BENDING CREEP AND LOAD DURATION OF DOUGLAS-FIR 2 BY 4s UNDER CONSTANT LOAD FOR UP TO 12-PLUS YEARS

Charles C. Gerhards

Retired Research General Engineer
USDA Forest Service
Forest Products Laboratory[1]
One Gifford Pinchot Drive
Madison, WI 53705-2398

(Received November 1999)

ABSTRACT

This paper finalizes research on graded Douglas-fir 2 by 4 beams subjected to constant bending loads of various levels and durations. Compared to results for testing in a controlled environment, results confirm that load duration did not appear to be shortened by tests in an uncontrolled environment, at least extending out to 12-plus years. By the same comparison, relative creep was considerably increased, however.

The extended data also confirm that no evidence was found for a threshold below which stress levels for lumber can be maintained indefinitely.

Based on the finalized prediction equations of this study and those of two previous studies, a factor of 2.0 for a 10-year load duration is more appropriate for Douglas-fir bending allowable properties than the 1.62 factor currently recommended. Also, bending deflections due to creep doubled sooner than commonly accepted. This research is important to structural engineers and code groups responsible for the safe design of wood structures when establishing new design criteria for load duration and deflection limits.

Keywords: Bending creep, relative creep, deflection, wood beams, lumber grade, controlled and uncontrolled environments, wood engineering, load duration, design criteria.

INTRODUCTION

The objective of the study leading to this final report was to evaluate the load duration characteristics of Douglas-fir graded lumber. The purpose of this paper is to finalize the evaluation of results from bending creep and load duration tests of graded Douglas-fir 38- by 89-mm (nominal 2- by 4-in.; hereafter called 2 by 4) beams under sustained loading for times out to 12-plus years. This paper necessarily includes some of the comprehensive results previously reported (Gerhards 1988a, 1991).

Creep, the time-dependent deformation of material under stress, is an important material characteristic because it sometimes leads to structural failure as either excess deformation or worse as collapse. The effect of creep can be seen as sag or distortion in old wooden structures. Floors may have a permanent sag as a result of transverse bending creep, or sides of beams where supported by posts may have differential amounts of creep as a result of lateral crushing perpendicular-to-grain. Creep can occur longitudinally in compression and tension, contributing to permanent sag in trusses. Accounting for lumber creep should result in better wood structures, especially when design is controlled by deflection limits. One conclusion of the previous study (Gerhards 1991) was that "at least 10% of both Select Structural and No. 2 beams in the unheated, uncontrolled environment doubled their initial deflections in less than 2 years, and 50% of the No. 2 beams appear to be headed for doubling in 10 years."

Since that earlier report, several studies on

[1] The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. This article was written and prepared by US Government employees on official time, and it is therefore in the public domain and not subject to copyright.

creep and load duration, as well as modeling of both, have been reported. Shen and Gupta (1994, 1997) evaluated creep deflections of Douglas-fir 2 by 4 beams under constant load in a protected natural environment out to 59½ weeks. Rouger et al. (1990) studied creep response of small spruce beams at various levels of stress in a constant moist environment out to 47 weeks; included were tests of four different species of large beams of both lumber and glulam in constant dry and moist environments. Toratti and Morlier (1994) evaluated creep of lumber beams of four different species and glulam beams in a protected natural environment for 4¾ weeks. Lumber creep has been modeled by Fridley et al. (1992b), Toratti and Morlier (1994), Rouger et al. (1990), and Toratti (1994).

As creep leads to collapse, load duration is another important lumber characteristic. Although several studies have evaluated load duration characteristics (for references, see Gerhards 1988a), few have dealt systematically with environmental effects on long-time loading. Fridley et al. (1992a) evaluated effects of constant and cyclic temperature and relative humidity on load duration of Douglas-fir beams. Lebatteux et al. (1996) studied the effectiveness of coating lumber beams on load duration in a protected natural environment with tests that began during each of the four seasons. They subjected the beams to increasing levels of stress until failure occurred, each step lasting perhaps 14 or 15 days (authors were not clear on time at each stress level). Structural engineers need to know how load duration characteristics determined from short-term tests in a controlled environment relate to design loads of long duration in uncontrolled environments. For structures that do not carry significant constant loads, reliability analyses by Ellingwood and Rosowsky (1991), Rosowsky and Fridley (1992), and Fridley et al. (1998) have shown that design is generally limited by a critical load pulse.

