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COMPARATIVE STUDY OF CREEP MODELS FOR WOOD AND TIMBER EXTRAPLOATED OVER 100 YEARS IN CONSTANT CLIMATE

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ABSTRACT: Timber elements should comply with serviceability requirements in the standards to meet deflection limits. Accordingly, understanding the wood's creep behavior is crucial for predicting the long-term performance of timber structures. Many studies have proposed different models to describe the creep phenomenon in wood and engineered wood products, each with varying degrees of accuracy, number of model parameters, and applicability over different time scales. However, most used creep models tend to be reliable solely over the time scale of the available experimental data they were fitted on, which is in most cases, only a few years. This study aims to improve the understanding of rheological models to enhance the reliability of creep curves in the serviceability limit state design of timber structures. To achieve this, the accuracy of creep curves must be ensured over long time scales, such as 100 years, where experimental data are lacking. First, several established creep models, such as Kelvin-Voigt type models, are compared for several sets of available experimental data, such as constant climate creep of spruce clearwood and timber. The models are fitted using regression analysis, and assessed with respect to their respective number of fitting parameters. Subsequently, the models' behavior is extrapolated to assess long-term performance over 100 years. For constant climate creep, it could be confirmed that 4-body Kelvin-Voigt type models perform best in terms of the balance between predictability and the number of fitting parameters.

KEYWORDS: Rheological Models, Wood Rheology, Creep, Viscoelasticity, Kelvin-Voigt

1 – Introduction

The long-term performance of the wood and engineered wood products (EWP) is significantly affected by creep, i.e., the time-dependent deformation under sustained load. In this regard, to explore the complexities of wood mechanics and its rheological behavior, various studies have established robust models to understand the creep behavior of wood. The foundational works in this domain, such as the principles established for conducting and evaluating creep tests, emphasize the influence of loading type, stress level, stress distribution, force-to-grain angle, and climatic stress on the creep behavior of wood [1], [2], [3]. These studies provide essential test methodologies that serve as a baseline for comparing models' accuracy. Further advancements introduced deformation-based rheological models, emphasizing the distinction between viscoelastic creep under constant climate and mechano-sorptive creep, which depends on both the moisture content and temperature as well as the rate of their changes [4], [5], [6], [7]. These models present a framework for analyzing the coupling of creep deformations with environmental factors in various wood species, with a primary focus on viscoelastic and mechano-sorptive effects and less emphasis on induced swelling and shrinkage. More recently, Trcala et al. [8] developed a generalized Kelvin chain-based model to provide a robust simulation of viscoelastic behavior, and Nguedjio et al. [9] demonstrated the efficacy of fractional derivative models, particularly the Thomson model [10] in capturing viscoelastic creep behavior. The scope of their work is limited to short-term investigations. Accurately predicting long-term creep in wood and timber structures for a period of 50 to 100 years remains a challenge due to the scarcity of experimental data spanning multiple decades. Current models and

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parameters are primarily fitted to mid- and short-term data (<10 years, often <1 year), limiting their ability in long-term analyses (≥ 50 years). Moreover, numerical methods to predict and validate long-term creep behavior are still underdeveloped, leaving a gap in assessing the structural performance affected by creep over extended timeframes. Addressing these limitations is critical to improving the predictive capability of creep models and their applicability in structural design codes.

In this work, the capability of some commonly used creep models in the prediction of creep behavior over up to 100 years is investigated. It is aimed to determine which models are more suitable for accurately predicting the long-term behavior of timber structures in constant climate. Creep curves are also especially of interest in the recently emerging finite element based design of timber structures [11]. Given the long-term implications of creep, investigating and refining predictive models is critical to improving the reliability of timber structures. Here, the ultimate aim would be the definition of an existing or "yet another optimized rheological model" that (1) improves the fit to available data, (2) demonstrates acceptable behavior over long-term time periods ≥ 50 years, and (3) minimizes the required number of fitting parameters at the same time. Analyzing the long-term behavior of timber structures requires a robust approach to modeling creep. The presented comparative study investigates the accuracy of different models for long-term prediction of creep behavior in timber structures. Using the insights gained from the fitting procedure, the 4-body Kelvin-Voigt model is examined in detail to assess its ability to accurately capture long-term creep trends in constant climate conditions. Then, different models are compared with each other to examine their accuracy for two constant climate analyses and also for a service class analysis against the established Toratti model B [12].

