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Creep Properties of Walikukun (*Schouthenia ovata*) Timber Beams

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Abstract: This study presents an evaluation of creep constants of Walikukun (*Schouthenia ovata*) timber beams when rheological model of four solid elements, which is obtained by assembling Kelvin and Maxwell bodies in parallel configuration, was adopted. Creep behavior obtained by this method was further discussed and compared with creep behavior developed using phenomenological model of the previous study. Creep data of previous study was deformation measurement of Walikukun beams having cross-section of 15 mm by 20 mm with a clear span of 550 mm loaded for three weeks period under two different room conditions: with and without Air Conditioner. Creep behavior given by both four solid elements model and phenomenological (in this case are power functions) had good agreement during the period of creep measurement, but they give different prediction of creep factor beyond this period. The power function of phenomenological model could give a reasonable creep prediction, while for the four solid elements model a necessary modification is required to adjust its long-term creep behavior.

Keywords: Creep; four solid element creep model; Walikukun timber; rheological model; phenomenological model.

Introduction

Creep is generally defined as an increase of deflection or deformation under a constant load. It reflects the long-term behavior of a material and is very significant in fiber-based materials such as timber. This creep phenomenon is well observed, for instance in building elements such as bending deformation of beams and axial deformation of wooden (shear) walls. Structural creep occured in high rise buildings causes dramatic change of end moment of beams [1]. Understanding creep behavior is necessary to deliver a proper design throughout desirable service life. In contrast, failure to understand creep behavior will lead to shortened service life as well as structural instability including P-Δ effect and long-term stress redistribution [2-5]. There are two ways to predict long-term creep of timber: through phenomenological model and mechanical or rheological model.

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The first method is utilizing mathematical function to best fit the short-term experimental creep data, while the second method is represented by a set of springs and dashpots whose constants are searched to best fit the short-term experimental creep data. In the rheological model, timber is assumed to behave as a viscoelastic material.

This study is aimed to examine the creep phenomenon of Indonesian Walikukun (*Schouthenia ovata*) timber species under two different indoor environments and to provide the constants required by rheological and phenomenological models. In addition, discussion on these two different models to predict the long-term creep phenomenon is presented.

Creep Models

The well accepted mechanical model to predict creep of timber is the four solid elements, or known as Burger model as shown in Figure 1(a). This model is derived by assembling Kelvin and Maxwell bodies in parallel configuration [3]. Having two dashpot elements, one in Kelvin body and another in Maxwell body, this model is capable to predict both primary and secondary creep. Governing equation to this four solid elements model is as follows [5],

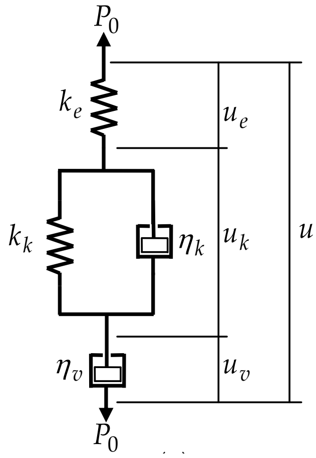
$$P+\left(\frac{\eta_v}{k_e}+\frac{\eta_v}{k_k}+\frac{\eta_k}{k_k}\right)\frac{dP}{dt}+\frac{\eta_v\eta_k}{k_e k_k}\frac{d^2P}{dt}=\eta_v\frac{du}{dt}+\frac{\eta_v\eta_k}{k_k}\frac{d^2u}{dt} \quad (1)$$

where P is applied load, u is element deformation, k_e, k_k, η_v, and η_k are the constants of the four solid elements model shown in Figure 1. The creep behavior of the Burger model under constant load P_0

