生材及び人工乾燥材の軸組における梁のクリープ(1)

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Creep of the Beam in Japanese Conventional Structures Composed of Green and Kiln-dried Timber. I. Differences in Relative Deflections of the Beams

Takashi TAKEDA* and Takanori ARIMA**

*Department of Forest Science, Faculty of Agriculture, Shinshu University
**Miyazaki Prefectural Wood Utilization Research Center, Miyakonojo, Miyazaki, 885-0037

Summary. The main purpose of this research was to evaluate the bending creep of beams in Japanese conventional structures (posts and beam constructions), known in Japanese as "jiku gumi." We built two wooden structures in order to carry out creep tests : one was composed of green timber (G) and the other of kiln-dried timber (D). Each structure was composed of four sills, four posts, two girders, and two beams. The tenon and mortise at specific locations in the members were processed with a molding machine at a sawmill. Long-term design loads were applied at the top of each beam. The deflections at mid-span were measured for each beam. Results showed that the ratios of total deflection to initial defection (relative deflection) over a 878-day period were 3.75 and 2.26 for the G and D structures, respectively. After unloading, the ratios became 3.04 and 1.50 for G and D, respectively. The additional relative creep deflection (=relative deflection−1) observed in G were approximately two times that found in D.

Key word : Mechano-sorptive creep, shrinkage, relative humidity, temperature

Introduction

In Japan, half of a million wooden houses are built every year, and approximately 80% of these are constructed using Japanese conventional timber structures[1] known as "jiku gumi"[2]. Many houses have been constructed using green timber. In these conventional structures, posts (105×105mm or 120×120mm) are placed on sills (105×105mm), and beams or girders (2100 or 3000×105mm) are jointed with the posts. The joints are tenon and mortise carved into various shapes, such as dovetail or gooseneck. These conventional structures, however, often face a common problem : time-dependent deflections, in addition to the effects of drying shrinkage, may cause the second level floors of these houses to become uneven. The deflection of wood structures in service is important as well as duration of load effects[3,4].

Requirements for deflection are important in design of timber structures, especially with regard to creep deflections[5] and shrinkage. In the guideline on structural design for light framing structures[6], the given ratio of total deflection to initial deflection was 2 for air-dried conditions, and 3 for cyclic humidity changes. The pioneering work on mechano-sorptive creep by Kingston and Armstrong[7] (1951) indicated that the creep deflections of beams increased rapidly in summer as the effects of temperature. Grossman[8] reviewed details of mechano-sorptive creep in 1976. In addition, there are many studies on the behaviors of creep : some studies have focused on creeps of wood and wood-based materials[9,10] or creeps of green and kiln-dried timbers[11], while some have examined the interaction between viscoelastic and mechano-sorptive creep[12]. There are, however, few studies on the creep of full-sized timber in Japanese conventional structures.

In this paper, creep tests on the beams in Japanese conventional structures composed of green and kiln-dried timber were conducted to investigate differences in relative deflections of the beams. Then, a predictive model for creep

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Table 1. Dimensions, density, and dynamic Young's modulus of structural members.

Structure	Species	Members	Width (mm)	Height (mm)	Length (mm)	Density (g/cm^3)	MC (%)	Ef (GPa)
D	Hinoki	Columns	105	105	1500	0.528	24.8	12.21
						0.516	23.3	9.71
			120	120	2400	0.413	17.5	7.93
						0.522	21.5	8.95
	Douglas-fir	Beams	105	300	3964	0.485	13.0	11.96
						0.499	14.1	11.29
		Girders	105	210	2694	0.498	11.6	12.53
					2678	0.458	12.4	9.64
		Sills	105	105	3940	0.430	9.3	8.07
						0.420	10.6	9.78
					2694	0.646	20.9	8.36
						0.577	16.1	7.46
G	Hinoki	Columns	108	108	1500	0.584	30.8	10.67
						0.521	28.5	8.38
			123	123	2400	0.535	28.2	7.28
						0.516	30.0	8.22
	Douglas-fir	Beams	105	300	3964	0.550	24.8	10.22
						0.642	32.0	14.83
		Girders	105	209	2694	0.569	26.3	10.09
					2678	0.507	18.0	12.28
		Sills	105	105	3940	0.577	22.8	9.42
						0.549	19.5	14.40
					2694	0.489	20.4	7.98
						0.593	26.0	12.07

