EVALUATION OF CREEP BEHAVIOR OF STRUCTURAL LUMBER IN A NATURAL ENVIRONMENT

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ABSTRACT

Creep behavior of structural lumber is being observed over time in a natural environment at the Forest Research Laboratory of Oregon State University. In a bending test, 20 Douglas-fir beams were subjected to a constant load. Deflections of the beams and daily fluctuations in temperature and relative humidity are being measured every day. This study reports the results of the first 14 months from April 1994 to June 1995. The objective of the study is to evaluate the long-term creep behavior of full-size structural lumber. Stiffness of the beams appears to have a strong influence on the magnitude of creep strain, and creep strain appears to follow the fluctuations in air temperature closely. The mechano-sorptive creep strain in this experiment was shrinking and swelling of the beam surfaces and was not tied to beam moisture content, which changed little over the experimental period. An existing five-element creep model did not describe creep behavior of the structural lumber in the natural environment. A four-element model and an empirical model were developed to include stiffness of the beams and air-temperature effects. The four-element model fits the experimental data well.

Wood used in construction shows notable creep behavior under sustained loads, which is known to have significant effects on the safety and serviceability of wood structures over their lifetime (10). Researchers have been studying this time-dependent behavior for decades (2,3), focusing mostly on small, clear wood samples subjected to constant environmental conditions (2,6,13,16). However, wood in service and small, clear samples behave differently, and wood under constant conditions behaves differently from wood under cyclic conditions. Wood properties change with moisture content (MC), which in turn depends on the temperature and relative humidity of the ambient environment; therefore, results of studies with small, clear samples may not be directly applicable to full-size structural beams. Investigations of structural lumber have shown that the level of applied loads, MC, and temperature are the most critical factors in creep behavior (3-5). A mechano-sorptive phenomenon has also been shown to occur when wood MC changes significantly under controlled cyclic environmental conditions (3).

Both mechanical and empirical creep models have been developed from previous investigations (1,3,5). Fridley et al. (3) developed a five-element model that includes a mechano-sorptive element from creep data for full-size structural lumber subjected to step-constant loads in several constant environments. The mechano-sorptive element was based on a function related to rate of change of the MC of the beam over time. The model predicted creep behavior of structural lumber in controlled cyclic environmental conditions. An empirical model, the power law, was successfully used in 1985 by both Gerhard and Hoyle et al. (5,7) to predict creep behavior of structural lumber subjected to constant load and constant environmental conditions. However, there are few studies of creep behavior of wood beams in a natural environment. It has been shown by Pozgaj (11) and Lu and Erickson (8) that creep deformation of wood beams increases in the drying phase and decreases in the wetting phase, and that swelling and shrinkage of wood beams are related to creep deformation.

The aim of this study was to establish a long-term experiment, with the main objectives being to 1) evaluate creep behavior of structural lumber in a natural environment; and 2) modify an existing model or develop a new model describing such behavior. This paper reports the creep strain measured over the first 14 months (about 10,000 hr.) and discusses the applicability of an existing model.

MATERIALS AND METHODS

Twenty Douglas-fir beams (No. 2 grade; 1.5 in. by 3.5 in. by 8 ft.) were selected from a local lumbermill as specimens for the creep test. The basic properties and characteristics of all specimens, after initial conditioning to 11 percent MC at 20°C with 69 percent relative humidity (RH), are given in **Table 1** along with critical defects. The

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TABLE 1. — Initial parameters of specimens.

Group	Specimen number	Width	Depth	Length	Modulus of elasticity Flatwise	Modulus of elasticity Edgewise	Modulus of elasticity Dynamic[a]	Weight	MC[b]	Specific gravity	Knot defects in load span[c]
		(in.)	(in.)	(ft.)	(× 10^6 psi)	(× 10^6 psi)	(× 10^6 psi)	(lb.)	(%)		
A	02A1	1.505	3.511	8.0	1.28	1.07	1.42	8.973	11	0.491	Centerline
	01A3	1.509	3.516	8.0	0.98	0.97	1.10	7.231	11	0.395	Centerline
	03A4	1.513	3.508	8.0	1.22	0.95	1.39	9.017	11	0.496	BEK
	04A5	1.489	3.457	8.0	1.23	0.93	1.33	8.179	11	0.446	CEK
B	17B2	1.513	3.538	8.0	1.32	0.98	1.50	8.708	11	0.481	TEK
	19B3	1.506	3.519	8.0	1.43	1.19	1.51	9.237	11	0.506	CEK
	18B4	1.502	3.511	8.0	1.38	1.21	1.45	8.620	11	0.468	Centerline
	20B5	1.519	3.520	8.0	1.46	1.30	1.51	8.267	11	0.444	Centerline
C	13C1	1.516	3.530	8.0	1.71	1.47	1.89	9.854	11	0.593	Centerline
	14C2	1.514	3.529	8.0	1.56	1.15	1.70	9.766	11	0.537	CEK
	16C4	1.512	3.515	8.0	1.50	1.65	1.59	9.237	11	0.505	Centerline
	15C5	1.517	3.530	8.0	1.56	1.27	1.64	9.083	11	0487	Centerline
D	05D2	1.512	3.515	8.0	1.90	1.89	1.96	9.877	11	0.528	NONE
	06D3	1.505	3.517	8.0	1.83	1.42	1.98	10.317	11	0.566	BEK
	07D5[d]	1.518	3.537	8.0	1.79	1.35	2.08	10.163	11	0.557	BEK
	08D8	1.521	3.510	8.0	1.81	1.68	2.10	9.832	11	0.536	Centerline
E	09E2	1.508	3.515	8.0	2.31	1.71	2.57	10.979	11	0.603	CEK(hole)
	10E3	1.509	3.515	8.0	2.18	1.96	2.37	10.053	11	0.552	BEK
	11E4	1.518	3.515	8.0	2.15	1.61	2.52	10.670	11	0.592	TEK(hole)
	12E7	1.526	3.539	8.0	2.06	1.53	2.26	10.406	11	0.564	CEK