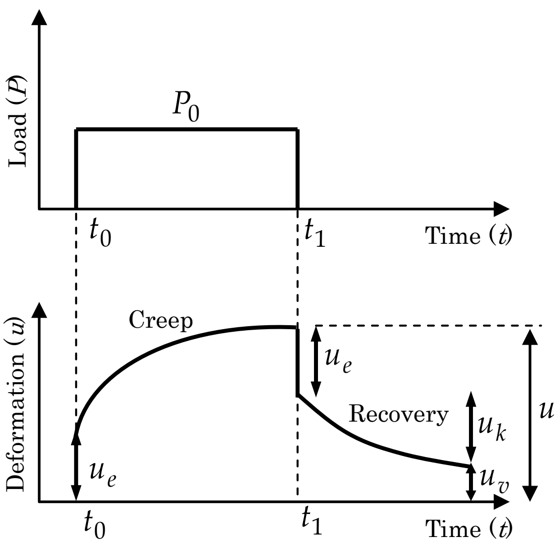
can be obtained by solving this second order differential equation using Laplace transformation method [5], taking into consideration the following initial conditions at $t_0 = 0$:

$$u_e = \frac{P_0}{k_e} \quad (2.a)$$

$$u_v = u_k = 0 \quad (2.b)$$



(a)



(b)

Figure 1. Creep Model for Viscoelastic Material: (a) Four Solid Elements Creep Model; and (b) Typical Generated Creep Behavior [3]

Solution of the above equation is given as,

$$u(t) = \beta_1 + \beta_2(1 - e^{-(\beta_3)t}) + \beta_4 t \quad (3)$$

where

$$\beta_1 = P_0 / k_e \quad (4.a)$$

$$\beta_2 = P_0 / k_k \quad (4.b)$$

$$\beta_3 = k_k / \eta_k \quad (4.c)$$

$$\beta_4 = P_0 / \eta_v \quad (4.d)$$

β_1 represents initial elastic deformation associated with the spring constan k_e ; β_2, and β_3 correspond to delayed elastic or recoverable creep component and are associated with the combined effect of the spring constant k_k and the dashpot constant η_k, and finally β_4 corresponds to irrecoverable creep component contributed by the dashpot constant η_v [6-9]. If the load P_0 is removed at time t equal to t_1, the creep recovery behavior of the Burger model can be derived from Equation 1 and superposition principle by considering that at t equal to t_1 and constant load P is taken as $-P_0$. This will give:

$$u(t) = \beta_2(e^{(\beta_3)t_1} - 1)e^{(-\beta_3)t} + \beta_4 t_1 \quad (5)$$

Typical creep and creep recovery behavior of Burger model can be seen in Figure 1(b). Recently, Ma et al. [10] based on their creep test results slightly modified Equation 3 proposed Equation 6. Here the constant λ is generally less than 1.0.

$$u(t) = \beta_1 + \beta_2(1 - e^{-(\beta_3)t}) + \beta_4 t^{\lambda} \quad (6)$$

Creep Data [11]

Creep data test used in this study was provided by Erlitasari [11] during her undergraduate thesis in the Civil Engineering and Environmental Engineering Department, Gadjah Mada University, Indonesia. In her work, she measured deflection of Walikukun timber beams (average moisture content 16%; average specific gravity 0.95) having cross-section of 15 mm by 20 mm with a clear length of 550 mm under one constant load at mid-span for three weeks period. Schematic of Erlitasari's creep test is illustrated in Figure 2 where continuous measurement of mid-span beam deflection, room temperature, and relative humidity (RH) was carried out. The test was conducted in two different room conditions: equipped with and without Air Conditioner (AC). Measurement of room temperature and RH in this two different room conditions during the test are presented in Figure 3. Temperature in these two room conditions are about the same, which is 27±1^{0}C, while relative humidity in the room equiped with AC (between 69% and 91%) is slightly higher but more stable than that in the room without AC (between 54% and 83%).

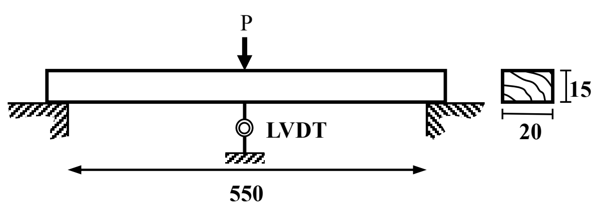


Figure 2. Schematic of Creep Measurement Carried Out by Erlitasari [11] (unit in mm)