G and D, structures composed of green (G) and kiln-dried (D) members ; Hinoki, *Chamaecyparis obtusa* Endl.; Douglas-fir, *Pseudotusuga menziesii* Franco these values were measured before processing ; Density ; measured using apparent volume and wight ; MC ; moisture content measured with electric -capacity wood moisture tester ; Ef, dynamic Young's modulus by the longitudinal vibration method.

behaviors will be presented in the next paper.

Experiments

Testing frames

For this study, we used two testing frames of Japanese conventional timber structures. One of these was composed of green timber (G) and the other of kiln-dried timber (D). Dimensions, density, and dynamic Young's modulus of each member were measured on 23 August, as shown in Table 1. The columns were made of Hinoki timber (*Chamaecyparis obtusa* Endl.), and the other members were made of Douglas-fir timber (*Pseudotusuga menziesii* Franco). A schematic diagram can been seen in Fig. 1. The columns on the left side of the figure were bigger than those on the right side. The bigger columns were modified as continuous colums.

Testing frames were constructed in the laboratory of Shinshu University on 25 August 1994. Temperature and humidity conditions in the laboratory were at ambient. The construction procedure of the frames was as follows. Four sills were placed on concrete ground in the laboratory. Two bigger columns and two smaller columns were erected on the sills at the corners. A shorter girder, shown on the left side of Fig. 1, was inserted into two bigger columns. After the beams were placed on shorter columns, they were inserted into

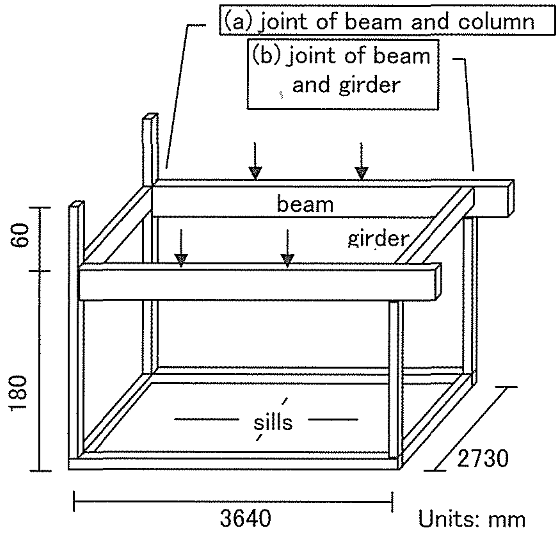


Fig. 1. Schematic diagram of structure for tests. Arrows, loading points; joint (a) and (b), see Fig. 2.

bigger columns (Fig. 2(a)). Then the longer girder, shown on the right side of Fig. 1, was subsequently placed on the beams (Fig. 2(b)). The tenon and mortise of the members were processed with a molding machine at a sawmill in Kanagawa. The joints of the columns and sills were tied with steel plates, and the joints of beams and columns were tied with "hagoita" bolt connectors.

Testing procedure

The applied load on each beam was a dead weight of 1300kg that was calculated on the basis of the long-term design load of 130kg/m^2 for beams specified in the old law[13], which was revised in 1998. Two concentrated dead loads (total weight=1300kg) were applied on each beam (the applied stress=4.91MPa), and the estimated stress level was approximately 0.1 on the assumption that bending strength of the beam was 50MPa according to the literature[3]. Two steel hangers were set to support each weight. The weight was supported on the forks of a baggage carrier, and was carried down very slowly, and was then placed on the hanger. The loading points were one third points of span, and are shown as arrows in Fig. 1. The loading started on 29 August 1994 (0 day), and continued until 23 January 1997 (878 days). Measurements ended on 5 March 1997 (919 days).