2 – Creep Models and Experimental Data from Literature

2.1 Creep factor

In the context of creep in wood and timber, the so-called creep factor (φ) is being used as a parameter in structural design codes, such as EN 1995-1-1 [13], to account for time-dependent deformation of timber structures. This factor provides a simplified means of incorporating creep effects into design calculations, allowing engineers to estimate long-term deformations based on short-term elastic responses. The constitutive formulation of the creep factor is given by :

$$\varphi = \frac{\text{Total deformation (elastic + creep)}}{\text{Elastic deformation}} \quad (1)$$

In EN 1995-1-1 [13], $\varphi_{EC5} = k_{def} = \varphi - 1$ to exclude the elastic deformations. The creep factor in Eq. 1 serves subsequently as a basis to evaluate and compare different rheological models.

2.2 Rheological creep models

The mechanical modeling of a material's time-dependent behavior in the context of creep often utilizes rheological components. The two most common components of the rheological models are the linear elastic Hook spring and the Newtonian speed-dependent damper, or dashpot (Figs. 1(a) and (b)). Further elements can be generated by a combination of these components (Figs. 1(c)-(e)), which leads to specific constitutive laws for rheological models. Among the established models, the Kelvin-Voigt and the Maxwell elements are very common. These can be further combined to form other models like the Standard Linear Solid (SLS) and the Burger's model [14]. Exemplary creep equations and the number of independent parameters of the constitutive equations of some of these models are summarized in Table 1.

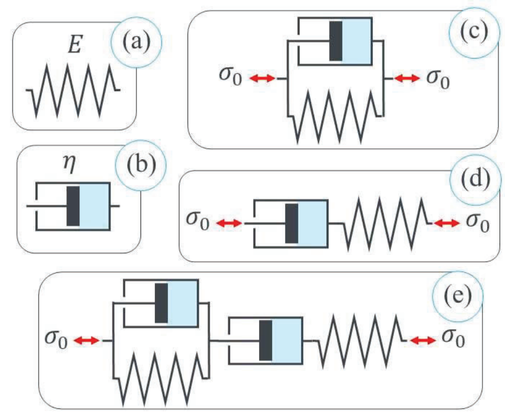

Figure 1. *Components of rheological models: (a) Spring and (b) dashpot. Established rheological models: (c) Kelvin-Voigt, (d) Maxwell and (e) Burger's model.*

Table 1: Creep equations for common rheological models.

Model	Creep equation (under boundary condition of constant stress σ_0)	Number of Parameters
Maxwell	$\varepsilon(t) = \frac{\sigma_0}{E_M} + \frac{\sigma_0 \times t}{\eta_M}$	2
Kelvin-Voigt	$\varepsilon(t) = \frac{\sigma_0}{E_K}\left(1 - e^{\frac{E_K}{\eta_K}t}\right)$	2
Standard Linear Solid (SLS)	$\varepsilon(t) = \frac{\sigma_0}{E_1} + \frac{\sigma_0}{E_2}\left(1 - e^{-\frac{E_2}{\eta}t}\right)$	3
Burger	$\varepsilon(t) = \left(\frac{\sigma}{E_M} + \frac{\sigma}{\eta_M}t\right) + \frac{\sigma}{E_K}\left(1 - e^{-\frac{E_K}{\eta_K}t}\right)$	4
Andrade	$\varepsilon(t) = \epsilon_0 + \beta \cdot t^m$	2
4-body Kelvin-Voigt	$\varepsilon(t) = \sum_{i=1}^{4} \frac{\sigma_0}{E_i}\left(1 - e^{\frac{E_i}{\eta_i}t}\right)$	8

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2.3 Available long-term experimental data for constant climate creep of wood and timber

Experimental data can be used for validating creep models, bridging the gap between the theoretical development of the models and real-world behavior. Long-term sets of data are particularly valuable for ensuring reliable extrapolations of creep models, and improving predictions for service-life performance of timber structures. In this respect, an extensive literature review was performed to identify suitable experimental datasets for the long-term predictions of this study. Here, the appropriate representative experimental data sets for one and multiple years suitable for validating and extrapolating rheological models are chosen.