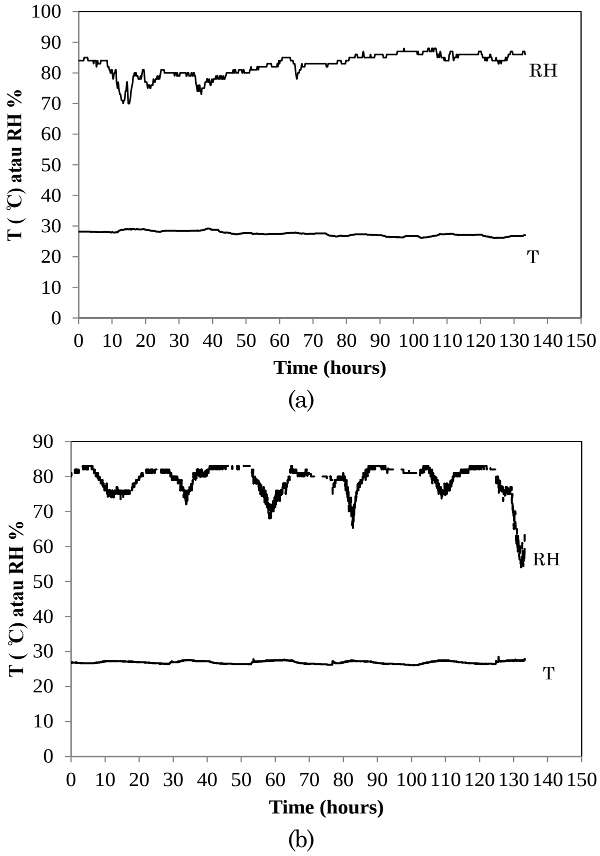


Figure 3. RH and Temperature Measurement During Creep Test: (a) Room Equiped with AC (b) Room without AC [11].

Erlitasari [11] loaded the beams at three different constant loads: 100 N; 175 N; and 250 N, which respectively, correspond to stress levels of 30%, 50%, and 70% of the bending load that causes failure in one month. Erlitasari did not provide further explanation of choosing this one-month failure, load as the basis in determination the stress level for creep measurement. Two beam specimens were prepared per each load level. Creep behavior and creep factor obtained from the measurement along with Erlitasari`s proposed equations are presented in Figures 4, 5, and 6 for the three different load levels. Creep factor defined in Equation 7 is the ratio of creep deformation, which is deformation developed from t_0 to t_1, to elastic or instantaneous deformation.

$$\text{Creep Factor} = 1 + \frac{(\delta_{t1} - \delta_{t0})}{\delta_{t0}} \quad (7)$$

Erlitasari`s proposed equation was derived based on phenomenological model where she found that power function best fitted the test data in general. As indicated by Figures. 4, 5, and 6, creep factor of the beam specimens kept in the room equiped with AC is less than that of the beam specimens kept in the room without AC.

Simulation Results and Discussion

Equations 3 and 5 were solved simultaneously using Toolbox Solver program available in Microsoft Excel [12] to best fit the creep data test of Erlitasari [11]. This Solver program uses iteration method to find coefficients of the equation that best fit the test data or producing the least of sum of square of error. These coefficients are summarized in Table 1 for three different load levels under two different room conditions obtained from two replicates. β_1 in the equations which defines the instant deformation (initial elastic deformation) increases in proportion to the load level, especially Specimen # 1. In the case of Specimen # 2, the magnitude of coefficient β_1 at load levels 175 N and 250 N are much greater than what we expect assuming linearly in proportion to the load level. In general, coefficients β_2 and β_3 increase as the function of load level as well though their magnitudes derived from two different room conditions are different one to another. The coeffient β_4 is found to be higher for a higher load level, but it is about the same magnitude for two different room conditions (see Table 1). Here we can see that a very good agreement was found between the experimental creep and its prediction developed by Equation 2, indicated by coefficient of correlation (R^2) close to one. This is an important consideration for creep prediction in the future [6].

