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# Rotational Creep of Pallet Joint Specimens

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## Abstract

The purpose of this study was to determine the effect of continued load on pallet joints. We describe the creep rotation of pallet joint specimens made of two wood species and with two different types of nails. Joints were subjected to three levels of applied moment and allowed to dry while under load. After approximately 5 months, the specimen rotation had increased 8 to 19 times. The creep rotation behavior of the joints as affected by species of deckboard and stringer, type of fastener, and amount of load is described by a mathematical model.

Keywords: Pallet, creep, joints, nails, rotation

## Introduction

Wood pallets, a major use of U.S. hardwood lumber, are employed for handling and storing many commodities. Pallets must be able to withstand weight for varying lengths of time. Determination of the amount of load a pallet can withstand requires a sound engineering analysis, using behavior of the pallet components as input.

Pallets that are placed in racks and subjected to continued load are likely to undergo creep deflection, which is caused in part by rotational creep of the joints between deckboards and stringers depending on the pallet load and support conditions. This report describes the effect of load level, wood species, type of fastener, and change in moisture content on the rotational creep of pallet joints.

This work is part of a larger cooperative research effort between the USDA Forest Service, Virginia Polytechnic Institute, and the National Wooden Pallet and Container Association. The aim of the overall research is to devise a computerized procedure for designing wooden pallets. The study reported here focused on the effects of long-time loading on wooden pallet joints of two different species.

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## Past Work

Several studies have investigated the performance of wood pallets made of different species and with different types of fasteners. Stern (1971, 1974, 1978) and Stem and Wallin (1976) examined overall pallet performance as affected by species and type of fastener. Stern (1976) determined the ultimate withdrawal resistance of nails and staples in deckboard-stringer joints assembled from 22 southern hardwoods. McLain and Stern (1978) likewise determined the withdrawal resistance of similar pallet joints of five western woods.

The characteristics of pallet joints have been studied to predict pallet behavior. Mack (1975) characterized pallet joints in a withdrawal test by the relative separation of the deck and stringer. Kyokong (1979) developed a relation between separation modulus (the slope of the withdrawal load versus deformation curve) and rotation modulus (the slope of the moment versus rotation curve). He showed that the rotation modulus is easy to determine and is less variable than the separation modulus. Kyokong used a single linear modulus value to describe the joint behavior; however, pallet joint behavior is nonlinear. Wilkinson (1985) recently described the moment-rotation of pallet joints with a two-parameter, hyperbolic tangent function.

All of the studies described above were concerned with short-time loading conditions. The aim of our study was to determine the effects of loading on moment-rotation behavior of pallet joints over an extended period.

## Experimental Design

### Variables

Several construction variables affect pallet joint behavior. The range of variables in industry practice is described in specifications produced by the National Wooden Pallet and Container Association (NWPCA) (1962a, 1962b, 1974). The particular variables in our study were species and dimensions of deckboards and stringers, type of fastener, and amount of load.

***Species.*** Two species were studied: (a) oak deckboard with oak stringer and (b) yellow pine deckboard with yellow pine stringer. The moisture content of all specimens was above the fiber saturation point at the time specimens were assembled.

***Deckboard and Stringer Dimensions.*** A 2-1/2-inch-wide by 5/8-inch-thick by 7-inch-long deckboard was nailed to a 1-3/4-inch-wide by 3-1/2-inch-high stringer (fig. 1). The deckboard and stringer were fastened with a single nail located at the center of their intersection. The nail was driven flush with the deckboard surface.

***Fasteners.*** The two types of nails (fig. 2) used in the study were (a) 2-1/4- by 0.112-inch hardened nail and (b) 2-1/2- by 0.120-inch stiffstock nail. Physical properties were determined for a 25-nail sample. The selected nails have the average physical properties (table 1) of high quality pallet nails and were included as a variable in a previous study by Wilkinson (1985).

***Load.*** The three load levels (table 2) were based on static moment-rotation tests of unmatched specimens from a preliminary study (unpublished data). The static moment-rotation curve is nonlinear. The initial slope was approximated by a straight line, and the point where the curve and straight line deviated was assumed to represent an approximate proportional limit. The applied loads represented approximately 30, 60, and 90 percent of this assumed proportional limit load.

***Replications.*** Five replications were evaluated for each combination of variables. A total of 60 specimens was tested. No attempt was made to match specimen material between different joint variables.