EXPERIMENTAL PROCEDURES

The experimental procedures were described in detail in Gerhards (1988a, 1991), but a summary is given here for the convenience of the reader.

Controlled environment

The objective of the experiment was to evaluate the effect of lumber grade (ASTM 1981) on duration of load; therefore, tests were conducted on three grades of Douglas-fir 2 by 4 lumber: Select Structural (SS), No. 2, and No. 3. The lumber was specially selected to have a control knot in the central 0.61-m (24-in.) length of each piece. The control knot was near the maximum allowed for each respective lumber grade, but warp characteristics were limited to those for SS. Control knots were not restricted in lateral location to either centerline or edge. With the exception of some tests in an uncontrolled environment, bending tests were carried out in a controlled environment (22.8°C, 50% relative humidity). The beams were tested on edge over a 2.13-m (84-in.) span. Load was applied at two points spaced 0.61 m (24 in.) apart and symmetrically located about midspan. The control knot was stressed in tension.

Three different series of two-step constant load levels were applied: high, medium, and low, depending on the level of load in the first step. Planned load levels included the 5th, 15th, 40th, and 70th percentiles of the static strength distribution. For the high series, the first step was 7 days at the 40th percentile followed by the second step of 14 days at the 70th percentile. For the medium series, the first step was 49 days at the 15th percentile followed by the second step of 56 days at the 40th percentile. For the low series, the first step was 365 days at the 5th percentile followed by the second step of 182 days at the 15th percentile. All changes in load were at the ramp loading rate of 136 kg (300 lb) bending load per minute. A set of 50 specimens was tested at each constant-load series; all sets of a grade were matched by equal distributions of static edgewise bending modulus of elasticity and control knot characteristics. An additional 50-specimen set of SS matched to the other SS sets

TABLE 1. *Average temperatures calculated from Weather Service records for Madison, WI in 1985.*

Month	Temperature (°C (°F))		
	High	Low	Mean
March	8 (46)	−1 (29)	3 (38)
April	17 (62)	7 (44)	12 (53)
May	22 (72)	11 (51)	16 (61)
June	23 (74)	13 (55)	18 (64)
July	27 (81)	16 (61)	22 (71)
August	24 (75)	14 (58)	19 (67)
September	21 (70)	12 (54)	17 (62)
October	15 (58)	5 (41)	10 (50)

was loaded at the 40th percentile for 279 days (high extended series). Specimen moisture content in this experiment averaged 10%.

Uncontrolled environment

In this phase, which was related to the main experiment, the objective was to determine how an uncontrolled environment affects constant load duration. Fifty SS and 50 No. 2 specimens matched by modulus of elasticity and knot characteristics to those of the same grade as used in the controlled environment were tested for 12-plus years (12.18 years for SS and 12.27 years for No. 2). The specimens were loaded with weights totaling 187.2 kg (412.7 lb) for SS and 105.2 kg (232 lb) for No. 2 on the same spans (support and load points) as used in the controlled environment study. Dead load tests were conducted in an unheated, enclosed building with some natural ventilation at the Valley View test site of the USDA Forest Service, Forest Product Laboratory, located about 10 miles southwest of Madison, Wisconsin.

Over the life of the experiment, temperatures inside the building were only occasionally monitored, but humidity was not measured. These limited data were within a few degrees of official Weather Service records for Madison, Wisconsin. The Weather Service has recorded temperatures and relative humidities at 3-h intervals on a daily basis for many years. A summary of the Weather Service data for March through October of 1985 is presented in Table 1 for average temperature and in Table 2 for daily maximum and minimum relative humidity values. These data will be discussed later.