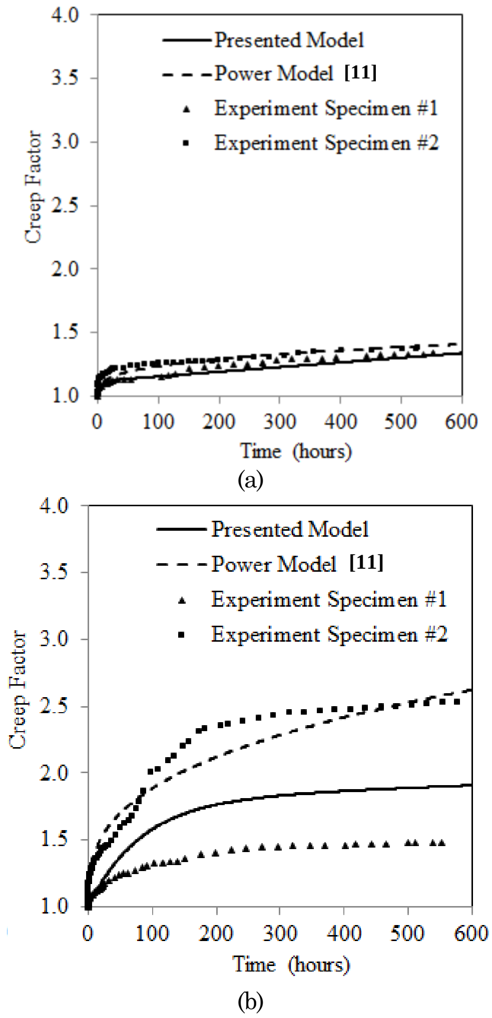


Figure 4. Creep Factor of Walikukun Beams Stress Level 30%: (a) Room Equiped with AC; (b) Room without AC

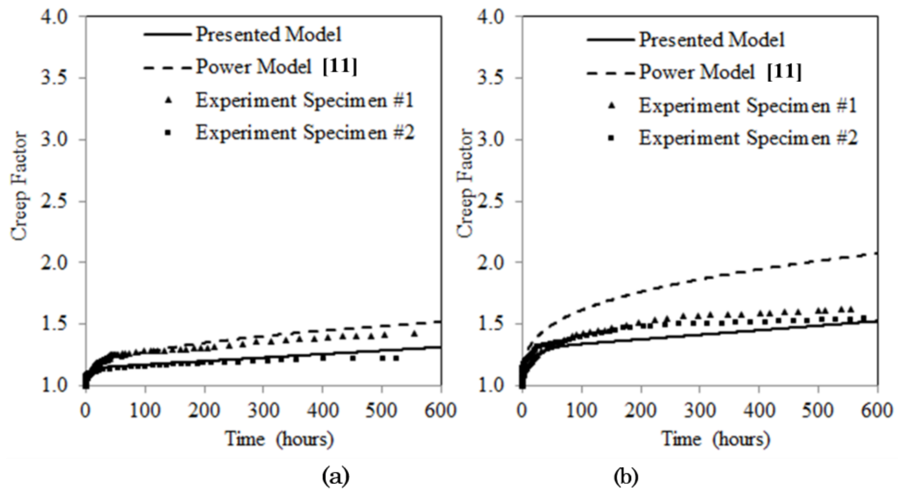


Figure 5. Creep Factor of Walikukun Beams Stress Level 50%: (a) Room Equiped with AC; (b) Room without AC

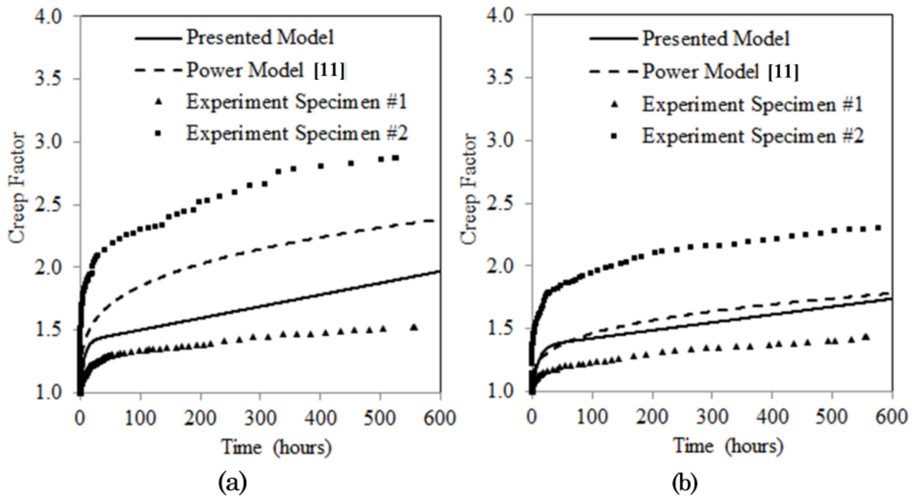


Figure 6. Creep Factor of Walikukun Beams Stress Level 70%: (a) Room Equiped with AC; (b) Room without AC

