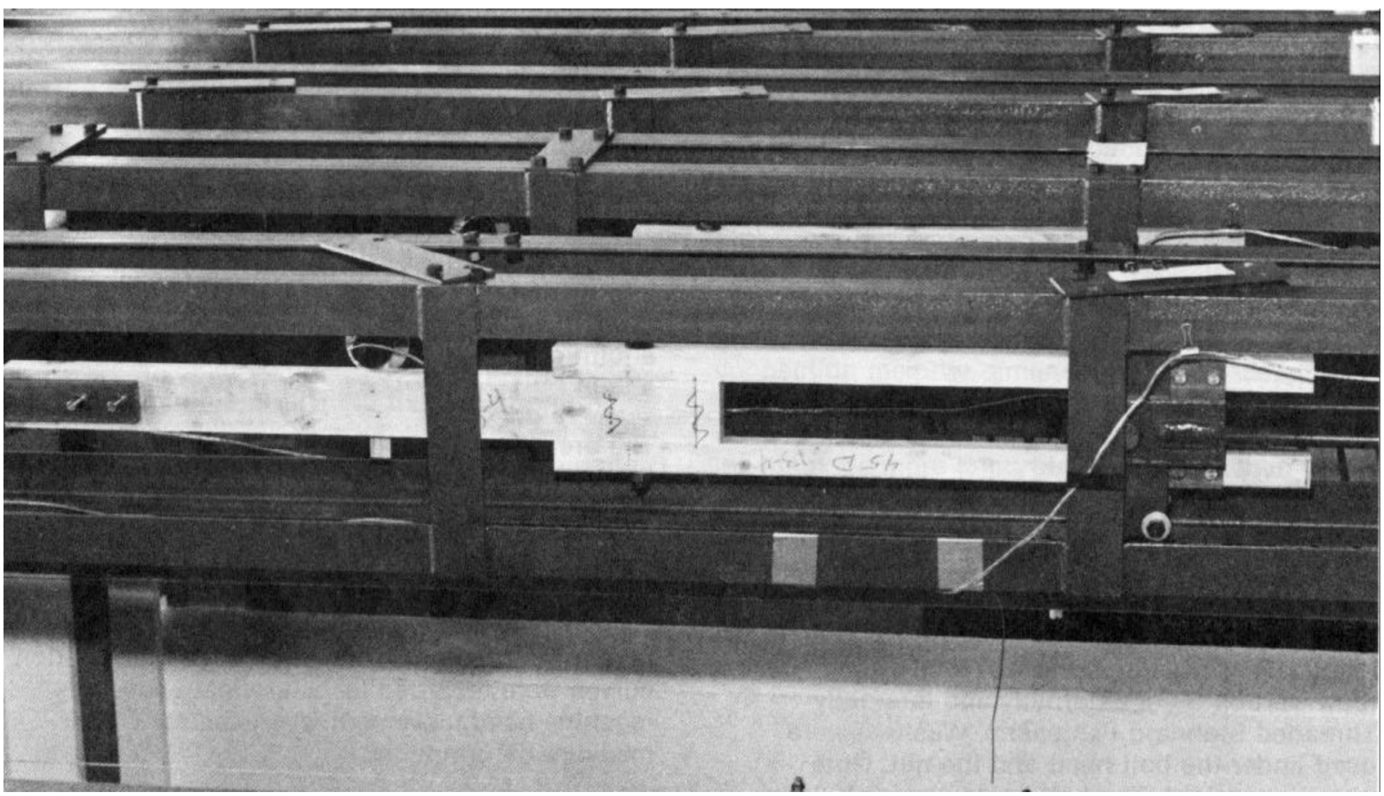

Figure 3—Bolted joint located in tension test frame for constant load test. (M85 0330-7)