For practical purpose, the deflection at mid-span was measured on the upper-side of the beam using a strain gauge transducer (DT-50A, Kyowa Co; stroke=50mm; accuracy=0.02mm). Another dial gauge was also set near each measuring point to provide unforeseen circumstances. The deflection was equal to the change of distance between the upper-side of the beam and the ground. The deflections would include the shrinkage of beam heights, and the mechano-sorptive deflections occurs with the shrinkage. The measurements were recorded automatically with the data-logger and by personal computer. The deflections measured at midnight were used since temperature and RH might change rapidly in the daytime. Temperature and relative humidity (RH) were also measured using weather auto-recorder (No.7210-00, Sato Co.) which was set near the testing frames. The cylindrical record papers were changed every week. The moisture content of all members was measured with an electric-capacity wood moisture tester (Moco HM-520, Kett Electric Laboratory) every week.

Results and discussion

Deflections of beams

The initial deflections of the two beams in structure D were 4.94mm and 4.13mm, and those in structure G were 5.31mm and 3.96mm. These values were greater than the estimated values given by dynamic Young's modulus data, as shown in Table 1; 4.09 and 3.86mm in structure D; 4.52 and 3.11mm in structure G. Since the each value (total deflection) was measured at the center of upper side of beam, then it included shrinkage of beam and movement of beam at the joint. The total defections were shown in Fig. 3 (a), and the bending deflections of the beams, which did not include shrinkages and movement, were shown in Fig 3 (b).

In this paper, we chose the former deflections for analysis because of practical purposes. Then, the ratio of deflections to the initial deflection (relative deflection) was calculated, and we discussed creep behaviors using the average of the two