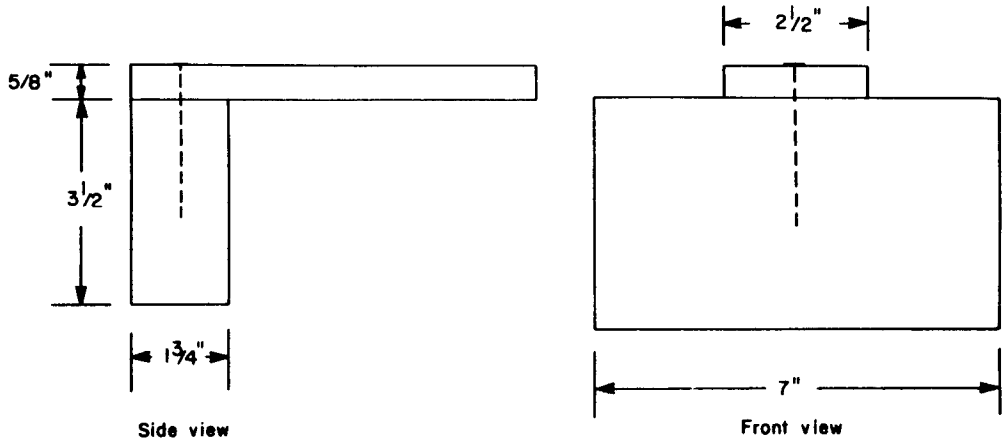


*Figure 1.—Joint geometry. Nail placed at the center of the deckboard and stringer. (ML86 5004)*

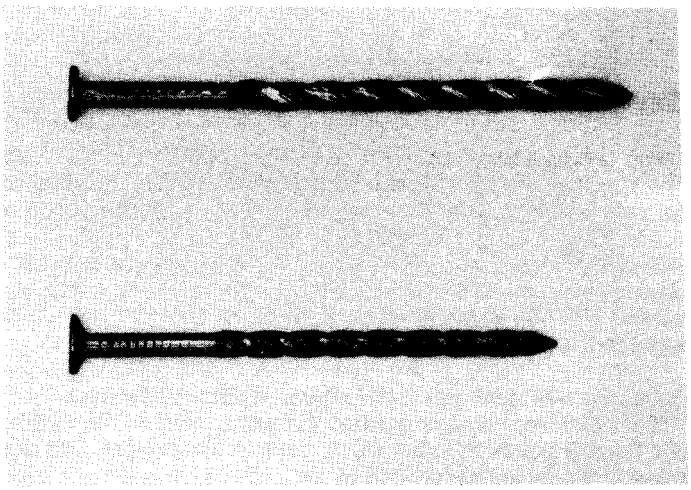

*Figure 2.—Fasteners studied were 2-1/2- by 0.120-inch stiffstock nail (top) and 2-1/4- by 0.112-Pinch hardened nail (bottom). (M150 944)*

Table 1.—Average physical properties of nails based on a sample of 25 nails

| Average property | 2-1/4-inch hardened nail | 2-1/2-inch stiffstock nail |
|---|---|---|
| Length, in. | 2-1/8 | 2-7/16 |
| Wire diameter, in. | 0.113 | 0.122 |
| Thread-crest diameter, in.[1] | .127 | .135 |
| Number of flutes[2] | 4 | 5 |
| Thread length, in. | 1.50 | 1.69 |
| Helix per inch | 5.33 | 4.73 |
| MIBANT bend angle, degree[3] | 21 | 48 |
| Head diameter, in. | .282 | .259 |

[1]Diameter measured on the thread crest.

[2]Number of continuous symmetrical depressions along the nail shank.

[3]A measure of nail stiffness as obtained by ASTM Standard F 680, Testing Nails.

Table 2.—Final moisture content of pallet joints[1]

| Species | Fastener | Load level | Average final moisture content[2] | |
|---|---|---|---|---|
| | | | Deck | Stringer |
| | | *Lb* | *Pct* | *Pct* |
| Oak | 3 × 0.120 | 13 | 9.3 | 9.9 |
| | | 26 | 9.3 | 9.9 |
| | | 39 | 9.3 | 9.9 |
| | 2-1/2 × 0.120 | 13 | 9.7 | 10.0 |
| | | 26 | 9.3 | 9.8 |
| | | 39 | 9.2 | 9.9 |
| Yellow pine | 3 × 0.120 | 8 | 10.4 | 10.9 |
| | | 16 | 10.8 | 10.7 |
| | | 24 | 10.0 | 10.7 |
| | 2-1/2 × 0.120 | 8 | 10.5 | 10.7 |
| | | 16 | 10.4 | 10.2 |
| | | 24 | 10.5 | 10.7 |

[1] Five replications of each experiment were performed.

[2] Initial moisture content of all specimens was above the fiber saturation point.

## Experimental Procedure

Creep tests were conducted in controlled conditions of 73°F and 50 percent relative humidity. The specimens were allowed to dry from their initial moisture content above the fiber saturation point to approximately 10 percent during the period of loading (table 2).

The stringers were securely fastened to wooden racks with lag screws (fig. 3). Load was applied with lead shot in buckets hung from eye bolts in the deckboards. Eye bolts were located 4 inches from the inside edge of the stringer. The applied moment was assumed to be equal to four times the applied load (table 2).

