Chapter 10
Effect of Time on the Mechanical Properties of Wood

The historically shaped wooden domes from solid wood, still built until the thirties of the 20th century, have a diameter up to 67.0 m—Kaszkarow [1] (1937). The constructions of such domes were built without applying steel nodes and wood gluing.

The increase of the dome diameters up to a span of 163.0 m, as discussed in Chap. 8, was obtained owing to the application of bars and girders from glued laminated timber connected with massive steel nodes, as well as such materials, such as concrete or polymer concrete. The completion of such domes became, in terms of computations and technology, more and more difficult and expensive. **New problems also come into being, being of significance for the experiments on the structures of domes from wood as well as other materials**.

The development of knowledge and numerical methods of the computation of constructions inspire for the completion of next domes of record-breaking diameters. However, the application of the conventional models of an elastic body in the calculations of wooden constructions yields, sometimes, unexpected results.

The differences between the classic results of theoretical calculations conducted on the basis of the models of an elastic body and the effects observed after years of operation, as described by Misztal B., reach up to 30% [2] (1999). This applies especially clearly to the limit states of the use. The identification of an visco-elastic model of wood is difficult due to various behaviours of wood depending on the direction of load and shift: longitudinal, flexible and crosswise.

It was demonstrated in the paper [3] (1966) by Kowal Z. and the paper by Kowal and Surkont [4] (1978) that time-dependent deformations and forces in constructions of rheological properties may be determined on the basis of the identified models of visco-elastic materials. In the paper [4] (1878) the authors deal with the analysis of spatial structures built from linear-visco-elastic bars, coupled articulated in nodes. They specify the formulae to assess the creeping shifts of visco-elastic bars, stretched by a load invariable in time. The authors also demonstrate that the elastic—visco-elastic analogy maintains its validity in the case of a random load of structure's nodes. Compiled in Table 10.1 are various visco-elastic models taken

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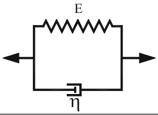
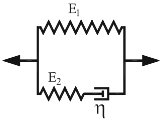
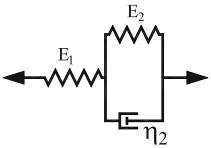
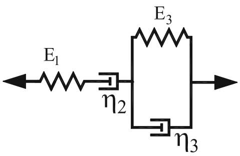
Table 10.1 Compilation of basic rheological models of materials [4] (1978)

Model of the bar	k	u(t) elongation
1	2	3
 Maxwell's model	$\frac{EA}{l}$	$\frac{P}{k}\left(1+\frac{E}{\eta}t\right)$
 Voight's model	$\frac{EA}{l}$	$\frac{P}{k}\left(1-e^{-\frac{E}{\eta}t}\right)$
 Zener's model	$\frac{E_1A}{l}$	$\frac{P}{k}\left[1-\left(1-\frac{E_1}{E_1+E_2}\right)e^{-\frac{E_1E_2}{\eta_2(E_1+E_2)}t}\right]$
 Standard model	$\frac{E_1A}{l}$	$\frac{P}{k}\left(1+\frac{E_1}{E_2}-\frac{E_1}{E_2}e^{-\frac{E_2}{\eta_2}t}\right)$
 Burger's model	$\frac{E_1A}{l}$	$\frac{P}{k}\left(1+\frac{E_1}{E_3}+\frac{E_1}{\eta_2}t-\frac{E_1}{E_3}e^{-\frac{E_3}{\eta_3}t}\right)$

into account. Shown in column 1 is the geometry of the models, in column 2 the elastic longitudinal stiffness, in column 3 the change u(t) of the elongation of bars in time.

Determined in Table 10.1: E—modulus of direct elasticity, A—section of the bar, η—damping parameter, k = EA/l—elastic longitudinal stiffness, l—length of the bar.

Theoretical and experimental research on the static and dynamic analysis of visco-elastic constructions have been conducted since the fifties of the 20th century. The basic theoretical papers in this direction (in the understanding of the operation of creep-exhibiting constructions) were conducted in Poland by: Nowacki [5] (1963), Kisiel [6] (1967), Kowal [7] (1964) et al.