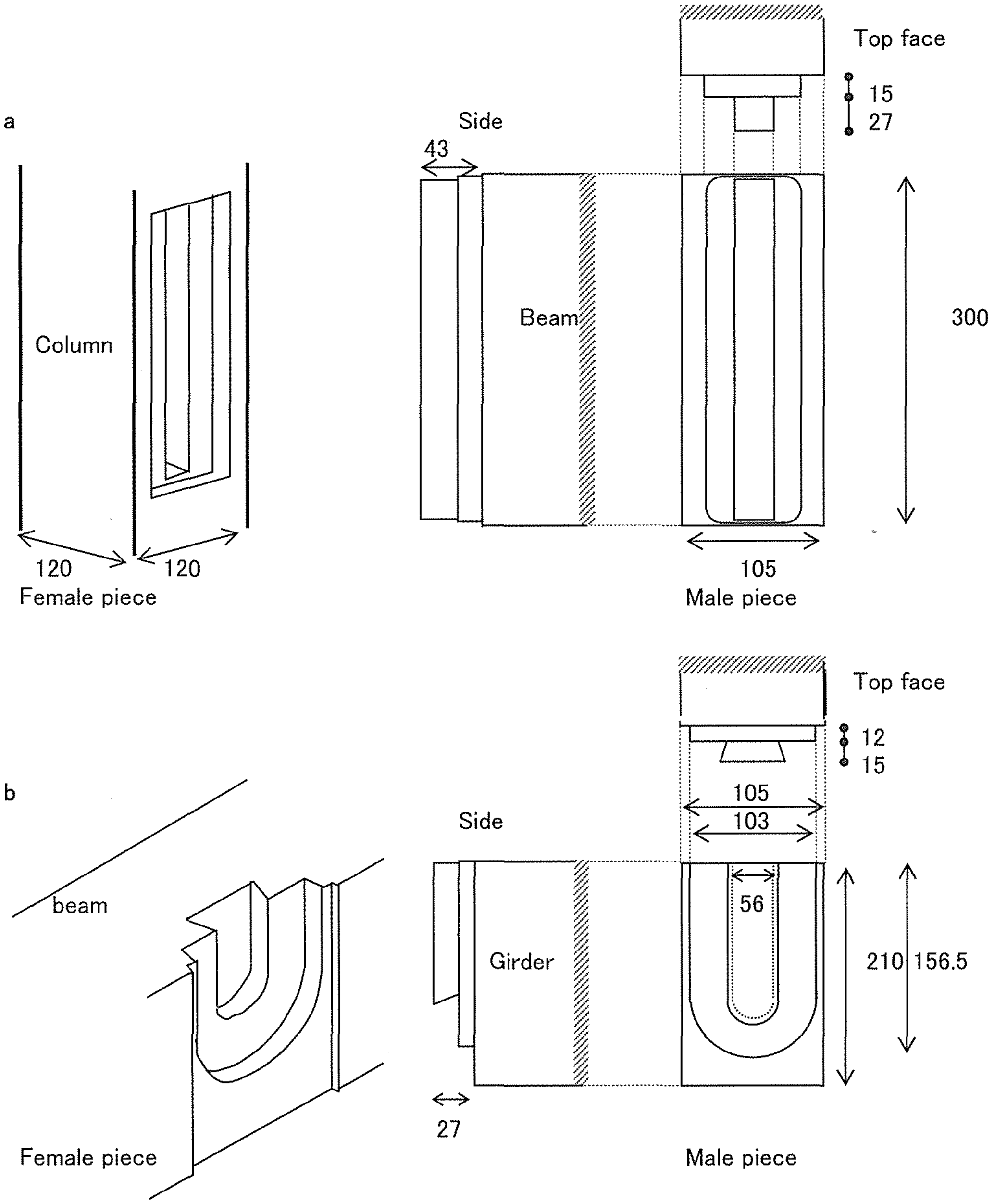


Fig. 2. Diagrams of joints. Joint of column and beam (a), joint of beam and girder (b) ; joint (a), "Hozo-sashi"(Tenon insert) ; joint (b), "Ari kake" (Hanging of ant shaped piece ; unit in mm.

relative deflections for each structure.

Figure 4(a) illustrates relative deflections for the whole experiment period. Temperature and relative humidity are shown in Fig. 4(b). It is clear that relative deflections in structure G were greater than those in structure D. For structure G, relative deflection rapidly increased in 100 days after loading, and the rate of relative deflection gradually decreased. After 400 days, relative deflection became stable, but it moved for the period between 600-680 days in summer. For structure D, the increase of relative deflections were smaller than that in G in 100 days after loading, but it waned subsequently similar to G. The values of relative deflections were tabulated in Table 2. The additional relative defection (= relative deflection-1) in G was 2.2 (=2.75/1.26) times that in D. The instantaneous recovery of relative deflections in D and G after unloading were 0.71 and 0.76, respectively.

In Fig. 5, the relative deflections for D and G were set on horizontal and vertical axis, respectively, for reasons of comparison. During the initial 100 days, differences between G and D in-