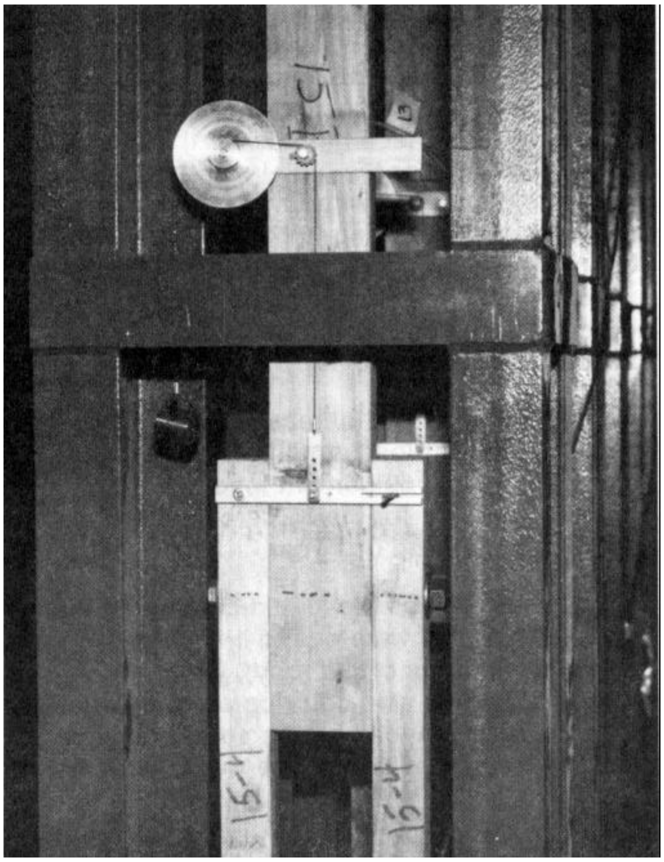

Figure 4—Method of measuring joint deformation during constant load test. (M86 0254-3)

Joint deformation was measured with variable resistor-type extensometers (fig. 4). Time-deformation data was monitored with a data logger and recorded on cassette tape. During application of the load, deformation readings were taken every 3 or 4 seconds. After the load had been on for approximately 1 minute, deformation readings were taken every 5 minutes. After 1 or 2 hours, this was extended to reading every hour. After 1 day, readings were taken every 6 hours for the remainder of the time the specimens were under load. Monitoring continued for a period of about 1 year.

After the specimens were unloaded, they were loaded to maximum load in a universal testing machine. This loading took place approximately 8 weeks after the specimens were unloaded. Specific gravity was determined for both side members and the main member.

Results and Discussion

Strength Data

Based on the specific gravity of the joint members (table 1), the matching between load conditions was good.

The maximum load (table 1) of the short-term specimens appears to be about 1,000 pounds less than the residual maximum strength of the constant load specimens. Similar strength increases have also been reported by Palka (1987) for truss-plate joints subjected to constant loads of different duration.

Only a few specimens (table 1) failed during the year of constant loading. These failures were usually associated with knots or brash grain pattern (perhaps pre-existing compression failures) in the wood members and were always away from the joint area.

The published design value for the joints in this study is 1,270 pounds. The design value was derived by applying certain factors to the short-term proportional limit load. The average proportional limit load for the short-term specimens was 2,940 pounds. Therefore, the 30 and 60 percent load conditions were at or below the average proportional limit load and above the design value.

Creep Data

Examination of a typical static load-deformation curve (fig. 5) can explain some of the results obtained. A typical curve has a nonlinear initial portion where the joint is being tightened and members start to bear on the bolt. This nonlinear portion depends on how well the joints are fabricated, how smoothly the holes are drilled, and it varies from joint to joint. This variation is included in the initial deformations (table 2) and consequent creep data.

The creep data (table 3) are presented as a ratio of the total deformation divided by the initial deformation to eliminate some of the effects of variable data. Results indicate that the creep rate was nearly zero after 3 months for the two lower load conditions. For the high-load condition, the creep rate decreased with time, but significant creep was still occurring at the end of 1 year. The continued creep of the high-load condition is as expected since these specimens were loaded beyond the linear portion of the static load-deformation curve (fig. 5).

The total deformation increased about 20 percent for the 30 percent load condition, about 40 percent for the 60 percent load condition, and about 140 percent for the 85 percent load condition at the end of 1 year.

Typical creep curves (fig. 6) indicate fluctuations in the data. These were due to breakdowns in the climatic conditions of the room. The massive size of the test frames also contributed to fluctuations in the data, as the load on the specimen was sensitive to the position of the weight attached to the cable.