A broad search on experimental creep data of various wood species and different engineering wood products (EWP) was conducted. At first, findings were categorized based on the wood species and EWPs, loading types, loading orientations (parallel or perpendicular to the grain), time period, climate conditions, and service classes. Among the available experimental data, only those of spruce were extracted. After sorting, the remaining sets of data with bending loading were compared for their relevance, duration (at least one year), and quality. Finally, only a few data sets remained, which cover creep over more than 1 year in a constant climate.

The graphs shown in Fig. 2 provide a non-logarithmic comparison of literature datasets after filtration, including measurements from Leivo, two sets of data from Gressel, and others [15], [16], [17], [18], [19], [20]. Each set of data is labeled according to the material type (Solid Timber (ST) and Clear Wood (CW)) and the author's name. The vertical axis exhibits the creep factor, which is calculated by dividing the total deformations by the instantaneous elastic deformation, see Eq. 1. A key observation from the figure is the large scattering of creep results across different studies. The variation in creep behavior is particularly evident in the divergence between "ST_Leivo" and "ST_Martensson", where "ST_Leivo" exhibits a noticeably higher creep factor over time. Among these, the "ST_Leivo", the "CW_Gressel_4-year", and the "CW_Gressel_7-year" datasets demonstrate a steady creep progression over time, following a clear and predictable trend that aligns well with the creep behavior required for extrapolation. These three mentioned datasets will therefore be used for various analyses in the following sections. In specific, the Gressel 7-year dataset offers a significantly extended measurement period than the other datasets, and this long-term scope could provide a more robust assessment for the creep models' behavior, bridging the gap between medium-term experimental data and long-term theoretical extrapolations. However, it should be noted that Gressel's 7-year dataset seems to represent the lower limit of possible creep factors. It is worth noting, the "CW_Gressel_4-year" and the "CW_Gressel_7-year" datasets are from two separate reports, [16] and the [17], the former with 20% load level (with respect to F_{max}) and the latter 30%.

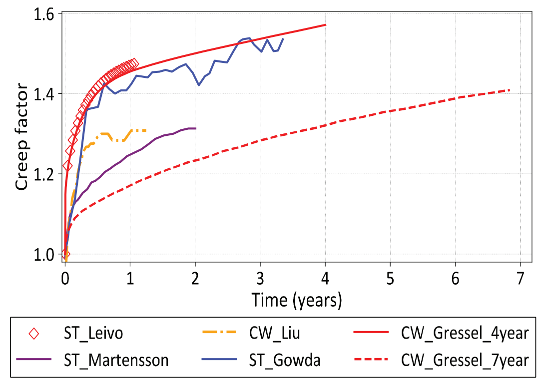

Figure 2. Comparison of the long-term experimental datasets, for constant climate, bending, and spruce (ST: Solid Timber and CW: Clear Wood).

3 – Fitting Procedure

3.1 General

In this section, firstly, the fitting quality of the Kelvin-Voigt-based models and the reasons for choosing the 4-body Kelvin-Voigt model are discussed. Then, the 4-body Kelvin-Voigt model is validated by comparing it to an established rheological model.

3.2 Fitting procedure's accuracy of models made of various kelvin-voigt combinations

Combining multiple Kelvin-Voigt elements is a widely used approach in rheological modeling to capture the complex time-dependent behavior of materials [21]. By varying the number of elements, different creep characteristics can be represented. Here, the long-term predictions of the various combinations of Kelvin-Voigt elements in the form of models made of one to six Kelvin-Voigt elements are compared with each other. All models were fitted to the 7-years experimental data from Gressel's [17]. The fitting procedure was carried out in two stages using Python tools: first, a linear regression model was trained on the given dataset to generate an extrapolated time series, ensuring a continuous transition between measured and predicted values. Second, a nonlinear regression approach was applied within the fitting function to determine the optimal parameters of each model.