Deflection was read with a dial gauge, which was mounted on a portable stand positioned so that the dial stem always touched the same point on the deckboard. Deflection was measured at a point 2 inches from the inside edge of the stringer. The deckboard rotation in radians was equal to the deflection divided by two.

Specimens were assembled just prior to fastening to the wood frames and applying load. After the load was applied, deflection readings were taken every few minutes during the first 2 to 3 hours. Readings were taken daily during the first week of loading and weekly thereafter. Specimens remained loaded for approximately 5 months, a period that represents the time industrial pallets usually remain stationary while in storage.

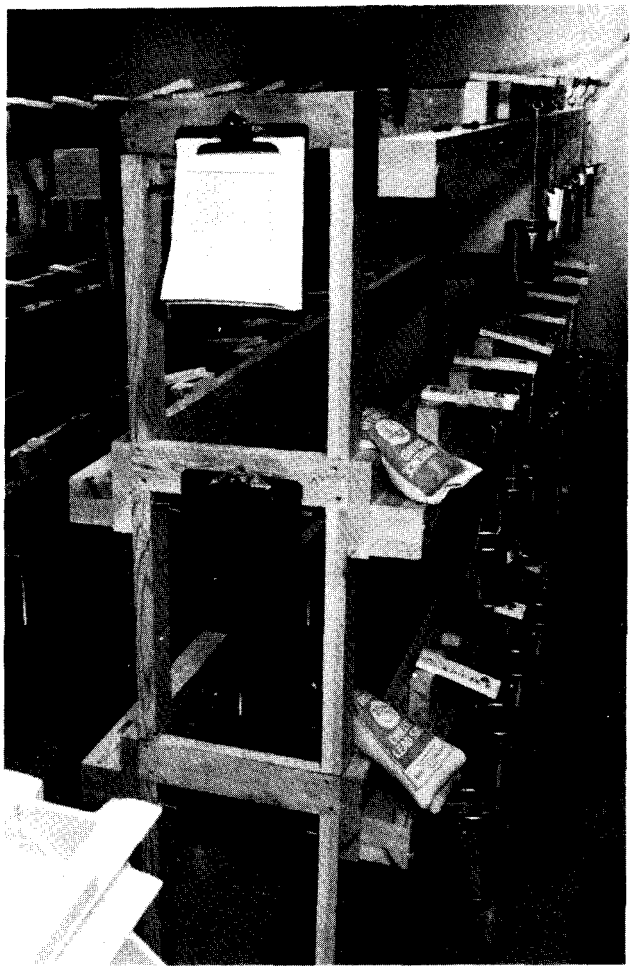

*Figure 3.—Experimental apparatus for obtaining creep rotation of pallet joints. Lead shot in the buckets produced the applied moment. (M150 767-2)*

## Results and Discussion

The creep rotation (figs. 4 and 5) is presented as a ratio of the rotation ($\theta$) at time ($t$) to the rotation after 1 minute ($\theta_1$) versus time. The rotation after 1 minute was selected as representing short-term static rotation. This was a reasonable assumption for the oak specimens, which agreed closely with static values, but not for the yellow pine specimens, which diverged from the static values (fig. 6). However, 1-minute readings were used since no readings that could be used to represent the static rotation were taken before 1 minute had elapsed.

The 1-minute rotations showed considerable variation in the amount of creep between specimens (fig. 6, table 3). Presenting the creep rotation as a ratio reduced the magnitude of the variation and provided a basis for relating creep rotation to static rotation. Final rotation values showed more variation between specimens (table 3).

Based on approximate calculations for a 48-inch pallet, the amount of deckboard rotation needed for pallet failure is on the order of 0.4 radians for yellow pine and 0.5 radians for oak. The ratios of the approximate failure rotation to the observed initial rotation were 47 to 18 for the oak specimens and 28 to 7 for the yellow pine specimens. Comparison with the observed ratios (figs. 4 and 5) indicates that most of the specimen rotations would not cause pallet failure during the period of observation. If center deflection is limited to 2 inches for serviceability, the corresponding deck board rotation is 0.17 radians. The ratios of 0.17 radians to the initial rotations were (a) 17, 11, and 7 for the oak specimens and (b) 13, 6, and 3 for the yellow pine. Thus, joint stiffness of a typical pallet decreases with time and drying conditions.