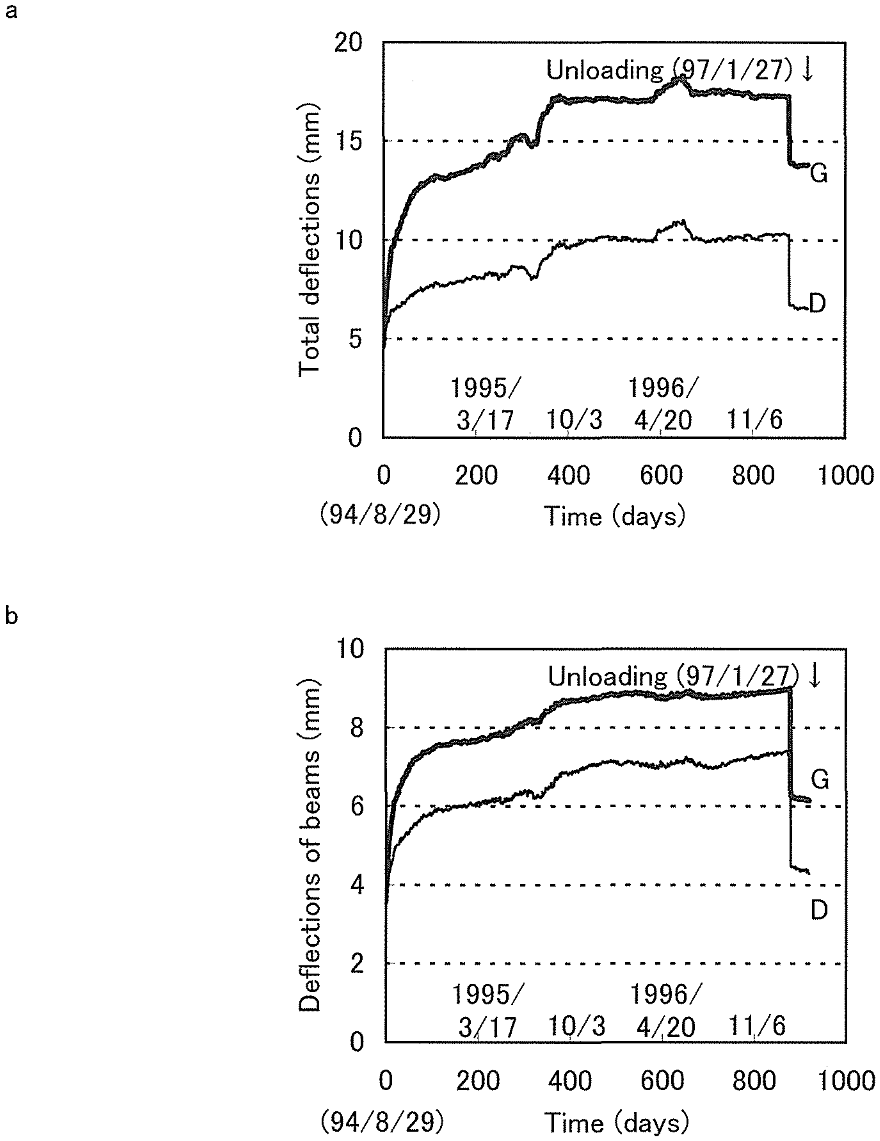


Fig. 3. Deflections of beams. a total deflections, fat and thin lines, test structures composed of green (G) and kiln-dried (D) timbers, respectively, b Deflections of beams.

Table. 2. Values of relative deflections during creep test.

Days	Date	G	D	Notes
0	29/August/94	1.00	1.00	Load is placed
7	5/September/94	1.60	1.26	
30	28/September/94	2.25	1.47	
100	7/December/94	2.84	1.69	
365	29/August/95	3.70	2.10	
647	6/June/96	3.98	—	Maximum in G
649	8/June/96	—	2.43	Maximum in D
731	29/August/96	3.79	2.23	
878	23/January/97	3.75	2.26	before removing the loads
879	24/January/97	3.04	1.50	after removing the loads
919	5/March/97	3.00	1.43	Final measurements

G, D : see table 1.