Table 1. Coefficients of Equation 2 Obtained from Toolbox Solver Program

Room condition	Load level	Specimen	β_1	β_2	β_3	β_4	R^2
Equiped with AC	30%	#1	5.398	0.542	0.056	0.002	0.981
		#2	3.223	0.479	0.214	0.001	0.965
	50%	#1	8.509	1.655	0.059	0.003	0.966
		#2	8.062	0.714	0.206	0.002	0.954
	70%	#1	14.109	3.127	0.062	0.007	0.993
		#2	10.656	6.974	0.245	0.017	0.977
Not-equiped with AC	30%	#1	4.752	1.514	0.016	0.001	0.993
		#2	5.109	6.292	0.009	0.001	0.986
	50%	#1	6.736	2.360	0.028	0.003	0.990
		#2	6.554	1.657	0.087	0.002	0.964
	70%	#1	11.798	1.805	0.065	0.005	0.985
		#2	15.814	8.164	0.132	0.012	0.972

Figure 4 shows the creep factor given by the Equation 2 along with the creep test data and power function proposed by Erlitasari [11]. In comparison to the Erlitasari's proposed power function, four solid elements model described in Equation 3 gave better agreement to the average creep data tests of both two room conditions, equiped with and without AC, as it has lower sum of squared errors as indicated in Table 2. The creep constants of four solid elements model presented in Figures. 4, 5, and 6 are summarized in Table 3 where each data is an average of the two replicates.

Table 2. Sum of Squared Errors (SSE) of the Models

Room condition	Load level	Specimen	Power Model [11]		Presented Model	
			SSE	Mean SSE	SSE	Mean SSE
Equiped with AC	30%	#1	0.099	0.108	0.118	0.188
		#2	0.118		0.257	
	50%	#1	0.147	0.468	0.078	0.100
		#2	0.789		0.123	
	70%	#1	31.640	21.852	0.823	6.444
		#2	12.065		12.065	
Not-equiped with AC	30%	#1	19.829	10.356	0.198	2.260
		#2	0.883		4.323	
	50%	#1	2.743	3.635	0.294	0.647
		#2	4.526		1.000	
	70%	#1	2.464	8.323	0.128	4.472
		#2	14.182		8.817	

Table 3. Average Creep Constants of the Four Solid Elements of Walikukun

Room conditions	Load level	k_e (N/mm)	k_k (N/mm)	η_k (N/mm-hour)	η_v (N/mm-hour)
Equiped with AC	30%	24.77	196.78	2148.72	0.66
	50%	21.14	175.39	1495.47	0.70
	70%	20.59	57.90	719.64	3.81
Not-equiped with AC	30%	20.31	40.97	2996.75	0.40
	50%	26.34	89.89	1943.29	0.60
	70%	18.50	84.55	1185.23	2.38

Here the authors can evaluate quickly only the constant k_e whose magnitude must equal to (instantenous) elastic bending stiffness of Walikukun timber beams under loading configuration illustrated in Figure 2. Knowing that clear-span length is 550 mm, beam cross section is 15 mm by 20 mm, and Modulus of Elasticity is 12000 MPa [9], elastic bending stiffness of the beam under one unit point load is $k_e = 48EI/L^3 = 19.5$ N/mm. This value is about the same with Maxwell spring constant (k_e) of the Burger model which is obtained by dividing the applied load with coefficient β_1 and this is found to be 18.50 to 24.77 N/mm. Previous reports also have shown that evaluation of the elastic bending stiffness of beam stuctures is straight froward from the information of Maxwell spring constant (k_e) of the Burger model [7, 12].

As the authors compare the creep constants of four solid element model found in the room equipped with AC to those found in the room without AC (see Table 3), it can be seen that all creep constants (except η_v) in the room equipped with AC show a uniform trend where they decrease with respect to increase of load level. This is because they are kept in more constant environment with minimum fluctuation of room temperature and RH. Common sense informs that the magnitude of these creep constants of one specimen are not comparable one to another and by nature they will be unique. The source of variation is because timber is a non-homogenous material and grading of the timber beam specimens was not performed before the test done by Erlitasari [11].