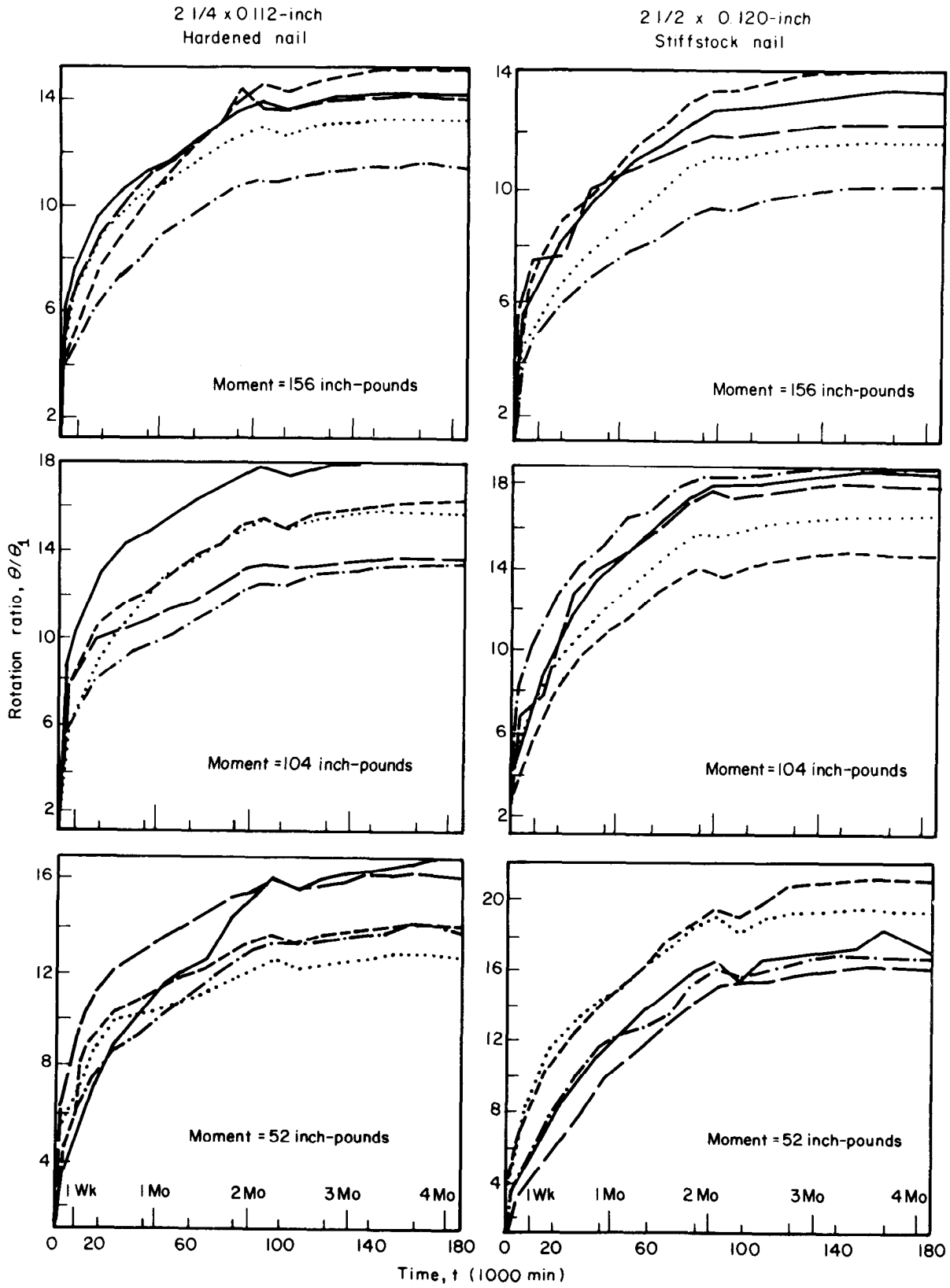


*Figure 4.—Creep rotation curves for oak specimens. Five replications. (ML86 5017)*