Table 1–Specific gravity and maximum joint load of specimens

Member number	Short-term specimens				Specimens loaded at 85 percent of short term				Specimens loaded at 60 percent of short term				Specimens loaded at 30 percent of short term			
	Specific gravity[a] of members			Joint maximum load[b] (lb)	Specific gravity[a] of members			Joint maximum load[b] (lb)	Specific gravity[a] of members			Joint maximum load[b] (lb)	Specific gravity[a] of members			Joint maximum load[b] (lb)
	Main	Left side	Right side		Main	Left side	Right side		Main	Left side	Right side		Main	Left side	Right side	
1	0.44	0.37	0.51	4,420	0.45	0.41	0.50	5,950	0.44	0.48	0.49	—[c]	0.47	0.40	0.49	4,810
2	0.49	0.48	0.56	4,570	0.45	0.50	0.58	4,670	0.45	0.48	0.56	5,140	0.46	0.51	0.54	5,370
3	0.43	0.46	0.55	4,600	0.45	0.47	0.55	5,830	0.43	0.45	0.51	5,030	0.45	0.47	0.48	5,480
4	0.46	0.48	0.53	4,640	0.47	0.46	0.48	5,590	0.50	0.50	0.50	4,870	0.44	0.51	0.50	5,540
5	0.48	0.46	0.44	4,440	0.49	0.41	0.42	4,870	0.49	0.40	0.42	4,920	0.47	0.41	0.41	6,580
6	0.42	0.40	0.49	5,020	0.44	0.38	0.47	—[c]	0.44	0.38	0.46	5,110	0.45	0.43	0.50	7,410
7	0.55	0.45	0.46	4,620	0.52	0.42	0.44	—[c]	0.51	0.46	0.49	5,090	0.57	0.42	0.44	5,810
8	0.40	0.42	0.46	4,860	0.41	0.44	0.46	4,510	0.39	0.45	0.45	5,560	0.40	0.46	0.50	6,200
9	0.44	0.43	0.57	4,110	0.43	0.55	0.41	6,140	0.43	0.53	0.40	5,320	0.42	0.51	0.39	6,340
10	0.56	0.52	0.50	5,340	0.48	0.51	0.53	—[c]	0.50	0.47	0.53	—[c]	0.51	0.57	0.49	7,320
11	0.43	0.47	0.53	5,110	0.44	0.47	0.55	5,960	0.46	0.45	0.51	6,400	0.46	0.47	0.52	4,850
12	0.47	0.42	0.51	4,800	0.48	0.38	0.48	6,000	0.45	0.38	0.50	6,730	0.48	0.40	0.51	5,760
13	0.50	0.44	0.52	4,600	0.48	0.45	0.50	6,230	0.46	0.46	0.54	6,620	0.45	0.46	0.54	4,140[d]
14	0.50	0 43	0.49	5,420	0.46	0.48	0.49	6,200	0.47	0.52	0.45	5,200	0.47	0.48	0.45	7,480
15	0.55	0.48	0.51	5,370	0.55	0.53	0.50	7,810	0.58	0.51	0.45	4,810	0.57	0.53	0.45	5,460
16	0.57	0.44	0.45	4,820	0.57	0.41	0.48	—[c]	0.55	0.43	0.47	5,110	0.52	0.48	0.47	—[c]
Average	0.48	0.45	0.50	4,800	0.47	0.45	0.49	5,810	0.47	0.46	0.48	5,420	0.47	0.47	0.48	5,900

[a]Specific gravity based on volume at test and ovendry weight.

[b]Maximum load determined after completion of constant load test.

[c]Specimen failed during the constant load test at locations away from the joint area.

[d]Specimen failed away from the joint area.

Table 2—Average and range of initial deformations for constant load specimens

Constant load (lb)	Initial deformation (in.)	
	Average	Range
1,440	0.120	0.027 - 0.234
2,880	0.183	0.099 - 0.342
4,080	0.207	0.147 - 0.285

Table 3—Ratio of total deformation to initial deformations for various lengths of loading

Elapsed time	Total deformation/initial deformation					
	Specimens loaded at 30 percent of short term		Specimens loaded at 60 percent of short term		Specimens loaded at 85 percent of short term	
	Average	Range	Average	Range	Average	Range
1 day	1.073	1.016 - 1.160	1.230	1.144 - 1.564	1.587[a]	1.341 - 1.944
1 week	1.091	1.013 - 1.210	1.275	1.157 - 1.627	1.781[a]	1.490 - 2.231
1 month	1.126	1.024 - 1.281	1.349[b]	1.166 - 1.802	2.035[a]	1.656 - 2.444
3 months	1.156[b]	0.980 - 1.367	1.409[a]	1.190 - 1.916	2.267[c]	1.819 - 2.684
6 months	1.182[b]	0.991 - 1.325	1.438[a]	1.214 - 1.983	2.330[d]	1.881 - 2.700
1 year	1.149[b]	1.000 - 1.303	1.444[a]	1.200 - 1.989	2.434[d]	1.717 - 2.894

[a]Value based on 14 specimens.
[b]Value based on 15 specimens.
[c]Value based on 13 specimens.
[d]Value based on 12 specimens.