[a] The dynamic MOE was measured with a Metriguard model 340 E-computer setup.
[b] MC = moisture content.
[c] BEK = both compression- and tension-zone edge knots; CEK = compression-zone edge knot; TEK = tension-zone edge knot.
[d] Reference specimen for modulus of elasticity.

specimens were sorted into five test groups, labeled A through E (low to high), according to their dynamic modulus of elasticity (MOE) and specific gravity. So that we might observe long-term creep behavior, we applied a low-level constant load determined in terms of the deflection limits of 1/360 of the span. Two 75-pound weights 2 feet apart were suspended from each specimen, as shown in **Figure 1.** The average applied stress level is about 6 percent of modulus of rupture (MOR) of defect-free seasoned wood, which is 55 percent of the allowable design stress for the No. 2 grade specimens used in this research (18). Since MOR for each specimen is not available, the applied stress level (percentage of the ultimate strength) may be different for each specimen because of the variation in MOR. Twenty deflection sensors measure deflections for the specimens.

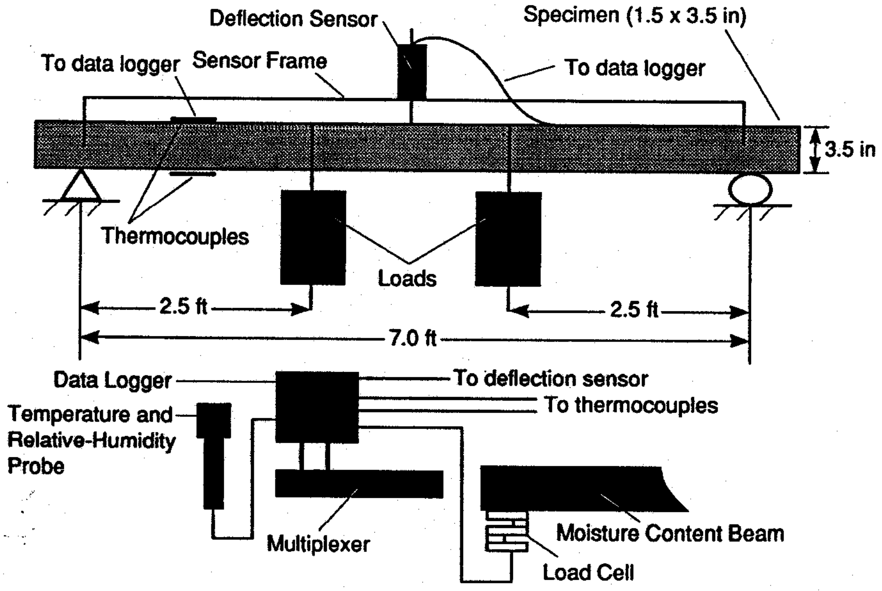

Figure 1. — Setup of the experiment, located in an open shed at Oregon State University.

One additional specimen, beam 21, conditioned with the others, was used for determining MC, which was monitored by means of a load cell recording weight change. To verify whether temperature at the surface of the specimens was the same as air temperature, two thermocouples were placed on the top and bottom surfaces of beam 21. A temperature and RH probe were used to detect temperature and RH of the ambient environment.

All 21 specimens were assumed to have the same MC (11%) as beam 21 in the control room (20°C, 69% RH) and were weighted before being taken to the experimental spot. The experiment was established in an open shed outside the Forest Research Laboratory at Oregon State University, where all data taken by the sensors were recorded by a data logger. Deflections and environmental conditions for each specimen were recorded every hour. Four observations per day were selected to correspond with daily maximum and minimum temperatures and daily maximum and minimum measurements of deflection. Data were lost from 4,800 to 7,500 hours because wires were accidentally disconnected from the data logger.

DATA ANALYSIS

Creep behavior in most previous publications is described in terms of strain; therefore, deflections were converted to strain by means of the geometric relationship (14). The elastic strain was determined from the deflection at 3 seconds after a specimen was loaded. Creep strain was determined by subtracting elastic strain from the total strain. The following power law was used to predict creep strain at the 10,000th hour:

$$\varepsilon(t) = \varepsilon_e + bt^n \qquad [1]$$

where:

$\varepsilon(t) =$ total strain at time t

$\varepsilon_e =$ elastic strain

b and $n =$ model parameters

Data for one of the specimens that was misrecorded were excluded. We assumed that MC of all specimens was the same as that of sample beam 21, which was calculated from its weight at time t and its original MC (11%). Elongation and contractions in all metal parts that could influence deflection measurement were negligible (14).