Fig. 3 displays the results of the fitted models, whereby each model is extrapolated over 100 years to assess its prediction for the long-term. As a reference, the k_{def} value for class 1 (k_{def} = 0.6 in EN 1995-1-1 [13]) and the calculation results by Schänzlin [22] are given. Schänzlin [22] calculated creep factors between 0.5 and 1.1 after 50 years in a constant climate with different models. The results demonstrate that models made of up to 3 Kelvin-

Voigt elements predict creep values that are relatively negligible or on the lower bound of the expected values for constant climate. The 4-body Kelvin-Voigt model with 8 parameters (n = 8) represents a very good fit (R^2_{adj} = 1.00). Adding more elements, i.e., 5-body and 6-body cases, does not increase the accuracy, while the number of required fitting parameters and the fitting effort increases.

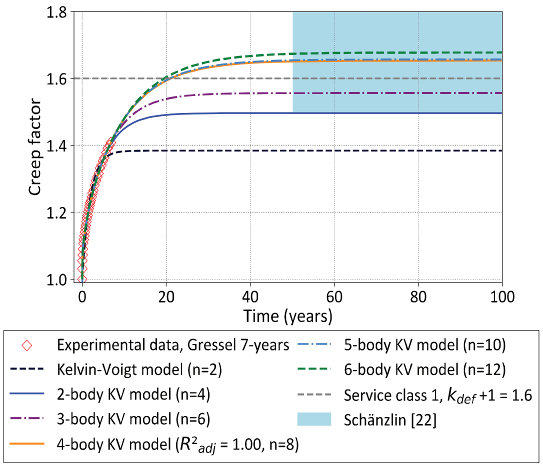

Figure 3. *Comparison of the extrapolation trends of the various Kelvin-Voigt combinations for fitting procedure accuracy analysis and comparison with k_{def} from EN 1995-1-1 [13] and calculation results of Schänzlin [22].*

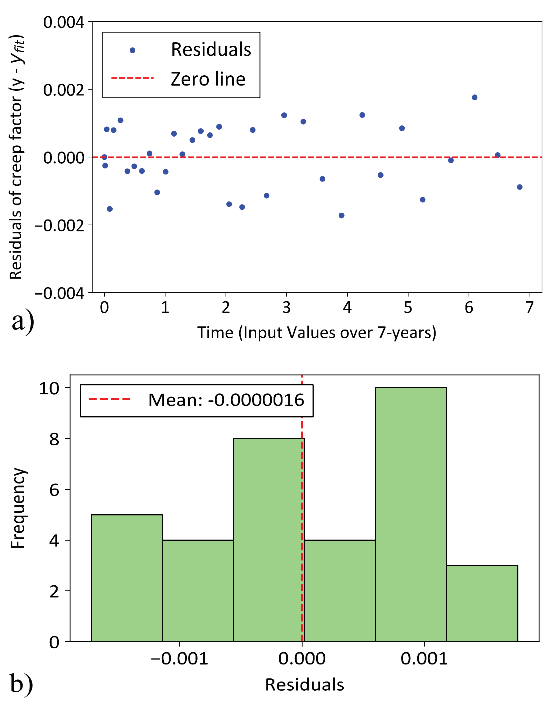

Figure 4. *Evaluation of fitting procedure accuracy in the case of residuals (a) distribution of residuals (comparsion of the experimental and predicted results) and (b) trend of residuals for 4-body Kelvin-Voigt model.*

In addition, the accuracy of the 4-body Kelvin-Voigt model and potential issues such as bias and overfitting are investigated by using histogram and residual-vs-input plots, see Fig. 4. The residuals represent the difference between the creep factor according to the data set and the fitted model datapoints. As shown in Fig. 4 (a), the residuals are closely clustered around the zero line for almost all input values. Residuals slightly deviate from zero (between 0.0015 and -0.0015), but these deviations are small compared to the absolute creep factors. Besides, there is no clear systematic deviation of the residuals over time, which indicates the fitting errors are random and are not influenced by time. The histogram in Fig. 4 (b) demonstrates an unimodal shape. This suggests that the residuals follow a normal distribution, which is a desirable property for a good fit. The fitting procedure yielded predictions that are very close to the observed experimental data. The calculated 'mean of residuals' and 'standard deviation of residuals' of this fitting procedure analysis are -1.6e^{-06} and 0.00093, respectively.