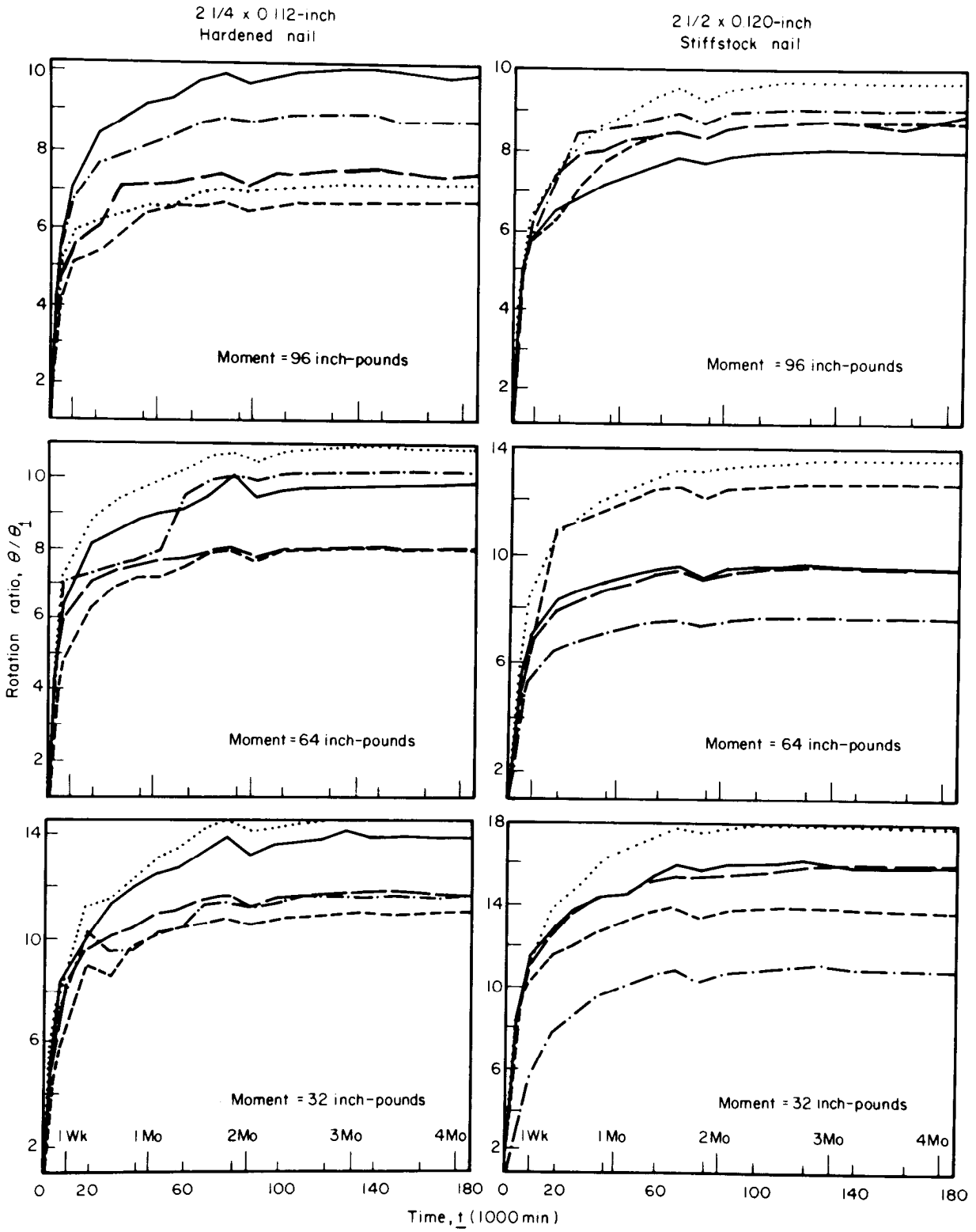


*Figure 5.—Creep rotation curves for yellow pine specimens. Five replications. (ML86 5016)*