In order to investigate further these two creep models, Figure 7 presents the predicted creep factor within one year given by the power function proposed by Erlitasari [11] and the four solid elements model for 50% load level. The curves having the same constants as those in Figure 4, but extend the time t up to one year or 8780 hours. Suprisingly that the curves given by the four solid elements model is higher as time t increases, while the curves obtained from the power function proposed by Erlitasari nearly reach a complete stop. It is suggested that precaution is necessary when four solid elements model is used to predict the creep factor beyond the period of measurement, because in the actual condition creep factor will come to a constant value after very long period of measurement. A close look to the Equation 2, the last term is the source of this ambiguity where this term increases as the elapsed time higher. Ma *et al.* confirmed this drawback of the four solid element model when they measured the creep factor of *Eucalyptus* wood [10].

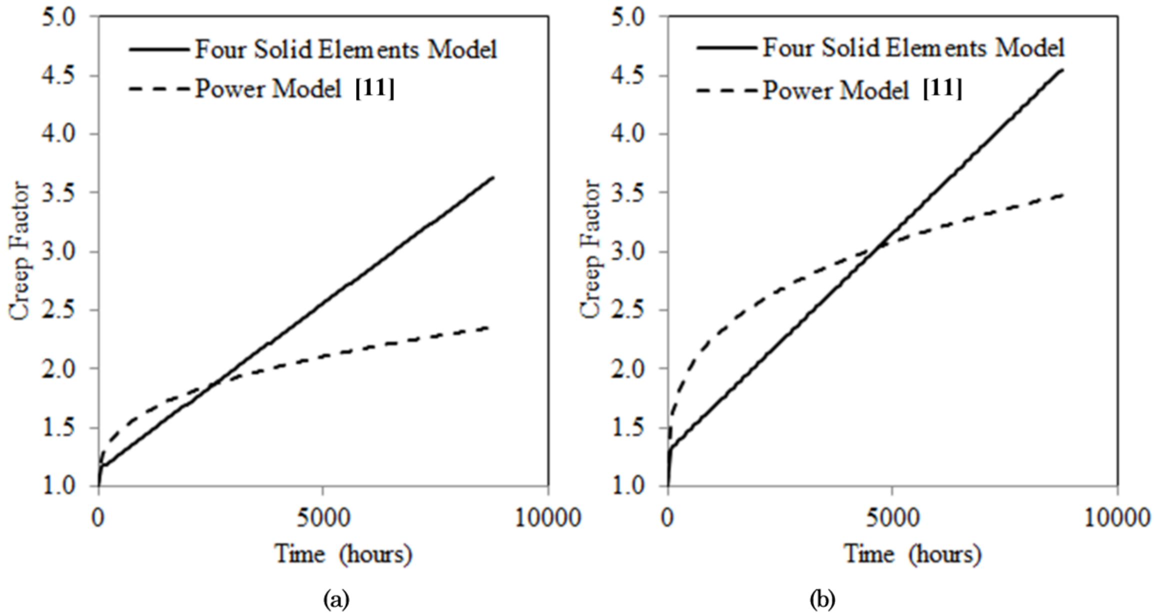


Figure 7. Predicted Creep Factor Given by the Power Function [10] and the Presented Model for Load Level of 50%: (a) in Room Equiped with AC; and (b) in Room without AC

Conclusions

Analysis of creep constants of four solid elements model was performed in this study utilizing creep measurement of Walikukun (*Schouthenia ovata*) timber beams of a previous study. Some conclusions can be drawn as follows: 1. Creep behavior given by both four solid elements model and phenomenological, in this case is power function, had good agreement during period of creep measurement, but they give different prediction of creep factor beyond this period; 2. The power function of phenomenological model gave a more reasonable creep prediction than the four solid elements model; 3. As previous study suggested, modification to the creep equation developed by four solid elements is necessary when this equation is used for creep prediction beyond the measurement period; and 4. Under room condition equipped with AC, the creep constants of four solid elements model showed a uniform trend in which they decrease with respect to the increase of stress level.

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