3.3 Fitting accuracy comparison with literature model

In order to optimize the presented 4-body Kelvin-Voigt model for the constant climate studies, the model fitting parameters are compared to established creep models. In this case, the Toratti's model B [12] described by Schänzlin [22] is used as a benchmark to examine the accuracy of the 4-body Kelvin Voigt model in long-term predictions. For this analysis, the 4-year experimental set of data from Gressel [16] is used. Input values of the implementation for Toratti's model B by Schänzlin [22] are the structural system, loading, member geometries, modulus of elasticity, initial moisture content and temperature, moisture content and temperature variation over time (here none). As all this information was not available for the 7-year test data of Gressel [17] but the 4-year test data of Gressel [16], the latter dataset is used for fitting the 4-body Kelvin-Voigt model.

Two approaches are used to fit two 4-body Kelvin-Voigt models to the 4-year test data of Gressel [16]. The first model ((1) in Table 2) is not fed with any initial guess to make the best fit and calculate its 8 fitting parameters (n=8) by its own. The second model ((2) in Table 2) is fed with initial guesses of fitting parameters (n=0) in the form of bound ranges close to the predefined values (i.e. $0.009 < \tau_i < 0.011$) in Toratti's model B in Table 2, boosted with a weighted loss function to better deal with the measurement uncertainties. The narrow bound ranges in the second model constrain the fitting algorithm to determine the characteristic times (τ_i), each increasing by a factor of 10. With this predefined structure, the corresponding J_i values (the model's other fitting parameters) are re-calculated. Second model follows the approach suggested by some reasearchs like Toratti's [12], which states that adding a Kelvin-Voigt element

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enables the model to predict time scales 10 times larger. The fitting parameters calculated in these models and the values of Toratti's model B are given in Table 2.

In Fig. 5, the 4-year set of data from Gressel [16] two fitted 4-body Kelvin-Voigt models, and results of the Toratti model B from Schänzlin [22] are displayed. The comparison highlights the accuracy of the fitting procedure and the good agreement of the 4-body Kelvin-Voigt model with Torrati's model B to predict the long-term creep deformations. This validates the 4-body Kelvin-Voigt model for constant climate as established rheological models like Toratti's model B, as the fitting parameters are very similar.

Table 2: Parameters of the fitted 4-body Kelvin-Voigt model (n=8, n=0) and Toratti's model B [12].

(1) Values of the 4-body Kelvin-Voigt model (n=8)				
element	1	2	3	4
τ_i	0.001	0.053	0.749	2.812
J_i	0.912	2.3556	0.5465	0.2142
(2) Modified values of the 4-body Kelvin-Voigt model (n=0)				
element	1	2	3	4
τ_i	0.01	0.1	1	10
J_i	0.0013	0.01	0.1	0.1
(3) Original Toratti model B values for Kelvin-Voigt elements				
element	1	2	3	4
τ_i	0.01	0.1	1	10
J_i	0.0686	-0.0056	0.0716	0.0404

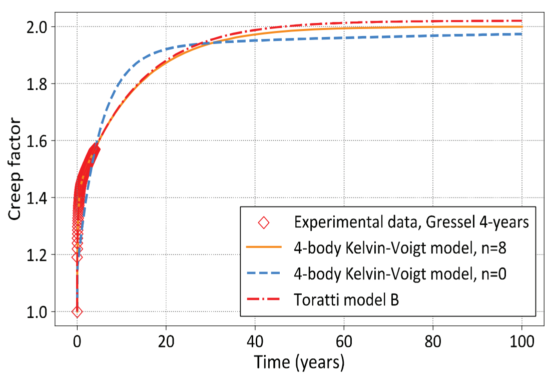

Figure 5. *Comparison of 4-body Kelvin-Voigt models with predefined (n=0) and without predefined (n=8) fitting parameters with the the 4-year set of data from Gressel [14] and the results Torrati model B from Schänzlin [22].*

4 – Comparative Study

4.1 General

The performance of the previously examined 4-body Kelvin-Voigt model is compared with other established creep models in this section. First, the long-term predictions of various creep models are compared with each other using the 1-year experimental data set of Leivo [15] in section 4.1. Then, the performance of these models is compared using the 7-year experimental data set of Gressel [17]. This was the longest available dataset for constant climate. Finally, the modified versions of the 4-body Kelvin-Voigt model boosted with extra elements to capture the mechanosorptive and swelling/shrinkage effects are compared with Toratti's model B, representing a service class analysis.