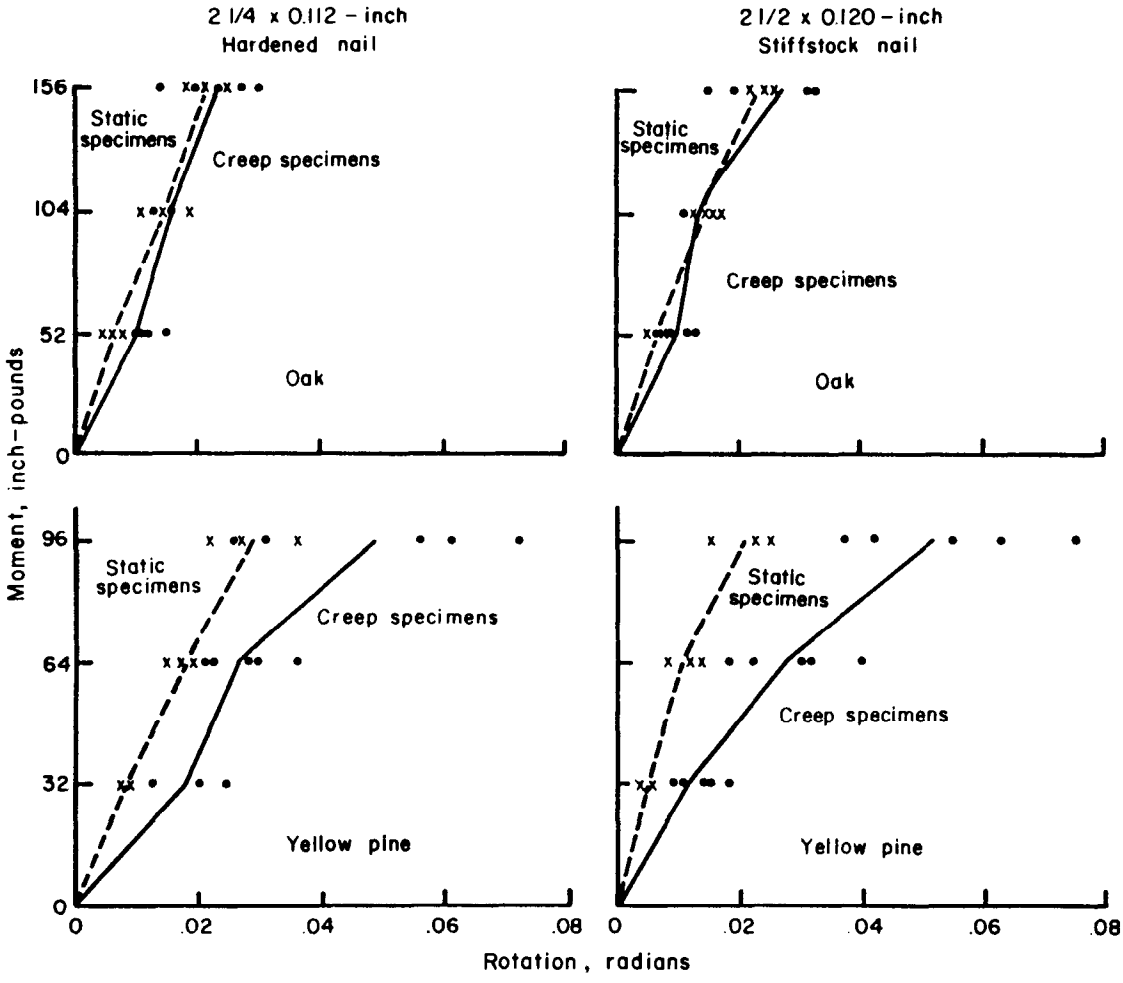


*Figure 6.—Rotation after 1 minute for oak and yellow pine creep specimens compared to the rotation of unmatched specimens under static loading. Lines drawn through average values. (ML86 5006)*

**Table 3.—Initial[1] and final[2] rotation of pallet joint specimens**

| Species | Fastener | Applied moment | Initial rotation | | Final rotation | |
|---|---|---|---|---|---|---|
| | | | Mean | Standard deviation | Mean | Standard deviation |
| | | *In. -lb* | *Rad* | | | |
| Oak | 2-1/4 × 0.112 | 52 | 0.012 | 0.003 | 0.167 | 0.034 |
| | | 104 | .016 | .003 | .247 | .033 |
| | | 156 | .023 | .006 | .308 | .063 |
| | 2-1/2 × 0.120 | 52 | .010 | .003 | .180 | .036 |
| | | 104 | .015 | .002 | .254 | .052 |
| | | 156 | .026 | .008 | .313 | .080 |
| Yellow pine | 2-1/4 × 0.112 | 32 | .018 | .005 | .223 | .036 |
| | | 64 | .028 | .006 | .259 | .063 |
| | | 96 | .049 | .020 | .388 | .140 |
| | 2-1/2 × 0.120 | 32 | .014 | .003 | .198 | .029 |
| | | 64 | .028 | .009 | .291 | .064 |
| | | 96 | .055 | .015 | .481 | .136 |

[1]One-minute rotation.

[2]Rotation after approximately 5 months.

To describe the creep rotation mathematically, the following function was fitted to the data using a nonlinear least squares routine.

$$\theta/\theta_1 = A\left[\tanh\frac{t}{C}\right]^B \qquad (1)$$

where

$t$ = time, minutes

$\theta$ = rotation at $t$, radians

$\theta_1$ = rotation at $t$ = 1 minute, radians

$A$ = equation parameter

$B$ = equation parameter

C = equation parameter, minutes.

The $A$ parameter represents a limiting ratio for the creep rotation. The C parameter represents the rate at which the limiting ratio is reached; i.e., a larger $C$ value indicates that a longer time is needed to reach $A$. The $B$ parameter indicates the amount of curvature in the creep rotation curve; i.e., for smaller $B$ values, there is a sharper bend in the curve. Equation (1) fits the experimental data very well (fig. 7).

The mean values and standard deviations of the three parameters are presented in table 4. The effects of species, fastener type, and applied moment were not consistent (fig. 8). An analysis of variance of the parameters showed significant second and third degree interactions among the joint variables which could not be resolved because of the large variations in the creep curves among replications and the small number (five) of replications.

Even though the effect of joint variables could not be statistically resolved, some general observations can be made. The creep rate (C parameter) is slower for oak than for yellow pine specimens. The percentage of creep rotation ($A$ parameter) is greater for oak than for yellow pine specimens when compared to the initial rotation. The curvature of the creep rotation curve ($B$ parameter) is generally greater for oak than for yellow pine specimens. The percentage of creep rotation and the curvature of the creep rotation curve decrease with increased applied moment.