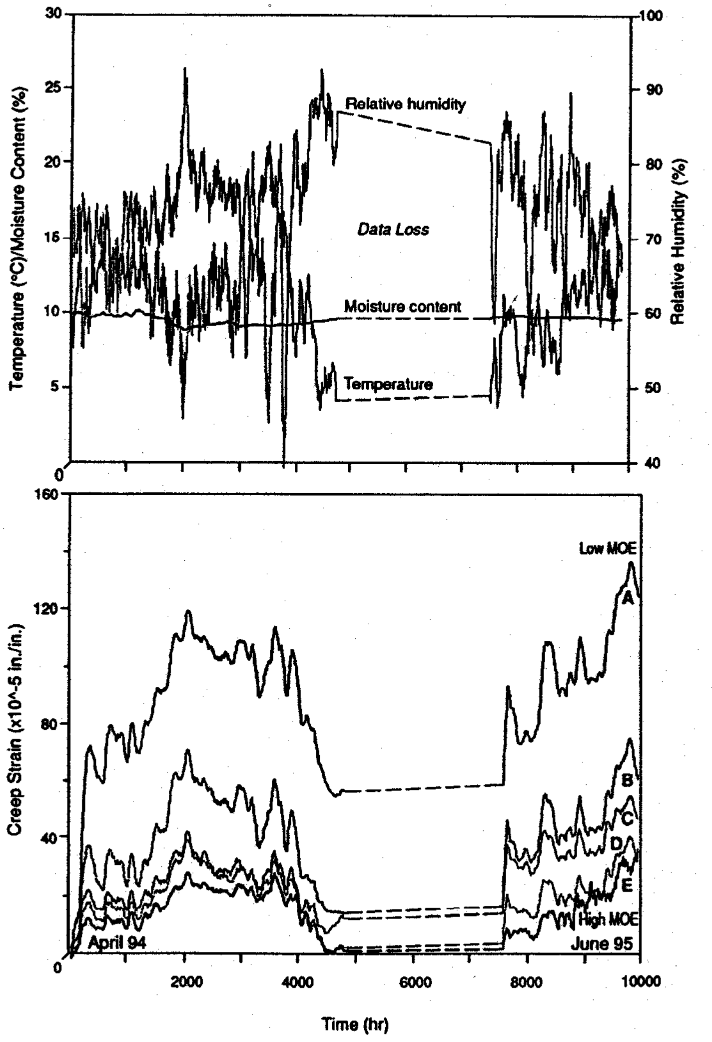

Figure 2. — Moisture content of sample beam 21 and environmental conditions (top); creep strains for sample groups A-E (bottom). The straight line is a period of data loss from 4,800 to 7,500 hours (Dec. 1994 to Feb. 1996).

THE MODELS

THE FIVE-ELEMENT CREEP MODEL

A five-element creep model developed by Fridley et al. (3) to predict the effects of load and environment, as well as mechano-sorptive effects on primary and secondary creep behavior, is composed of a Burger model (1) and a mechano-sorptive element. For a constant load, the model is expressed as follows:

$$\varepsilon(t) = \frac{\sigma}{K_e} + \frac{\sigma}{K_k}\left[1 - exp\left(-\frac{K_k t}{\mu_k}\right)\right] + \frac{\sigma t}{\mu_v} + \frac{\sigma}{\mu'_{ms}}|\Delta w|\left[1 - exp\left(-B_w t\right)\right] \qquad [2]$$

where:

$\varepsilon(t) =$ total strain at time t for the applied stress σ

$K_e =$ the Hookean spring constant

K_k and $\mu_k =$ respectively, the Hookean spring constant and the viscosity of the Newtonian dashpot of the Kelvin element

$\mu_v =$ the viscosity of the Newtonian dashpot

$\mu'_{ms} =$ the constant with units of force per unit area

$\Delta w =$ w_e-w_i, where $w_e =$ the eventual equilibrium MC in the new environment and $w_i =$ the initial MC in the original environment

$B_w =$ the constant associated with the time required to achieve moisture equilibrium

In the model, the mechano-sorptive strain (the last term in Eq. [2]) mainly depends on changes in MC, Δw, and the parameter μ'_{ms}. The mechano-sorptive element was developed under controlled environmental conditions (3). Since experimental data in a constant environment were not available in this study, we used the same reference parameters and constants as in Equation [2] except for K_{e0}, which is edgewise MOE measured at the reference condition 20°C, 69 percent RH. Other elements of the experimental design, including species, grade, and dimension of specimens, in this study are the same as in Fridley et al. (3).

THE FOUR-ELEMENT CREEP MODEL

The four-element Burger model has

been successfully used for predicting creep behavior of wood (3,7,13); however, all applications have been conducted under a constant or controlled environment. Since MC of specimen 21 changed little during the experiment in this study, we developed a four-element model, based on the Burger model, with air-temperature fluctuations and MOE effects added to adjust for natural conditions.

TABLE 2. — Deformation of specimens, by group. (A = low MOE; E = high MOE.)