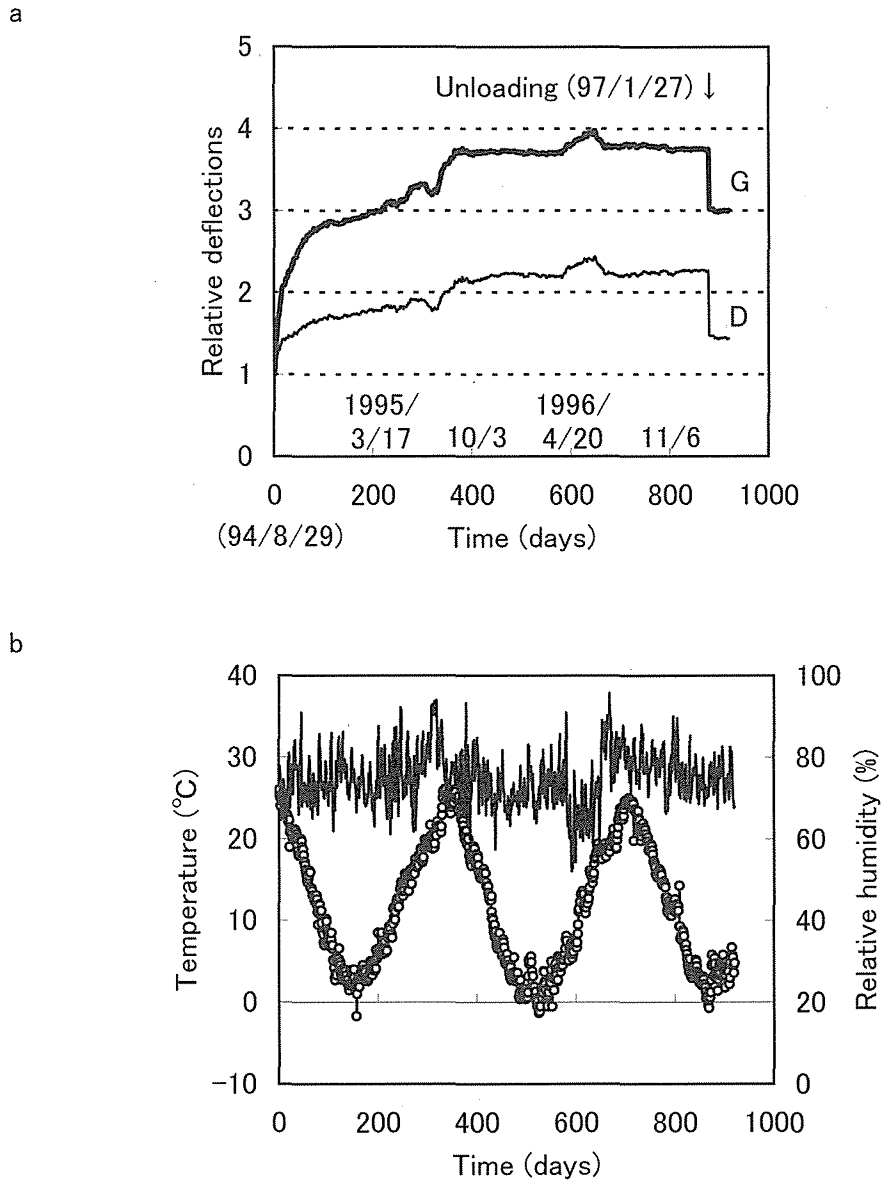


Fig. 4. Relative deflections and climates. a relative deflections, fat and thin lines, test structures composed of green (G) and kiln-dried (D) timbers, respectively, b temperature and relative humidity (RH), open circles, temperature ; lines, RH, respectively.

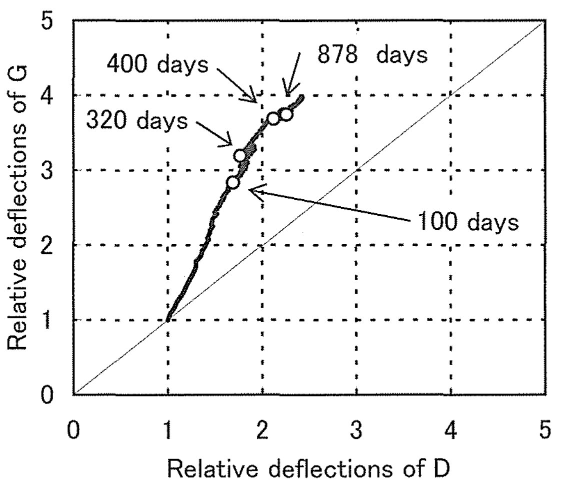


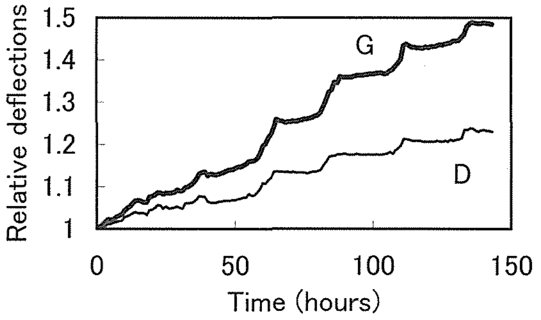
Fig. 5. Comparison of relative deflections between G and D.

creased steadily, and the slope of the regression line was 2.85 by the least square method. In this period, the increment of relative deflections in structure G was 2.85 times that of structure D. After 100 days, the slope decreased : the slope was 1.37 during 320-400 days and 0.93 during 400-878 days.