The $A$ parameters indicate that the l-minute rotation had increased 8 to 19 times by the end of 5 months (table 3). This increase was due partially to the applied load and partially to loss in moisture content. In actual pallets, restraint placed on the opposite end of the deckboard by adjacent stringers would probably prevent such large increases in rotation.

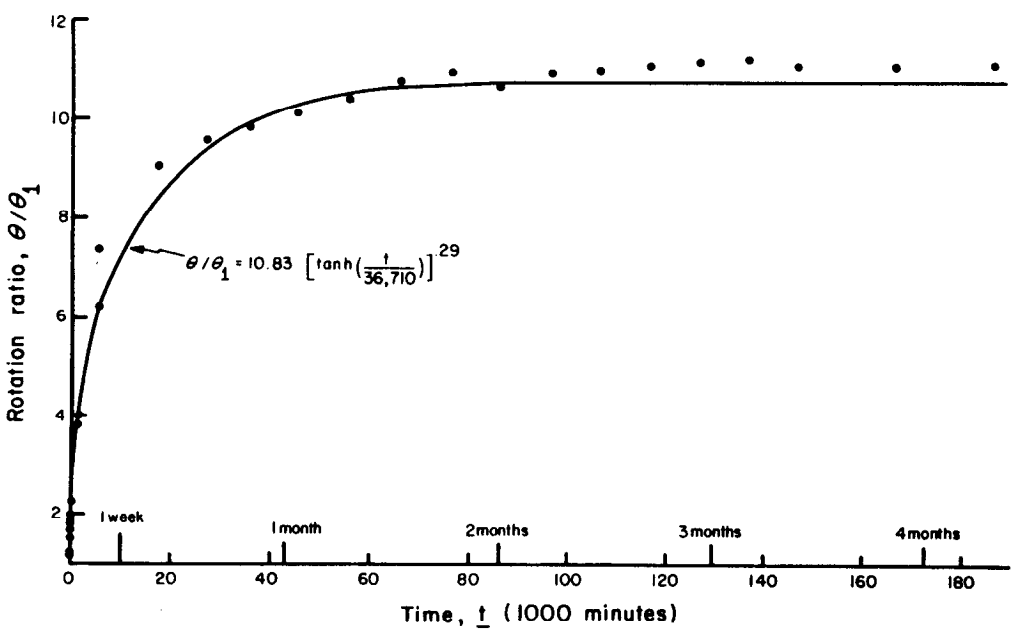


*Figure 7.—Typical fit of equation (1) to the experimental creep rotation curves for a yellow pine specimen with 2-1/4- by 0.112-inch hardened nail. The applied moment was 64 inch-pounds. (ML86 5005)*

Table 4.—Parameter values obtained by fitting $q/q_1 = A\left[\tanh \frac{t}{C}\right]^B$ to the experimental creep rotation curves (five replications)

| Species | Fastener | Applied moment | A | | B | | C | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean | Standard deviation | Mean | Standard deviation | Mean | Standard deviation |
| | | *In. -lb* | | | | | - - - (1,000 min) - - - | |
| Oak | 2-1/4 × 0.112 | 52 | 15.22 | 1.77 | 0.34 | 0.09 | 10,145 | 2,619 |
| | | 104 | 15.71 | 1.72 | .33 | .05 | 8,542 | 2,954 |
| | | 156 | 14.10 | 1.39 | .32 | .03 | 8,979 | 1,655 |
| | 2-1/2 × 0.120 | 52 | 19.03 | 2.11 | .43 | .04 | 10,122 | 1,411 |
| | | 104 | 17.77 | 1.60 | .38 | .04 | 8,223 | 959 |
| | | 156 | 12.85 | 1.51 | .29 | .03 | 10,502 | 1,838 |
| Yellow pine | 2-1/4 × 0.112 | 32 | 12.44 | 1.59 | .38 | .04 | 3,873 | 393 |
| | | 64 | 9.43 | 1.33 | .27 | .03 | 4,620 | 2,468 |
| | | 96 | 8.06 | 1.37 | .21 | .03 | 4,357 | 446 |
| | 2-1/2 × 0.120 | 32 | 14.80 | 2.60 | .37 | .05 | 3,276 | 628 |
| | | 64 | 10.56 | 2.35 | .33 | .06 | 3,134 | 397 |
| | | 96 | 8.78 | .61 | .24 | .03 | 4,258 | 880 |