In his paper [5] (1963) Nowacki W. formulates the mathematical fundamentals of statics and dynamics of linearly visco-elastic structures, the solutions of statics and dynamics of visco-elastic systems as well as the propagation of visco-elastic waves. He subjects the variation in time to the mathematical analysis, as well as the responses of materials and building constructions to load, a long-lasting load in particular. He demonstrates that the model of a perfectly elastic body is insufficient to the description of the state of stress and strain of the majority of building materials.

In his paper [6] (1967) Kisiel I. defines several basic rheological models, anticipating the option of their introduction to theoretical analyses in the building industry, in geotechnics (M/V model) in particular. He describes the operational mechanism of external forces as static loads on the soil. He introduces the mathematical analysis on the basis of two-parameter rheological models according to the rules of creep theory, elasticity and plasticity theory. He resolves, on the basis of rheological models adopted, rheological tasks for soils. It should be emphasized that the creep of soil has its impact on the creeping distortion of constructions seated on the soil, including wooden constructions.

In [8] (1982) Ganowicz R. demonstrated that the theoretical description of the creep process using determinist methods is impossible. In the opinion of the author, neither does the visco-elasticity theory reflect the behaviour of wood. The creep curves of visco-elastic materials are smooth, on the other hand, the experimental curves of creeping distortions of wood and visco-elastic materials being tested exhibit random variations of creeping distortions caused by random effects that can be described using the modified Poisson's process.

In her paper [2] (1999) Misztal B. noticed on the basis of own research and that conducted by other authors that the use in the analysis of wood of visco-elastic models leads to the observed variations in time of constructional elements from wood, wood-based materials and steel. She called attention to the fact that the creep of wood, wood-based materials and complex trusses from wood, wood-based materials and steels follows with a time-variable speed. At the first stage of the transverse load the creep speed is the highest. At the next stages of the creep process, the creep speed decreases. Deflections increase more and more slowly since in the creep process the deflection increments decrease.

In [9] (2002) Socha T. described the experimental testing of wooden beams of 5×11 cm dimensions being bent under the action of long-term static loads. He describes the results of the testing using several rheological models. The author is of the opinion that the basic rheological models, also including the Burger's model, do not describe the observed creeping distortions of beams. He proposes, however, the use of the Kelvin-Voight's model that in the opinion of Misztal B. neither describes well the behaviour of wood under the impact of a dynamic coercion.

In the paper [10] (2006) Rautenstrauch K, Doehrer A. and Harnack R. suggest the series connection of one-parameter and two-parameter models to calculate the creep coefficient of wooden compressed posts of 16/16 cm dimensions.

In the opinion of the author, the adoption of such an expanded model, as shown in Fig. 10.1, increases the difficulties in the assessment of the stiffness moduli of an element or a construction in the long-term testing. For the model shown in

Fig. 10.1 Rheological model applied by the author of the paper [10]

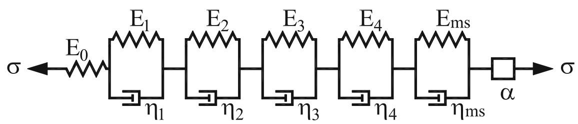


Fig. 10.1, the number of constituent values of the modulus of direct elasticity E_i after the time $t \rightarrow \infty$ of the construction's operation is difficult to determine:

$$\frac{1}{E_t} = \frac{1}{E_0} + \frac{1}{E_1} + \frac{1}{E_2} + \frac{1}{E_3} + \frac{1}{E_4} + \frac{1}{E_{ms}} \tag{10.1}$$

It is evident from the formula (10.1) that the higher is the quantity of E_i in the computational model, the more difficult is the assessment of the construction's stiffness in the time t.

In his paper [11] (1982) Pożgaj A. describes the trials of the long-term, 3000hrs-lasting bending of beams from spruce wood, of 11 × 11 mm and 20 × 20 mm sectional dimensions. It follows from the testing that a higher relative creep is demonstrated by samples of a larger section. **At the ratio of the sides of a rectangle such as 1:4, the creep of samples of a larger section is by 20–30% higher than that of samples of a smaller section. This information should be verified whether it operates in relation to high-dimensional domes built from glued elements of massive sections operates—as discussed in Chaps. 8 and 9, Figs. 9.14 and 9.15**. Pożgaj A. also demonstrated that the rise in the moisture content of the tested sample results in a decrease of deflection and vice versa. He notes down that deflection variations occurred with a various intensity. It points out to a sample that responded differently. The author suggests that abnormalities are caused by the wavy course of the fibre. Besides, he points out that larger samples respond to moisture content and air temperature variations with a delay as compared to smaller samples—he calls it inertia. As regards the impact of air temperature, he expresses an idea that temperature affects creep to a lower degree than moisture content. He is of the opinion that under the given ambient conditions, the impact on the creeping deflection of wood is exerted by the magnitude of load and the time of operation, moisture content, wood density and dimensions of the cross-section area of the sample. The author states that he did notice the creep process stabilization after 3000 h of the experiment.