Group	Specimen number	Experimental elastic deformation	Theoretical elastic deformation[a]	Creep deformation at 10,000th hour
		(in.)		
A	02A1	0.212	0.214	0.296
	01A3	0.290	0.274	0.336
	03A4	0.261	0.218	0.376
	04A5	0.282	0.242	0.540
B	17B2	0.242	0.197	0.272
	19B3	0.218	0.199	0.272
	18B4	0.213	0.210	0.220
	20B5	0.187	0.198	0.171
C	13C1	0.137	0.157	0.143
	14C2	0.164	0.175	0.293
	16C4	0.174	0.189	0.160
	15C5	0.178	0.181	0.209
D	05D2	0.148	0.154	0.156
	06D3	0.154	0.152	--[b]
	07D5	0.176	0.141	0.216
	08D8	0.128	0.143	0.112
E	09E2	0.116	0.117	0.117
	10E3	0.120	0.127	0.132
	11E4	0.125	0.119	0.133
	12E7	0.138	0.129	0.196

[a] Calculated using dynamic MOE from Table 1.

[b] Data lost.

Because data processing showed that the shapes of the creep curves for the specimens from each group were the same but of different magnitude (**Fig. 2**), the specimens with lower MOE had higher creep strain than those with higher MOE. Therefore, an MOE factor was included in the model. The MOE factor, Q, defined as the ratio of a reference MOE over a tested MOE for each specimen, was based on the average value for edgewise MOE, E_e, of all specimens listed in **Table 1**. Specimen 07D5 was chosen as the reference beam because its MOE (1.35×10^6 psi) was closest to the average MOE of all specimens. The modified four-element model developed in this study to include MOE and temperature effects is as follows:

$$\varepsilon(t) = Q * \left\{\frac{\sigma}{K_e} + \frac{\sigma}{K_k} * \left[1 - exp\left(-\frac{K_k * t}{\mu_k}\right)\right] + \frac{\sigma * t}{\mu_v}\right\} \qquad [3]$$

where:

$\varepsilon(t) =$ total strain at time t

$Q =$ MOE factor

$\sigma =$ the applied stress

$K_e =$ the Hookean spring constant associated with elastic deformation (i.e., modulus of elasticity)

K_k and $\mu_k =$ respectively, the Hookean spring constant and the viscosity of the Newtonian dash pot of the Kelvin element

$\mu_v =$ the viscosity of the Newtonian dashpot associated with unrecoverable strain

However, if the four parameters, K_e, K_k, μ_k, and μ_v in Equation [3] are constant, the prediction will be a smooth exponential curve; therefore, temperature fluctuations were added.

The following quadratic functions were assumed to adjust K_e, K_k, μ_k, and μ_v for the temperature effects:

$$K_e(\alpha) = K_{e0} * \left(1 + q_1 * \alpha + q_2 * \alpha^2\right) \qquad [4]$$

$$K_k(\alpha) = K_{k0} * \left(1 + q_3 * \alpha + q_4 * \alpha^2\right) \qquad [5]$$

$$\mu_k(\alpha) = \mu_{k0} * \left(1 + q_5 * \alpha + q_6 * \alpha^2\right) \qquad [6]$$

$$\mu_v(\alpha) = \mu_{v0} * \left(1 + q_7 * \alpha + q_8 * \alpha^2\right) \qquad [7]$$

where:

$\alpha =$ a relative temperature factor, defined as:

$$\alpha = \frac{T - T_0}{T_0} \qquad [8]$$

where:

$T =$ temperature at time t

$T_0 =$ temperature at the reference condition

K_{e0}, K_{k0}, μ_{k0}, and $\mu_{v0} =$ model parameters at the average condition

q_1 to $q_8 =$ constants

The average environmental condition is needed for fitting the power law, Equation [1], to experimental data for reference beam 07D5. The fitting curve is considered to be creep data under that condition. Data for the first 5,000 hours were used to develop the model. Average creep strain, ε_{avg}, is then calculated with Equation [1] by substituting regression results for b and n. After that, K_{k0}, μ_{k0}, and μ_{v0}, the reference parameters, are determined by using the SAS NLIN procedure (12) with the four-element model, Equation [3], and the average creep strain data, ε_{avg}. Equations [4] through [7] are then substituted for the four model parameters, K_e, K_k, μ_k, and μ_v in Equation [3]. The eight model constants, q_1 to q_8, are determined by the SAS NLIN procedure (12) with Equation [3] and the experimental data for reference specimen 07D5.

THE EMPIRICAL MODEL

Like the Burger model, the power law, Equation [1], is also popularly used for describing creep behavior of wood in a constant environment (5,7). The power law in this study is expressed as follows in order to consider the temperature and MOE effects:

$$\varepsilon_r = \varepsilon_t - \varepsilon_e = Q * \left[b(\alpha) * t^{n(\alpha)}\right] \qquad [9]$$

where:

$\varepsilon_r =$ creep strain

ε_t = total strain at time t
ε_e = elastic strain
Q = the MOE factor defined as in the four-element model
$b(\alpha)$ and $n(\alpha)$ = model parameters, functions of the relative temperature factor, α, described in the following functions:

$$b(\alpha) = b_0 * \left(1 + r_1 * \alpha + r_2 * \alpha^2\right) \quad [10]$$

$$n(\alpha) = n_0 * \left(1 + r_3 * \alpha + r_4 * \alpha^2\right) \quad [11]$$

where:

b_0 = 5.98×10^{-5}; $n_0 = 0.2$, obtained using linear regression with reference specimen 07D5, introduced in the four-element model
r_1 to r_4 = the model constants

The model constants, r_1 to r_4, are determined by the SAS NLIN procedure (12) with the modified power law model, Equation [3], and experimental data recorded from the reference specimen in a natural environment. Again, data for the first 5,000 hours were used to develop the model.