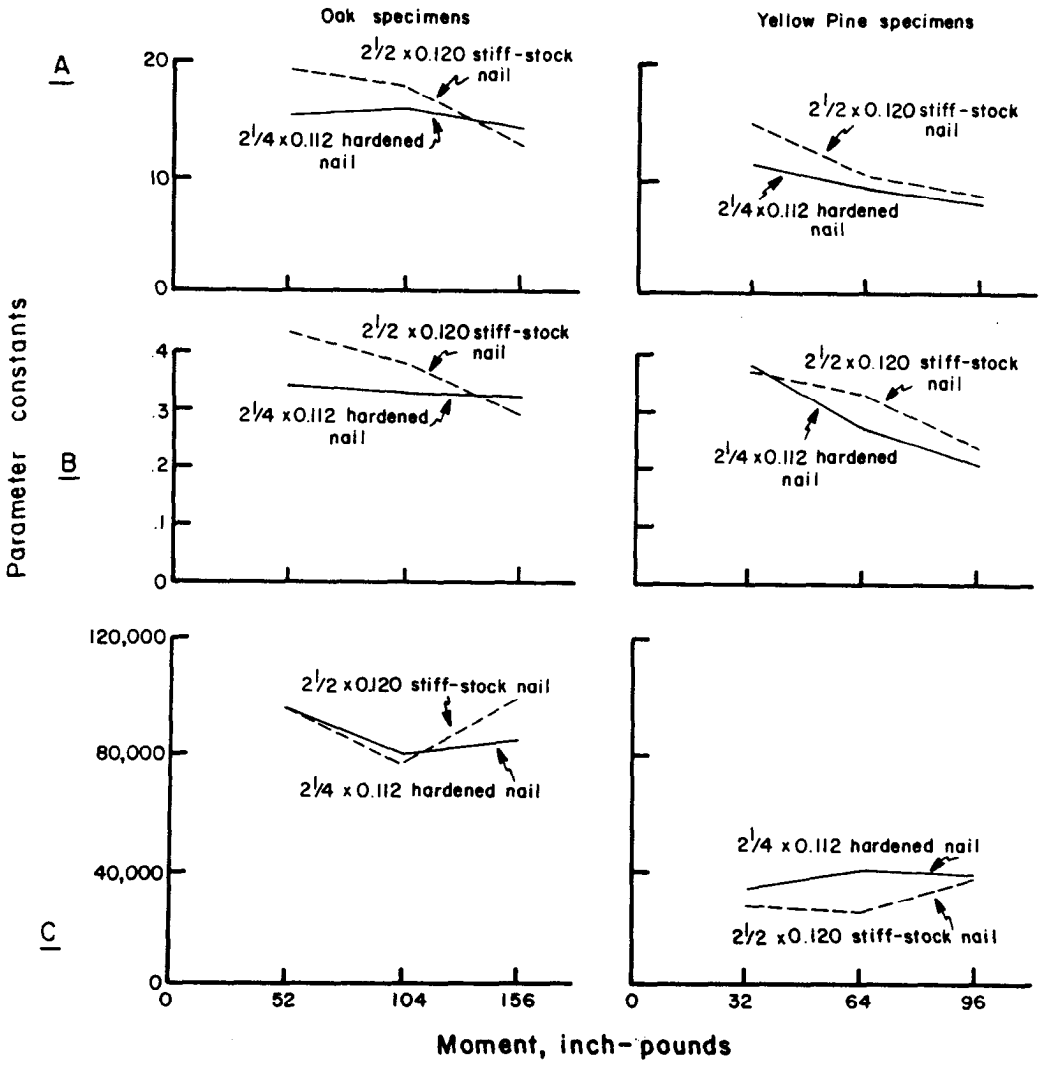


*Figure 8. —Trend of equation (1) parameters with applied moment for oak and yellow pine specimens. (ML86 5003)*

## Summary of Findings

This report describes the creep rotation of pallet-joint specimens due to the combined effect of applied moment and material drying. The study is part of a large cooperative research effort to develop a computerized design procedure for wooden pallets. Moment-rotation creep data are presented for two wood species and two nail types, based on five replications. The primary findings are as follow:

1. The specimen creep rotation curves can be described by a three-parameter hyperbolic tangent of the form

$$\theta/\theta_1 = A\left[\tanh\frac{t}{C}\right]^B \qquad (2)$$

where

$t$ = time, minutes

$\theta$ = rotation at $t$, radians

$\theta_1$ = rotation at $t$ = 1 minute, radians

$A$, $B$, and $C$ = equation parameters.

2. No consistent relation between the equation parameters and joint variables could be obtained due to the limited nature of the study. Some general observations are (a) all three specimen rotation parameters *(A,B,C)* appear to be larger for oak than for yellow pine, and (b) two of the parameters *(A,B)* tend to be inversely related to bending moments.

3. During the 5 months of loading the specimen rotation increased 8 to 19 times compared to the l-minute rotation. In actual pallets, the restraint placed on deckboards by adjacent stringers would be expected to reduce the amount of rotation during extended loading.

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