Allowance for creep in the study of the reinforced wood-based constructions

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Abstract. The article deals with the problem of considering the time factor in the study of the stress–strain state of the reinforced wood-based constructions. A brief analysis of the theory of creep methods, geometric dependence of influence coefficient establishing the character of the efforts distribution in the complex wood-based constructions has been given. The data on the tests of the reinforced wood-based constructions under continuous loading depending on the level of loading and the reinforcement percentage have been listed.

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Introduction

It is necessary to consider the influence of the wood characteristic features for the complex reinforced wood- based constructions because it allows to assess the calculation layout accurately and to ensure the required reliability and durability. [1], [2]

Creep, influencing the work of the reinforced wood-based constructions, can be referred to the characteristic properties of wood as it causes strains developing in time. The reinforcement resisting the development of these strains is the source of the additional strains which lead to the change of the strain-stress state. Thus modern design regulations require carrying out the calculation layout considering creep influence. [1], [2]

In the conditions of the modern development of Russia, wooden constructions have a lot of incontestable advantages such as: high strength, durability, economy, low heat conductivity, aesthetic expressiveness etc. which find more and more application in construction and in the large span constructions in particular. But at the same time wood has some negative properties: it depends on the construction property and its defects, the necessity of the considerable consumption of high quality lumber, creep under durable loading etc. that constrain the sphere of application and worsen wooden construction qualities. [1]

It is possible to eliminate these drawbacks by reinforcing the sections of the wood-based constructions with steel and glass-fibre plastic reinforcement. It allows to reduce the consumption of wood, to lower the assembly weight and to increase the wood-based constructions reliability. [2], [3], [4]

Reinforced wood-based constructions – are complex constructions made of wood, reinforcement and glue compounds.

Research of the reinforced wood-based constructions and the study of the stress-strained state under short time and lengthy loading demanded to work out the methods of calculating the layout considering such distinctive features as the stress-strained state of the constructions, variety of the materials in the complex constructions, work compatibility, wood creep, glue compound etc. H. Granholm (Sweden) proposed the first research and development of the reinforced wood-based constructions. [4], [5] Also, studies conducted research laboratories of the Czech Republic, Finland, USA, Germany, etc.. [6], [7], [8], [9] The first elaborations in the sphere of calculation of the reinforced wood-based constructions in Russia were proposed by V.U.Shchuko. [3] L.S.Chebotaryova, V.M.Sorotkin, A.Y.Kozulin, V.PH.Bondin, Y.Ph.Chlebnoj and others studied the calculation of the RWC (reinforced wood-based constructions) under a short term impact. [2] It is very important to consider time in calculating the reinforced wood-based constructions because it determines the duration of the loading action that influences the wooden constructions strength and deformability.

The process of the effort redistribution occurs in the complex reinforced wood-based constructions that are composed of the materials different in fabric and composition, so this process should be considered when calculating the RWC. [1], [2], [10], [11]

The analysis of lengthy tests results under the RWC loading has shown that the process of the redistribution of efforts between the reinforcement and the wood occurs because of various degrees of the RWC material creep. As a result normal tension in the reinforcement can considerably increase and slow down accordingly. [1], [12] On the whole similar redistribution of efforts is a very positive factor because the additional loading of more homogeneous (isotropous) material occurs and the wood (nonisotropous material) is unloaded. This fact is very important from the viewpoint of assessing the construction reliability because the material subjected to the influence of such factors as fabric defects (cellular-fibrous) and natural defects (knots, curly grain etc.) is unloaded. Despite the fact, that a lot of investigations in the field of calculation the reinforced wood-based constructions have been carried out and these investigations are of theoretical and practical importance, the RWC calculations considering lengthy loading and factors of the effort redistribution in the sections of the elements cause certain difficulties because the calculations don't consider the actual behavior of the wood which is the basic construction material, the compliance of the wood and the reinforcement junction in the anchorage area.

At the same time Hooke's law that links stress and strain by the linear and nonlinear dependence, represented by the diagrams of the material action, excludes time that is one of the most important independent variables of the strain law. Herewith the link between the strain, the stress and the time is not functional and cannot be expressed in differential or integral form. In case this link were functional, the value of the relative [epsilon] at the moment [ti:] would not depend on the process of the additional loading, i.e. on the value of the strains at the time preceding the moment [ti:]. Thus numerous experimental investigations have shown that the character of the preceding load affects the subsequent strains. Therefore the functional dependence cannot reflect the character of the material strain precisely.

The Theory of Creeping or the Theory of Strain has been greatly developed. The investigations have shown that the wood strain change under the loading can be rated as the linear creep and the wood can be considered as an elastic and ductile material. Under the constant loading the strain of the sample at the time [ti:] is determined by the expression

$$\varepsilon(t,\tau) = \sigma\delta(t,\tau) \quad (1),$$

where $\delta(t,\tau) = \frac{1}{E} + c(t-\tau)$, or, using the theory of aging:

$$\varepsilon(t) = \frac{\sigma(t)}{E(t)} + \int_0^1 K(t,\tau)\sigma(t)d\tau \quad (2),$$

where $K(t,\tau) = -\frac{d}{d\tau}\delta(t,\tau)$.