The uncontrolled environment specimens

TABLE 2. *Frequency of daily maximum and minimum relative humidity values calculated from Weather Service records for Madison, WI in 1985.*

Month	Relative humidity (%)							
	>90	90 > 80	80 > 70	70 > 60	60 > 50	50 > 40	40 > 30	30 > 20
Maximum								
March	7	18	5	1				
April	4	10	11	3	2			
May	2	13	10	3	3			
June	10	12	7		1			
July	20	10	1					
August	29	2						
September	24	6						
October	22	6	3					
Minimum								
March		3	4	3	6	9	5	1
April		1	1	1	3	13	11	
May			1	3	4	5	15	3
June			3		10	10	6	1
July		1	1	2	10	13	4	
August		1	2	8	10	4	6	
September		6	5	6	6	7		
October		2	4	5	9	5	3	3

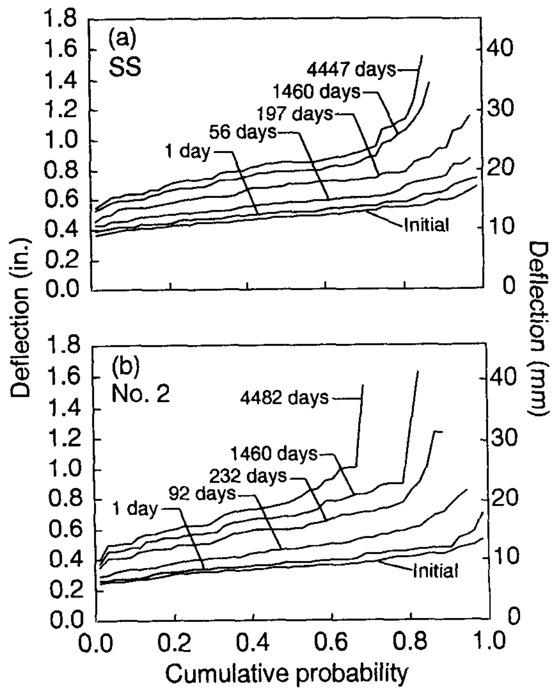

FIG. 1. Cumulative frequencies of beam deflections at selected times during the 12-plus years under sustained constant load in an uncontrolled environment: (a) 50 SS specimens, (b) 50 No. 2 specimens.

were loaded by hand. It took about 1 min to apply full load to a given specimen. Deflections were monitored as each preweighed steel weight was added to a load platform suspended from the specimen and several times during the first few hours after full load was attained. Because of the time needed for hand loading and monitoring, the 100th specimen was not loaded until more than 30 days after the first specimen was loaded. No. 2 specimens were loaded first, with the first of that set started on March 4 and the last on March 6, 1985. Loading of SS specimens was started on April 8, and the last of that set was loaded on April 10, 1985.

The dead loads in the uncontrolled environment were chosen to represent 10-year design loads. Based on the original 100 static strength tests of each grade, dead loads were determined by dividing the 5th percentile static strength values by 1.62, the 10-year load duration factor in common use (AF&PA. NDS. 1997). The 1.3 factor for safety was not included. Later, an improved estimate of static strength was determined by combining all ramp loading failure specimens (original static strength specimens and specimens that failed at loads below the first constant load level) (Gerhards 1988a). Results revealed that the 105.2-kg (232-lb) dead load times 1.62 represented the 8th percentile rather than the 5th percentile of the No. 2 static strength distribution. Note that the dead load is equivalent to 14.6 MPa (2,120 lb/in.^{2}) for SS and 8.2 MPa (1,190 lb/in.^{2}) for No. 2. Current design bending stresses for Douglas-fir 2 by 4s in the dry use condition are 15.5 MPa (2,250 lb/in.^{2}) for SS and 9.3 MPa (1,350 lb/in.^{2}) for No. 2 (AF&PA. NDS. 1997). The higher design stress used for commercial No. 2 Douglas-fir reflects the inclusion of lumber downgraded for nonstrength characteristics such as warp and wane.

Deflections of the uncontrolled environment specimens were monitored with a digital gauge (sensitive to 0.0127 mm (0.0005 in.)) mounted in a rigid frame. The digital gauge was zeroed in the rigid frame on a reference precision granite rail before specimen deflections were measured. The frame was designed to rest on marked spots on the upper beam surface of each 2 by 4 over the supports so that the deflection of the top of the beam at midspan could be measured without the influence of shrinking or swelling of beam height. The upper surfaces at the marked spots and at the center were lightly planed and locally varnished to minimize surface imperfections. Because of the remoteness of the test site, creep deflections were monitored periodically: several times during the first day, daily for the first work week, then weekly for a few months; but as time went on, less frequently until only three or four readings a year were made. The moisture content of the specimens in this environment were not monitored but would have changed with daily and seasonal changes in humidity. At the end of the 12-plus years of sustained loads, the residual deflec-