In the paper the authors [12] (1982) Moliński W., Raczkowski J. tested the effect of ultra-violet radiation on the creep process of samples from pine wood, of 11 × 11 mm dimensions and a height of 110 mm. The experiments were conducted at the constant value of the tensile force amounting to 0.40 of the temporary rupture force. After the testing it was found that UV radiation eminently intensifies the creep process. The increase in creeping distortions due to the action of UV rays followed from the beginning of the application of the set static load. **UV radiation, in the set creep period, produces a sudden increase in the creep speed, exceeding up 6–8 times the creep speed before the exposure to illumination. The stabilization of the creep process after the switch-off of the illumination was noticed. The term of photo-mechanic creep was introduced**. The authors also specify that after the testing of the samples from an early wood of a fir-tree, after 8 h of radiation, the tensile strength dropped by 30%. In their opinion, the lowering of the strength gives evidence of the destruction of cellulose fibres on which the tensile strength of wood depends. **In the opinion of Misztal B., the drop in the tensile strength after the UV exposure results from the destruction of the matrix and the weakening of the fastening of fibres in the visco-elastic matrix**.

In their paper [13] (2003) the authors Drelich R., Karczmarek M., Kubik J. describe the examination of the impact of ultrasonic waves on the creep of pine wood, in three different directions. The authors did not describe the effect of the wave on the creep process of wood.

In the paper [14] (2003) the authors Kasprzyk H., Wichłacz K. examined the chemical composition of pine wood at a temperature of 120–172 °C, as well as that exposed to gamma rays by doses of γ = 20–11000 kGy.[1] **It was found that the carbohydrate constituents of wood exhibit a significantly lower resistance to high temperature and high γ radiation does than lignin**. At the dose of 4500 kGy cellulose undergoes a full degradation and the content of pentosanes drops down to 70%. The content of lignin practically did not change, as it did not change for samples soaked at 172 °C, for 114 h, and those exposed to the radiation dose of 11000 kGy. The content of extraction substances abruptly rose both in cold and hot water, at 1% of NaOH, in the benzene-methanol mixture, with the rise of the radiation dose and temperature.

The impact of wood density on the propagation of ultrasonic waves along fibres was examined by the authors Marcinkowska A., Moliński W. in their paper [15] (2003). The experiment was conducted on samples of pine, oak and beech wood. It was found that the propagation speed of ultrasounds along fibres, in the mature wood tissue, of pine and beech wood, decreases, and for beech wood it rises along the rise of its density. It was noticed that **the length of anatomical elements (e.g. length of fibres) and not its density is an essential factor affecting the sound transmission along fibres**.

The authors Roszyk E., Moliński W. [16] (2003) described the results of the wood creep testing under the cyclic conditions, the non-symmetrical variations of the moisture content of the compressed zone of beams being bent. The testing was conducted on samples from the whitish part of pine wood, on the model of a free-supported, single-span beam, burdened with two forces concentrated in the span. The comparative testing of beams of an 8% moisture content and wet beams was conducted. It was found that wet wood features, in comparison with dry wood, an increased susceptibility to creep, especially in the initial period of the process. Besides, it was stated that **the wetting of the compressed zone of the beam being bent since the moment of its loading intensifies the creep process to a higher degree than in the case when the wetting process occurs in the period of the settled creep**.

The results of this testing may be used to determine the parameters of rheological models. In the opinion of the author, the sufficient forecasting of the behaviour of actual constructions is provided by models of several parameters, for instance, the

[1] 1KGy—kilo Grey—radiation dose unit.