The computation analysis has shown that there are no reliable methods of the RWC calculation considering creep. The main processes concerned with the stress redistribution lead to the change of the standard strains in the reinforcement elements, tangent stresses in the glue line that connects the reinforcement with wood, elements deflection, but at the same time without considering creep. [1]

The reliable evaluation of the complex stress-strain state which arises in the reinforced wooden constructions is possible if the actual time – varying changes of the material that occur under loading, i.e. creep, are considered. Rheological properties of wood reinforcement and glue compounds have been studied sufficiently. Thus we can conclude that low behaviour of the reinforcement creep and glues at normal temperature as well as little time of the creep process attenuation for this materials are the main reasons of the increase of the time-varying RWC deformations is the wood creep.

Thus to determine the SSC (stress-strain condition) of the RWC and considering the continuous loading, it is considered that the reinforcement in time functions elastically and is connected to the wood stiffly.

We use the mathematical tool of the Theory of Elasticity and the Theory of Creep for considering creep. The solution applies to the sphere of the linear creep where the strain is concerned with constant stress. The notion of linearity and nonlinearity gives the isochronous creep curve built in "the stress-strain creep" coordinates. Wood is practically referred to the linear creep materials when stress doesn't exceed the limit of the long strength value.

It is supposed that the RWC works in the first sphere of strain under the operational loading. The general law of the elastoplastic and the elastoviscous materials can be used to describe the process of the wood strain in this sphere. The hereditary functions of these materials are determined by the experiments according to the results of the creep tests so the Theory of Elasticity and the Theory of Creep can be applied here. There is no complete physical – mechanical explanation of the wood creep nature to the present day. At the same time the most widespread viewpoint on the creep nature comes to the fact that the development of these deformations is the result of the water shift in the walls of the cells, viscous deformations and deformations of the cellular fibrous skeleton. This viewpoint allows to consider wood to be an elastoplastic and elastocreep material.

The Theory of Creep implies establishment of the dependence between the stress, the strain and the time that is represented by the following function:

$$\varepsilon(t) = \Phi[\sigma(t); t \,\&\, \tau] \quad (3),$$

where [epsilon] [ti:] – are the complete relative strain at the time [ti:] ; [sigma] [ti:] – is the stress at any time moment ; [ti:] – is the time of counting ; [tau] – is the current time coordinate.

All the existing theories of creep are of the phenomenological character, i.e. they are based on the description of the most studied experimental phenomenon.

The Theory of Elasticity has been applied to the determination of the long time loading influences as it was the most applicable to the time strain assessment of the wood-based constructions.

The calculation considering creep has been carried out to get the theoretical results of the SSC strain assessment. The calculation has been based on the Theory of Elasticity and the following assumptions have been accepted.

wood has been considered to be a homogeneous material

there is the linear dependence between the complete wood strains

(instantaneous elastic strains)

absolute strain values (elastic and nonelastic) not depending on the stress have been accepted

the principle of the superposition is actual for the creep strain as well as for the elastic instantaneous strains

reinforcement functions elastically without any shift relative to the wood

The analysis of the wood creep isochronous curves under the stress not exceeding the limit of the long term strength has shown that wood can be referred to the linear creep materials. The general equation of the linear creep can be presented as:

$$\varepsilon_w(t) = \varepsilon_0(t) + \sigma_w(\tau_1)\cdot\delta(t,\tau_1) + \int_{\tau_1}^{t} \frac{d\sigma_w(\tau)}{d\tau}\delta(t,\tau)d\tau \quad (4),$$

where [epsilon] [΄ziərəu] [ti:] – is the instantaneous strain caused by the strain applied at the time [tau] [wʌn]; $\sigma_w(\tau_1)\cdot\delta(t,\tau_1)$ - is the creep strain arising at the time [ti:] from the long term operation of the initial stress [sigma] ['dʌblju:] [tau] [wʌn].

The expression under the integral is the sum of the instantaneous strain and the creep strain by the time [ti:]. This quotation is considered to be the general quotation of the Theory of Creep. Geometric dependences for the influence coefficients [kei] [es]; [kei] ['dʌblju:] that determine the redistribution of the stress between the wood and the reinforcement have been received when solving the task using the method based on the Theory of Elastic and Creep Body (the theory of G.M.Maslov- N.CH.Aratunan, V.N.Bikovsky for the reinforced curving elements. The influence coefficient for the linear creep can be presented in the simplified form:

$$K_w(t) = e^{-\xi\varphi_t} \quad (5)$$

$$K_s(t) = \left[1 + \frac{1}{n\mu\rho}\cdot(1 - e^{-\xi\varphi_t})\right] \quad (6),$$

where [phi] [ti:] – are the creep characteristics; [mu] – is the reinforcement coefficient; [en] – is the ratio of the modules of the reinforcement and wood elasticity.

The definition of the creep characteristics [phi] [ti:] was given using the experimental data of the long time investigations of the symmetrically reinforced wooden beams with the span from 2,25 to 18,0 m. The degree of the uploading was 0,3; 0,5; 0,6 from the crushing load. The reinforcing rate was in the range of 1,42 – 3,27%. The creep characteristics value [phi] [ti:] was determined according to the edge wood strains data, compressed and expended zones and deflections. [1]

The tests of the reinforced beams have shown that at the value of normative loading, the value of the creep characteristics is within the limits of 0,153…0,170, and at the level of the calculation loading it increases to 0,180…0,315. [1]

It has been stated that the creep characteristic values depend on the degree of the reinforcement from 1,25% to 3,3% and the value of [phi] [ti:] increases to 17%. The problem of the creep velocity, depending on the level of loading, has been studied in the process of the long term tests of the reinforced beams. [1]

The experimental data have shown that the higher is the stress level the more is the initial velocity and the longer is the period of the manifestation of the wood creep in the reinforced wood-based constructions.

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