4.2 1-year fitting (constant climate)

The Kelvin-Voigt, SLS, Burger, Andrade, and 4-body Kelvin-Voigt models are fitted to experimental data of Leivo [15] for bending creep of clear wood spruce samples under constant climate (35% RH, 20°C) and 5 MPa 3-point bending loading over one year , see Fig. 6(a). Adjusted R square values were used for comparing the goodness of fit. The simple Kelvin-Voigt model (R^2_{adj} = 0.80) provides the poorest fit due to its simplicity. This model, consisting of a spring and dashpot in parallel, assumes an asymptotic approach for the strain towards a steady value and neglects the long-term progression of creep. Consequently, it fails to accurately capture the creep progression for time ≥ 0.8 years. The SLS model also fails to provide a good fit with R^2_{adj}= 0.85. Burger's model with R^2_{adj}= 0.93 and the Andrade model with R^2_{adj}= 0.99 better represent the viscoelasticity and time-dependent creep behavior using incorporated additional parameters. However, the number of parameters influences the goodness of fit. While the Andrade model achieves a high R^2_{adj} with only 2 parameters, the 4-body Kelvin-Voigt model, with 8 parameters, achieves the best fit (R^2_{adj}= 1.00). This highlights the superiority of the 4-body Kelvin-Voigt model, which achieves the best fit while providing the expected creep stabilization. This stabilization was reported in studies [12] and [22], which demonstrated that different creep models exhibit stabilization as creep transitions from the primary phase, characterized by a decelerating strain rate, to the secondary phase, characterized by a steady-state strain rate. In contrast, the Andrade model, despite its high R^2_{adj}, presents a continuous creep progression.

In Fig. 6(b), these models are extrapolated over a 100-year period to assess their long-term predictions. As a reference, the k_{def} value for service class 1 (k_{def} = 0.6 in EN 1995-1-1 [13]) and the calculation results by Schänzlin [22] are given. Schänzlin [22] calculated creep factors between 0.5 and 1.1 after 50 years in a constant climate with different models. To highlight the relative changes and to capture the wide range of predicted creep values in long-term analysis, results are shown on logarithmic axes. The Kelvin-Voigt and SLS models predict negligible creep progression over time, which results in 20 to 30 percent lower creep values than calculated by Schänzlin [22]. The Burger's model predicts a continuous increase in creep and therefore significantly overestimates the long-term creep deformations. The Andrade model yields similar results as the calculations by Schänzlin [22]. However, it predicts a continuous increase in creep, which contradicts the assumption of creep stabilization. The 4-body Kelvin-Voigt model presumably has the most balanced and physically realistic behavior. It stabilizes at a creep factor value inside the range of calculation results of Schänzlin [22]. It therefore seems to provide the most satisfying prediction of the long-term creep models.

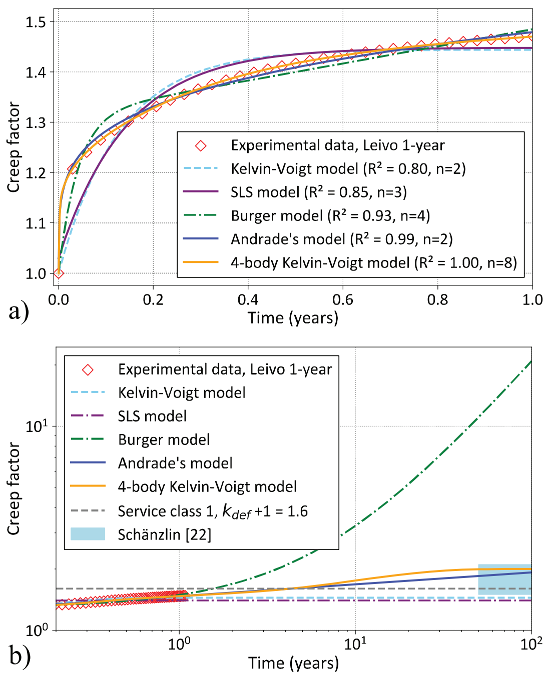

Figure 6. *(a) Comparison of various fitted creep models and experimantel data of Leivo [15] over 1 year and (b) Comparison of extrapolated model curves over 100 years.*

The results point out the conceptual differences of these models due to their constitutive formulations for both the medium-term fit and the long-term accuracy. While simple Kelvin-Voigt and SLS models and the more complex Burger's model fail to extrapolate realistically, the Andrade model with only two parameters and the 4-body Kelvin-Voigt model with eight parameters provide more promising extrapolations. The stabilization of the 4-body Kelvin-Voigt model arises from the inherent ability of this model to incorporate multiple Kelvin-Voigt elements in series to effectively capture different phases of creep with respect to time (see 3.3).