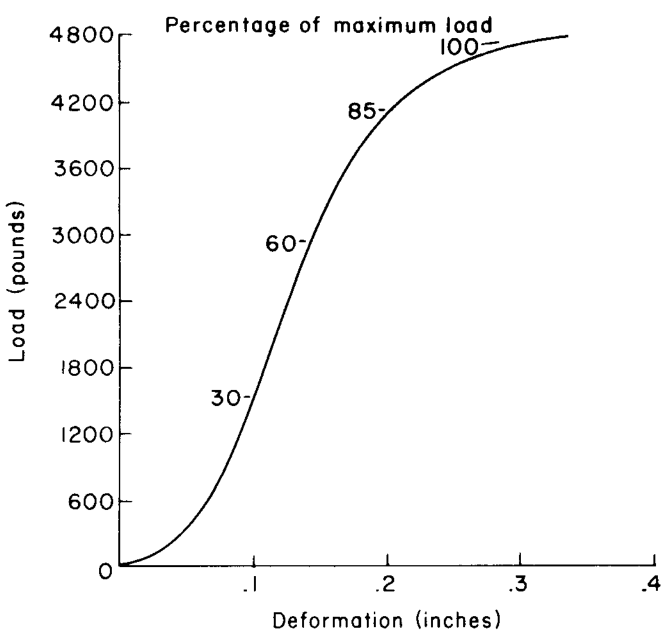

Figure 5—Typical static load-deformation curve. (ML88 5385)

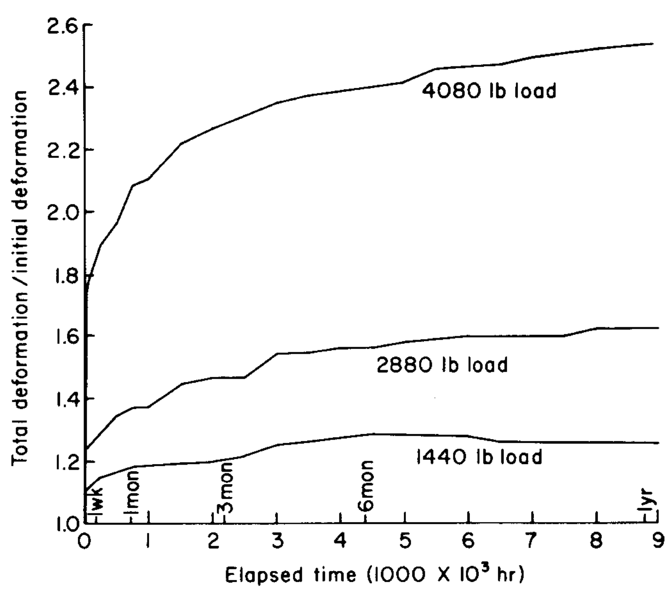

Figure 6—Typical creep curves. (ML88 5388)

Concluding Remarks

A few general remarks can be made as a result of this study.

1. The maximum strength of the specimens appears to have increased after 1 year of constant load. A gain of strength after 1 year has also been observed for truss plate joints; however, it is not understood why this occurs. Failures during the constant load test were associated with wood failures at growth characteristics away from the joint.

2. The creep rate approached zero after 3 months for specimens loaded at 30 and 60 percent of the ultimate short-term load. For specimens loaded at 85 percent, the creep rate decreased with time, but considerable creep was occurring at the end of 1 year.

3. The results of this study were quite variable. This would indicate that large sample sizes would be required to model the creep behavior of bolted joints reliably.

4. There appears to be an insignificant duration-of-load effect for the first year of service under controlled environmental conditions for bolted-wood joints with a width-to-bolt diameter ratio of six (Mode II failure), as long as load levels are at or below those on which the design values are based.

This study was very limited in scope. Future research efforts should be directed at short width-to-bolt diameter ratios (Mode I failure) and large width-to-bolt diameter ratios (Mode III failure), as these failure modes may produce different time-dependent effects. It would also be beneficial to produce a large enough data base to arrive at mathematical models for predicting time-dependent behavior.

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