Effects of relative humidity on relative deflections

The initial 6-day creep behaviors were shown in Fig. 6(a), and temperature and relative humidity (RH) were shown in Fig. 6(b). Relative deflections tended to increase rapidly when the

(a) Relative deflections



(b) Temperature and RH

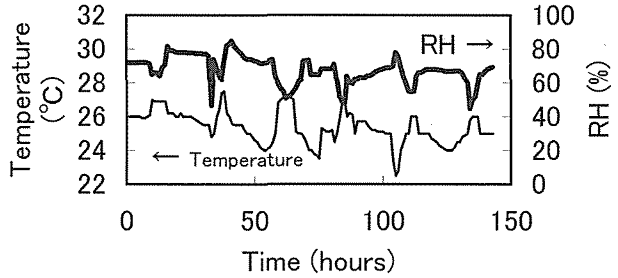


Fig. 6. Initial six-day bending creep behaviors and temperature and relative humidity (RH). a Fat and thin lines, G and D, respectively ; b fat and thin lines, RH and temperature, respectively.

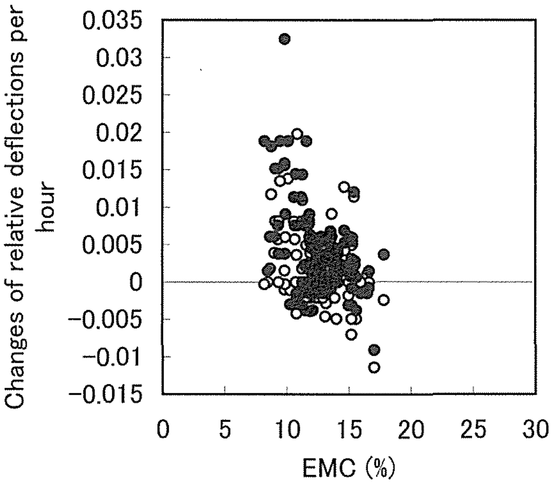


Fig. 7. Relationship between creep rates and equilibrium moisture content (EMC) during initial six days. Filled and open circles, G and D, respectively ; EMC (%) was calculated by Simpson's formula.

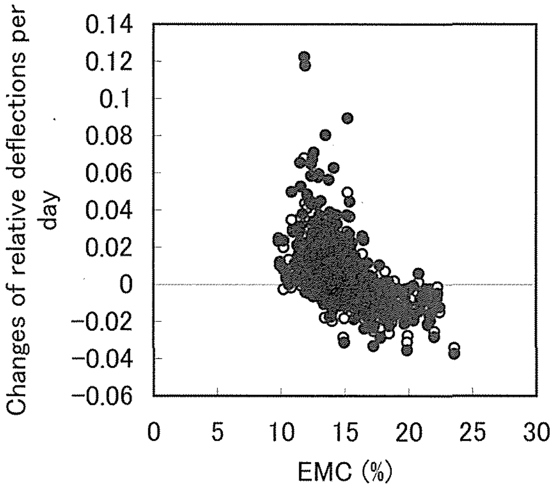


Fig. 8. Relationship between creep rates and EMC during whole loading period. Filled and open circles, G and D, respectively ; EMC (%) was calculated by Simpson's formula.

temperature increased or when the RH decreased. To investigate the relationship between relative deflections and RH, values of equilibrium moisture content were determined using Simpson's formula[14] with temperature and RH data at first. The formula is :

$$\mathrm{EMC}=\{K_1K_2h/(1+K_1K_2h)+(K_2h/1-K_2h)\}\times 1800/W \quad (1)$$

where EMC is the percent of moisture content, h corresponds to relative vapor pressure (relative humidity/100) and W is molecular weight of the polymer unit that forms the hydrate. Equation (2), (3), and (4) gave the values of K_1, K_2, and W, respectively.

$$K_1=3.730+0.03642T-0.0001547T^2 \quad (2)$$

$$K_2=0.6740+0.001052T-0.000001714T^2 \quad (3)$$

$$W=216.9+0.01961T-0.005720T^2 \quad (4)$$

where T is temperature in degrees Fahrenheit.