A computer program, Statgraphics (15), was used to statistically compare the data for predicted and experimental creep.

RESULTS AND DISCUSSION

CREEP BEHAVIOR IN THE NATURAL ENVIRONMENT

Temperature, RH of the ambient environment, and MC of the sample beam are shown in **Figure 2**, along with the creep strain for one specimen from each group.

The environmental data show that the MC of sample beam 21 changed little during the 14 months, although daily temperature and RH fluctuated frequently (**Fig. 2**). Wood beams do not respond to quick changes in environmental conditions. Also, average temperature, 16°C, and average RH, 69 percent, during the 14 months were close to the conditions of the control room.

Creep strain at the 10,000th hour, calculated with Equation [1] and converted into creep deformation for each specimen, is listed in **Table 2**. The experimental elastic deformation and the theoretical elastic deformation (derived with the equation in the Western Woods Use Book (19)) are also given. The value of elastic deformation decreases from group A to group E as expected, as does the value of creep deformations (the 10,000-hr. deformation). The same trend for creep strain can be observed in **Figure 2**, which indicates that MOE affects not only elastic deflections but creep strain as well. It also could be due to the different levels of stresses on specimens. Although the applied stress for each specimen is the same, the stress level in each specimen, defined as the percentage of MOR, may not be the same because of the variation in MOR.

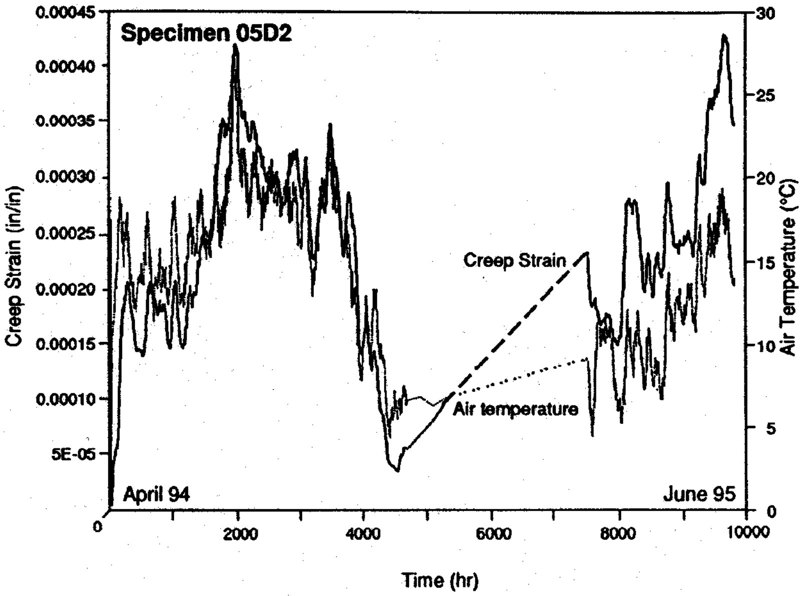

Figure 3. — Air temperature and creep strain for a specimen of group D.

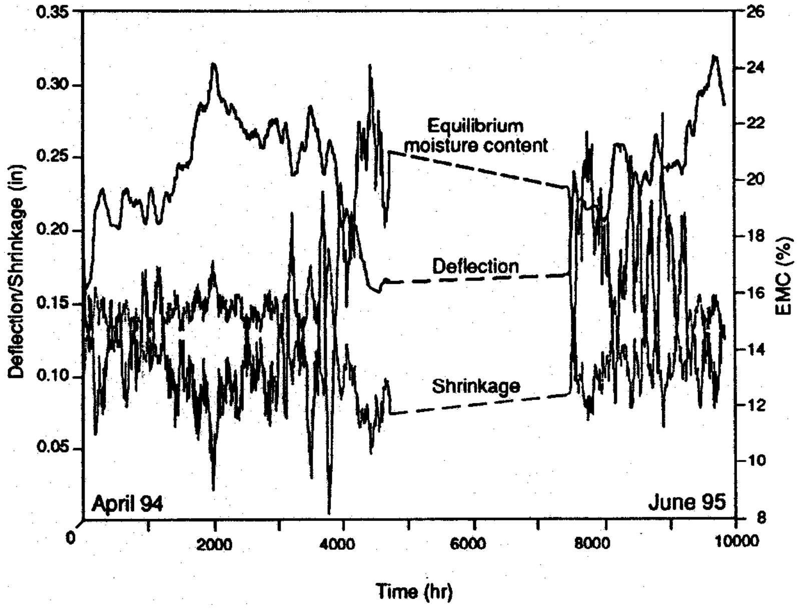

Figure 4. — Deflection, shrinkage, and equilibrium moisture content.