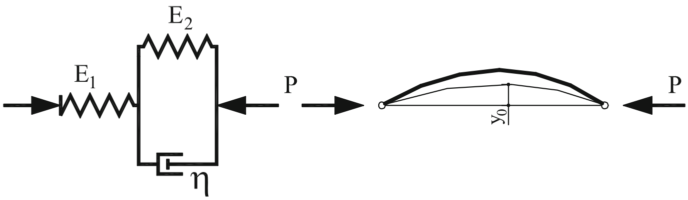


Fig. 10.2 Standard model adopted for the analysis of compressed bars from wood [17]

standard model or the Zener's model. An example of the application of the standard model for the examination of the creep of an axially compressed post is shown in Fig. 10.2.

The module E_t of the standard model shown in Fig. 10.2 after the time t = ∞ amounts according to [17] to:

$$\frac{1}{E_t} = \frac{1}{E_1} + \frac{1}{E_2}, \rightarrow E_t = \frac{E_1 E_2}{E_1 + E_2} \tag{10.2}$$

The standard model, like that of Zener, is a sufficient model to control the regression curve of creeping shifts for constructional wood species, e.g. pine and spruce.

Worth noticing is the observation described in [18] of actual constructional systems from wood, confirming the durability and reliability of wooden constructions. In his publication [18] (2007) the author Ajdukiewicz A. describes the disaster of a steel roof caused by the action of snow bags. Due to the overloading, this roof fell on a wooden roof operated for sixty years, of a constructional schematic as shown in in Fig. 10.3 and dimensions: 44.60 m wide, 102 m long, made from wooden, single-pitch truss of a 22.26 m span. A damage to the wooden roof followed, but this roof did not collapse.

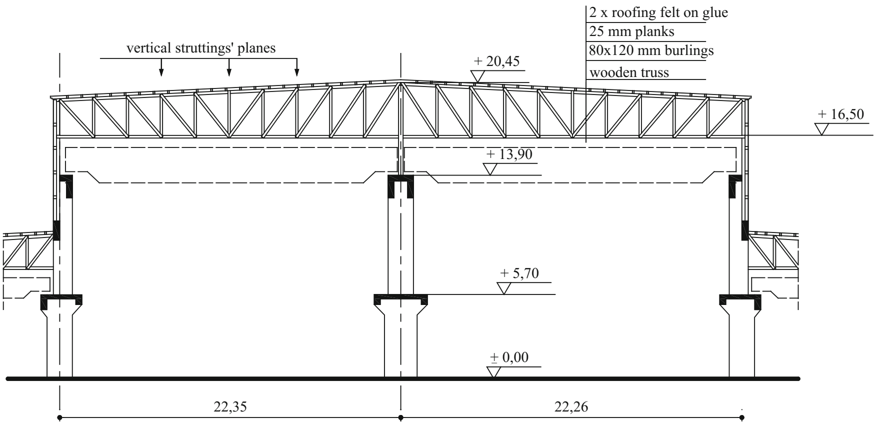


Fig. 10.3 Cross-section of the wooden roof according to [18] on which the steel roof fell

The problem of the assessment of the physical properties materials necessary for the objective calculation of wooden constructions grows along with the development of materials engineering, the wood gluing technology in particular.

For millennia, wood has been known for its rheological features. In the building of domes in which load-carrying elements are subject to high permanent, dynamic and climatic loads, the factors intensifying the wood creep process are of special importance. As follows from the publications discussed, the following factors belong to them: effect of the exposure to UV radiation, gamma radiation, the dynamic interference of environment, moisture content variations, even the dimensions of structural elements. These factors can provoke both creeping distortions, permanent, local cracks, as well as they can initiate the growing degradation of a material up to the destruction of the structural system. The effects of this process can be noticed, while watching historical facilities in which various deformations of elements and the whole wooden architectonical forms followed. The increase of axial and transverse forces results in the deflection and shortening of wooden bars. The accompanying phenomenon of wood creep can initiate the node-through process and the loss of the load-capacity of wooden domes, especially gridshell domes. This should be taken into account in the course of the calculation of wooden constructions, including domes of diameters larger than 67.0 m.

It follows from the description of the testing included in Chap. 10 that in the engineering practice the methods of a quick, non-destructive diagnostics of constructional elements from wood are essential. The author shows in Chaps. 11 and 12 the possibility of using the dynamic testing to determine the physical properties of wood and wood-based materials as well as for the evaluation of the technical state of the constructional elements of the domes discussed in the papers [19] (2004), [20] (2006), [21] (2008), [22] (2009), [23] (2010).

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