Fig. 7 shows the relationship between the EMC and creep rates, which are expressed as changes

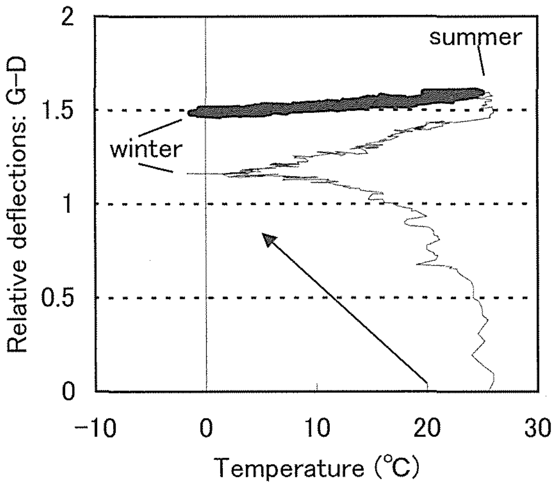


Fig. 9. Relationship between temperature and differences between relative deflections of G and D. Circle, loading started point ; arrow, duration time ; thin and fat lines, before and after 400 days, respectively.

in relative deflections per hour. The deflections increased rapidly when EMC was low, and vice verse (EMC is low during the day, and high at night). Correlation coefficients between EMC and creep rates were −0.442 in G, and −0.311 in D at the 1% significant level.

Similar relationships between EMC and creep rates were observed throughout the whole loading period, as shown in Fig. 8. In this case, EMC at midnight and creep rates as changes in relative deflections per day were used. Correlation coefficients between EMC and creep rates were −0.472 in G, and −0.551 in D at the 1% significant level. These results suggest the possibility of predicting chganges of relative deflections using EMC data.

Effects of temperature on relative deflections

The relative deflections seemed to vary greatly when temperature was high as shown in Fig. 4. Differences in the relative deflections of G and D were plotted against temperature in Fig. 9. In the initial period along the arrow in the figure, the differences increased greatly. But the plots were finally on a straight line. After 400 days, the correlation coefficient between temperature and the difference was 0.937. But the slope of the linear regression line of the differences on temperature was very small (=0.00385). Additional study will be needed in order to analyze the phenomenon.

Conclusion

The results of the bending creep test of beams in Japanese conventional structures are summarized as follows. The two test structures were used. One was composed of green timber (G) and the other of kiln-dried timber (D).

1. After 878 days, ratios of total deflection to initial deflection were 3.75 and 2.26 for structure G and D, respectively. After unloading, the ratios became 3.04 and 1.50 times for G and D, respectively.
2. Rates of creep deflections tended to decrease as relative humidity increased.
3. Differences in the relative deflections of G and D increased as temperature increased after 400 days, but the changes of the differences were small.

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生材及び人工乾燥材の軸組における梁のクリープ(I)　梁の相対たわみにおける差異

武田孝志*・有馬孝禮**

*信州大学農学部森林科学科

**宮崎県木材利用技術センター

要　約

本研究の主要な目的は，在来軸組構法における梁の曲げクリープを明らかにすることである。クリープ試験を行うに当たって，２つの木造構造体を用意した。１つは生材(G)のみで，もう１つは人工乾燥材(D)のみで構成した。各構造体は，４本の土台，４本の柱，２本の桁，及び２本の梁で構成されている。部材の特定の位置にあるほぞ等は，工場のモルダで加工した。長期設計荷重をそれぞれの梁の上面に載荷して，各梁のスパン中央のたわみを測定した。878日後の初期たわみに対する総たわみの比（相対たわみ）は，それぞれＧとＤで3.75，2.26になった。除荷後では，それぞれＧとＤで3.04，1.50となった。付加的な相対クリープたわみ（＝相対たわみ－１）は，ＧはＤの約２倍となった。

キーワード：メカノ・ソープティブ・クリープ，収縮，相対湿度，温度