In general, creep strain for specimens within each group are similar, and **Table 1** shows that MOE and specific gravity within each group are also similar. However, specimens 04A5, 14C2, 07D5, and 12E7 apparently have higher creep strain than others in the same group. This appears to be related to defect characteristics and MOE of the individual specimens. The four had edge knots located at the center of the load span in the compression zone, causing cross grain all the way into the tension zone. The presence of knots reduces the mechanical properties of wood beams subjected to bending

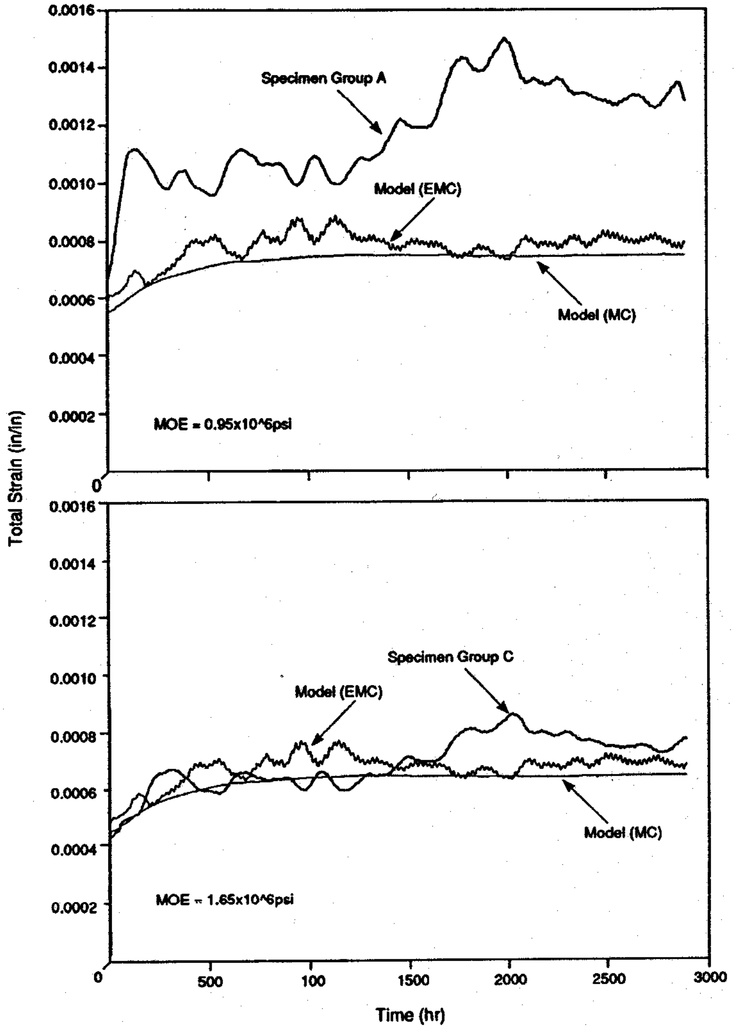

Figure 5. — Creep strain predicted for groups A and C with the five-element model (3).

stresses (9), and leads to more creep strain. In addition, the edgewise MOE of the four specimens was the lowest within the group.

It can also be observed from **Figure 2** that the shape of creep strain curves for all specimens is similar but has a different vertical shift. From experimental data, it seems that creep strain is higher for low MOE specimens than for high MOE specimens because of the variation in MOE. However, different stress levels (percentage of actual MOR of the beams) may also cause this.

The creep-strain curves follow fluctuations in air temperature, as shown in **Figure 3** for one specimen from group D. Since the shape of the curves for all specimens is the same, we conclude that creep strain follows fluctuations in air temperature. This agrees with findings of previous studies in which stiffness of wood decreased as temperature increased under constant MC (4,5,16). Fridley et al. (4), in a load duration test on structural lumber under several constant levels of temperature, found that creep strain increased when temperature increased under the same level of applied stress.

The mechanical properties of wood generally decrease when heated and increase when cooled (18). MOE has a negative linear relationship to temperature under constant MC and below about 150°C (18). Because creep strain increases as MOE decreases, air temperature may affect creep behavior of full-size beams in a natural environment more than MC does.

Measurements for 3 months showed that the air temperature and the temperature on both surfaces of beams were almost identical; therefore, MC on the beam surfaces should change with the ambient environment, although MC of the entire beam is unaffected. That is, MC on the wood surfaces should reach equilibrium with that in the air. Equilibrium MC (EMC), calculated according to the *Wood Handbook* (18, Eq. [3-1]), from the recorded temperature and RH data, is shown in **Figure 4**. Wood is dimensionally stable when the MC is above the fiber saturation point (about 30%). It changes dimension as it gains or loses moisture below that point, shrinking when losing moisture and swelling when gaining moisture in the cell walls. In addition, it is an anisotropic material: it shrinks most in the tangential direction of the annual growth rings. Shrinkage in the tangential direction can be calculated with Equation [3-2] given in the *Wood Handbook* (18).

In **Figure 4,** shrinkage of the beam follows the change of the beam deflections, but is opposite to the fluctuations of EMC. The deflection of the beam increased when EMC decreased, and vice versa; that is, when the beam was in the desorption condition, the deflection increased, and when it was in the adsorption condition, the deflection recovered. The phenomenon can also be observed in **Figure 2**: when MC starts decreasing around 1,500 hours, the creep strain for each strain curve starts increasing; the reverse is true from around 2,000 hours, when MC starts increasing.