4.3 7-year fitting (constant climate)

Based on the literature review and the selection of the 7-year experimental dataset from Gressel [17] as the longest available set of experimental data, a new extrapolation of rheological models is conducted, see Fig. 7. Comparing this to the previous extrapolation based on Leivo's 1-year data, this analysis provides similar insights. The Burger's and SLS models fail again to present a reasonable extrapolation. The Andrade model captures again a generally accurate behavior of creep over the long-term 100-year run, while it may exaggerate the creep progression for time periods above 100 years, having a continuous increase. In contrast, the 4-body Kelvin-Voigt model stabilizes inside the range of the calculation results of Schänzlin [22] and therefore provides a more realistic long-term prediction again.

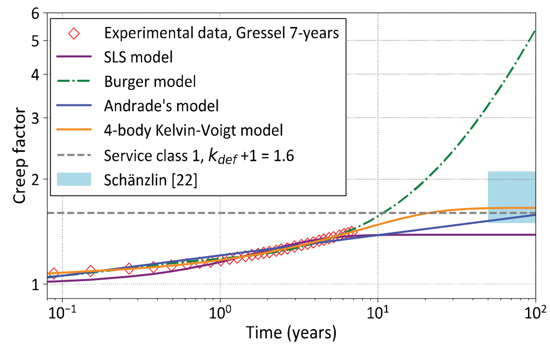

Figure 7. *Comparison of extrapolated model curves over 100 yearsfitted to 7-year experimental data of Gressel [17].*

It is important to highlight that the predicted creep values from extrapolation are dependent on the experimental data the models are fitted to. In the previously investigated Leivo data in Fig. 6b, the 4-body Kelvin-Voigt model exceeds the k_{def} = 0.6 from EN 1995-1-1 [13] just after 5 years. However, in Fig. 7, the creep values predicted with the same model but fitted to Gressel's 7-year data exceed k_{def} = 0.6 after 20 years. For both fitted 4-body Kelvin-Voigt models, the predicted values over 50 years remain in the range of the calculation results of Schänzlin [22], i.e., between 1.5 and 2.1.

4.4 General models and service classes

Here, the effects of the environmental conditions of service class (SC) 1 according to EN 1995-1-1 [13] are examined against the previous constant climate investigations. Calculations with Toratti's model B [12] with moisture contents ≤12% and temperatures around 20°C resembling SC 1 are used as a basis for the analysis of this section. A schematic view of the Toratti model B with its elements is given in Fig. 8.

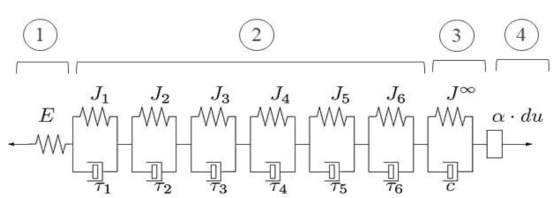

Figure 8. *Toratti's model B [12], made of (1) one elastic strain, (2) six visco-elastic Kelvin-Voigt, (3) one mechano-sorptive Kelvin-Voigt, and (4) one hygroexpansion elements.*

To investigate the accuracy of the previously described extrapolation procedure for SC 1, an enhanced version of

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the previously discussed 4-body Kelvin-Voigt model is employed. It contains extra elastic strain, hygroexpansion, and mechano-sorptive (MS) elements. In addition, another model with six Kelvin-Voigt bodies is presented. The latter model is similar to Toratti's model B, which contains six Kelvin-Voigt bodies, plus elastic strain, hygroexpansion, and mechano-sorptive components as represented in Fig. 8, overall with 16 independent parameters. A 10-year segment of data calculated with Toratti's model B serves as the input for the fitting of the models. Table 3 provides the parameters of the calibrated Toratti model B and the modified 6-body Kelvin-Voigt model.