This phenomenon was also observed by Lu and Erickson (8) in an experiment in a controlled environment, and the behavior was defined as mechano-sorptive creep . Wood under load shows greater deformation when subjected to MC changes than when under constant humidity. Lu and Erickson concluded from their results that mechano-sorptive creep of the beam in bending was actually produced during the first desorption and adsorption cycle. With subsequent MC cycling, additional creep was due to shrinking and swelling of the beams. It was also experimentally shown in Toratti's study (17) that when more humidity cycles were introduced, the mechano-sorptive effect decreased.

The time period for moisture cycles in Lu and Erickson's experiment was about 570 hours and the change of MC for each cycle was about 10 percent. The dimensions of their specimens were

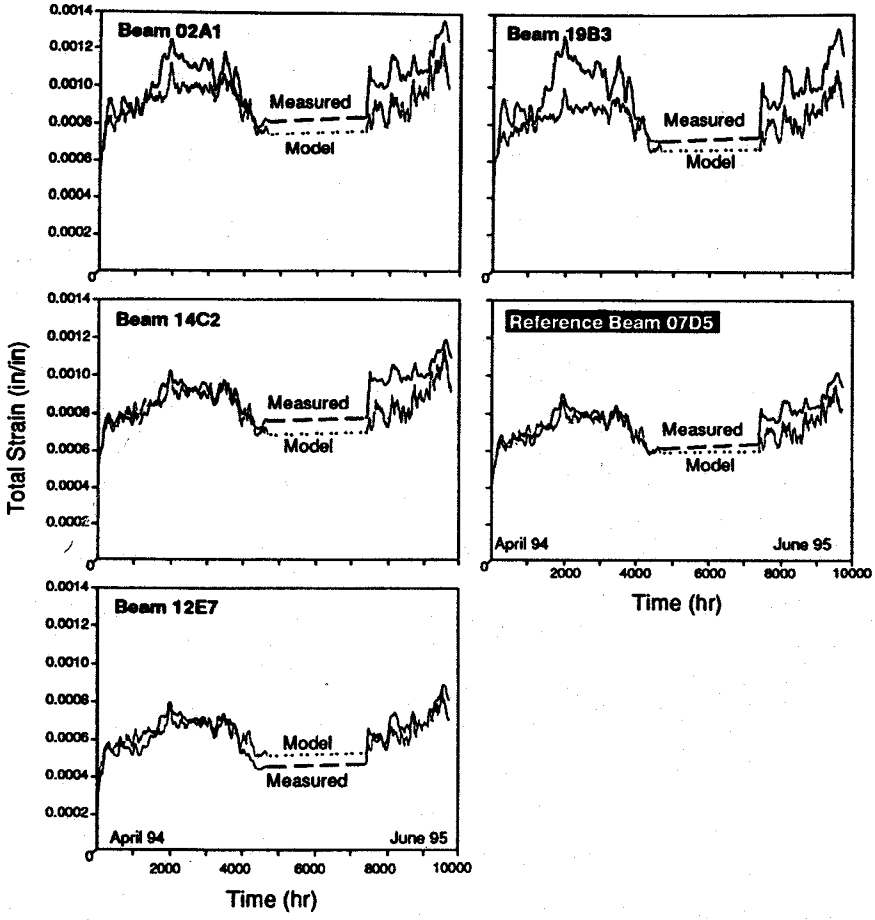

Figure 6. — Creep strain predicted with the modified four-element model and measured creep strain for reference beam 07D5 and beams from other groups.

0.9 by 0.5 by 18 inches (8); therefore, there was sufficient time for the small specimens to reach EMC. However, as has been discussed, only the surface of a beam can reach equilibrium with the environment when full-size specimens are used. This study shows that the major contribution to mechano-sorptive creep is from dimensional changes of the beam.

The prediction for creep strain of structural lumber in a natural environment with the five-element model (3) is shown in **Figure 5**. Only the first 3,000 hours of data were used to compare the model prediction with the experimental data. The mechano-sorptive element in the model seems to have no effect on creep strain in this experiment. When the mechano-sorptive element is removed, the predicted curve with the Burger model is exactly that of the predicted curve with the five-element model, showing no mechano-sorptive effects, because that element is dominated by changes in MC and Δw, which in this experiment changed little. **Figure 5** also shows curves predicted with EMC for beam surfaces and with MC of the entire beam in the mechano-sorptive element. Neither curve predicts the experimental result very well.

It can also be seen from **Figure 5** that the five-element model does not predict the fluctuations in total creep strain due to the shrinking and swelling of the beam with MC changes on its surfaces. Although the five-element model includes temperature effects, its contribution to the creep strain is small. It seems that the mechano-sorptive element is applicable only in a controlled cyclic environment when there is a significant change in MC of the entire specimen.

The predicted result is close to the experimental data for group C, but far below that for group A (**Fig. 5**), although the measured MOE was used, probably because of MOE effects, since the group-C MOE was similar to that in Fridley et al. (3), and the group-A MOE was smaller. Stiffness appears to affect not only elastic strain but creep strain.

It appears that a creep model should include a parameter that takes MOE effects into account, so that the model can describe behavior of beams with different MOE values.

The model parameters in Fridley et al. (3) were determined under constant or controlled cycles with large MC changes, another reason that the five-element model does not predict creep behavior of structural lumber in a natural environment.