Table 3: Parameters used in the calibrated Toratti model B and the parameters used for the modified 6-body Kelvin-Voigt.

Kelvin-Voigt elements' parameters in Toratti's model B						
element	1	2	3	4	5	6
τ_i	0.01	0.1	1	10	100	5000
J_i	0.0686	-0.0056	0.0716	0.0404	0.207	0.550
Kelvin-Voigt elements' parameters in 6-body Kelvin-Voigt model						
element	1	2	3	4	5	6
τ_i	0.01	0.1	1	10	100	5000
J_i	0.0013	0.01	0.1	0.1	0.328	0.914

Other elements' parameters in 6-body Kelvin-Voigt model				
parameter	beta [1]	dMC/dt (1/h) [2]	E_u (MPa) [3]	alpha [4]
value	0.05	0.0002	13000	0.0006

[1] Exponent for the elastic strain term.
[2] Rate of moisture content variation.
[3] E-modulus as a function of moisture
[4] Hygroexpansion coefficient

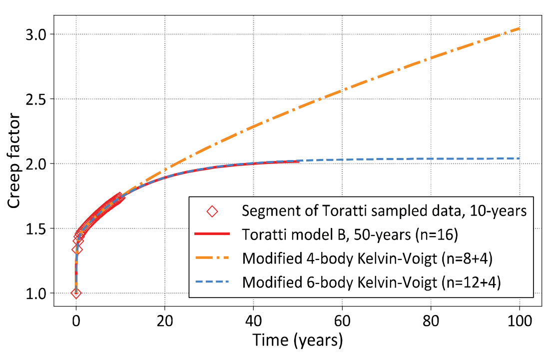

Figure 9. *Comparison the modified 4-body and 6-body Kelvin-Voigt models with the prediction of Toratti's model B.*

The results are presented in Fig. 9 and highlight the long-term behavior of creep models under environmental SC 1 conditions. The 4-body Kelvin-Voigt model with extra MS elements, with 4 Kelvin-Voigt elements and 4 additional parameters, predicts a more pronounced increase of the creep factor over time, diverging from Toratti's model B. In contrast, the 6-body Kelvin-Voigt model with extra MS elements, with 6 Kelvin elements and 4 additional parameters, closely aligns with Toratti's model B up to 50 years. Beyond the 50-year point, the 6-body Kelvin-Voigt model stabilizes, which highlights the model's capacity to capture long-term creep stabilization. This exemplary analysis of SC 1 conditions highlights the advantage of a model with 6 Kelvin-Voigt elements over a more simplified model with 4 Kelvin-Voigt elements, as the former achieves a promising balance between accuracy and long-term stabilization for SC 1 and the latter fails to acquire this balance.

5 – CONCLUSIONS

In a comparative study, it was demonstrated that various creep models predict markedly different long-term creep deformations. These differences stem from the inherent differences in the models' analytical formulations. Simple models like the Kelvin-Voigt, SLS, Burger, and Andrade models fail to either achieve the desired accuracy or to capture the stabilization trend that is assumed for creep over long-term periods. The more complex 4-body Kelvin-Voigt model achieved a better fit for constant climate than the previously mentioned models. The fitting parameters calculated for the 4-body Kelvin-Voigt model in constant climate were similar to the parameters used in Toratti's model B [12]. Using the results of a literature review on available constant climate experimental data, data sets from Leivo [15] and Gressel [17] were chosen for further studies. The 4-body Kelvin-Voigt model provided a realistic extrapolation of the long-term creep deformations in constant climate. However, in a comparison of Toratti's model B and an enhanced version of the 4-body Kelvin-Voigt model containing extra elastic strain, hygroexpansion, and mechano-sorptive elements, the enhanced 4-body Kelvin-Voigt model failed to accurately predict the long-term creep deformations in service class 1 conditions. An enhanced Kelvin-Voigt model with 6 bodies yielded nearly identical results as Toratti's model B. While a model with 4 Kelvin-Voigt bodies was sufficient to accurately predict the long-term stabilizing creep behavior in constant climate, a model with 6 Kelvin-Voigt bodies was required for service class 1 conditions according to EN 1995-1-1 [13]. For numerical design of timber structures using creep curves, the influence of varying climate has to be investigated further. However, this study initially confirms the suitability of Toratti model B.

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