For calculations of average creep strain with the four-element model, we used the regression results $b = 5.98 \times 10^{-5}$, $n = 0.2$. The edgewise MOE of reference beam 07D5 was K_{e0}, 1.35×10^6 psi. **Figure 6** shows the creep curves predicted with Equation [**3**] and the experimental curves for reference specimen 07D5 and specimens from groups other than D. Although the predicted curves are not on top of the experimental curves, they follow the fluctuations and match the experimental curves in magnitude. The change rate, however, is different: the predicted strain generally changes faster than the experimental strain. The fluctuations in the predicted creep strain are the same as that of air temperature. Wood responds to the temperature changes more slowly than does air; only the temperature of the wood surfaces can fluctuate as rapidly, which probably accounts for the difference.

Predicted strain is close to the experimental strain for both the first 5,000 hours and the remaining time, but the curve fit is better for the first 5,000 hours, probably because the model parameters were determined from data for those hours only.

Figure 7 shows creep curves predicted with the empirical model (the modified power law, Eq. [**9**]), and experimental curves for reference specimen 07D5 and specimens from groups other than D. In addition to predicted creep changing faster than experimental creep, as previously seen, it can be observed that MOE has the same effect on creep strain as it does on elastic strain. In general, creep strain predicted with the modified power law is also close to the experimental creep strain of

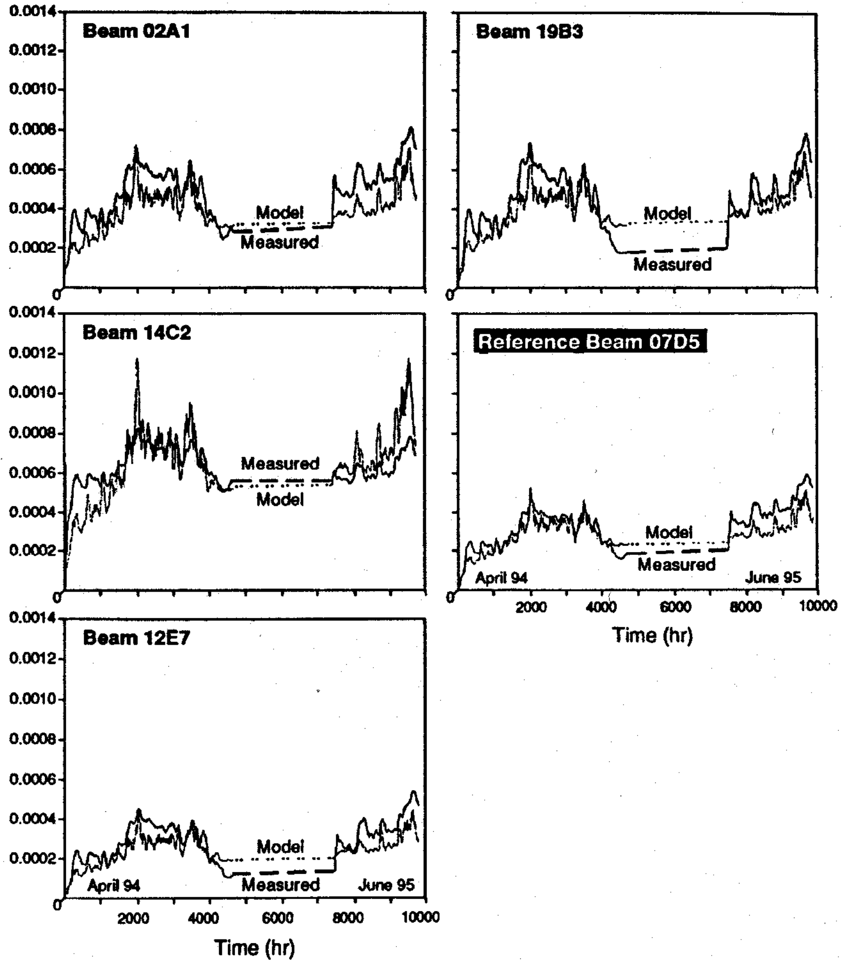

Figure 7. — Creep strain predicted with the empirical model and measured creep strain for reference beam 07D5 and beams from other groups.

every specimen. The MOE factors, Q, in the power law are the same as those in the four-element model.

The comparison by Statgraphics (15) shows that the data predicted with the four-element model are statistically equivalent to the experimental data; however, the data predicted by the modified power law are not; therefore, the four-element model, Equation [3], is a better predictor of creep behavior of structural lumber in a natural environment.

SUMMARY

From analysis of 14 months of data from the creep experiment with full-size structural lumber in a natural environment, it may be concluded that creep deformation can be much larger than elastic deformation and may depend on the stiffness of the beams.

The five-element creep model does not predict behavior of structural lumber in a natural environment. Because of little change in MC in the specimens, the mechano-sorptive element did not contribute to creep strain of structural lumber under the natural cyclic environmental conditions of this study. The mechano-sorptive creep strain was likely shrinking and swelling of the beam surfaces.

Fluctuations of creep strain followed variations in air temperature. Temperature fluctuations and edgewise MOE were found to have major effects, and were used in a four-element model and power-law models. The predicted strain from these models was statistically equivalent to that of the experimental data.

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