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Dynamic parameters of the free vibrations of various wood species

Introduction

Wood used for the construction of prestigious building facilities has to show high strength parameters taking into account the required durability of the building. The wood selection and choice is a difficult task. Such wood selection is required that out of the mass of planks the best wood is selected in order to build it into the most strained sections whilst the elements of a worse quality should be used in less burdened zones, or rejected. In the daily practice the wood choice follows against visual inspection. For instance, the Japanese company, Miyazaki Prefectural Wood Utilization Research Center, in charge of the accomplishment of the Konohana Dome in the city of Miyazaki made, in 2002, the choice of the best planks according to the measurement of the spacing between wood fibers. Figure 1 shows the sections of planks cut out in 45-year-old Sugi trees (*Cryptomeria japonica*) used for the construction of the carrying element. Those planks were picked out for the elements of the structure so that the spacing distances between the fibers are included in the range of 4 mm through 14 mm.

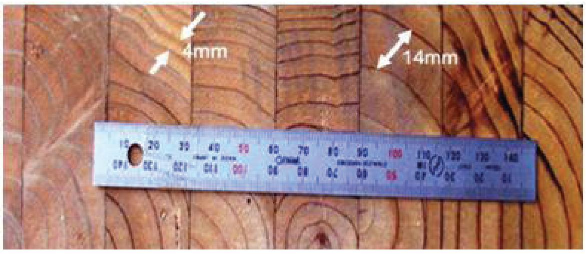

Fig. 1. Planks selected against the criterion of the spacing distance between the fibers [7]

Il. 1. Deski wyselekcjonowane na podstawie kryterium odległości pomiędzy włóknami [7]

Bibliography research

In order to develop the method to select the planks forthe construction of carrying elements, the author called the attention to the potential selection of wood basing on the dynamic testing.

To recognize the issue, the author conducted the bibliography research in the field of the dynamics and theory of viscoelastic materials. In Poland, several authors dealt with the issues of the viscoelastic construction dynamics. The first problem in the theory of viscoelastic materials was formulated and resolved by Kowal in the 60s of the 20th Century. In his paper [1], he studied the vibrations: of a viscoleastic beam and a rigid beam on the supports: viscous, viscoelastic and rigid. He determined the dynamic coefficients to determine the maximum vibration amplitude and maximum forces in the system. In his paper [6], Nowacki presented the mathematical rudiments of the dynamics of linear viscoelastic constructions. In his paper [3], Langer specified the solutions related to the dynamics of viscoelastic system and the propagation of viscoelastic waves. He demonstrated that the model of an elastic body was insufficient to describe the state of stress and strain of the majority of building structures. The method of dynamic vibration coercion was applied by Kowal et al. [2] in practice, to detect damaged girders in the ceiling roof having a construction of pre-tensioned pre-stressed girders. Upon the induction of vibration in successive girders, the frequencies of their vibration were measured, and their values showed the girders of a lower rigidity. The girders of a reduced rigidity due to mechanical damages demonstrat-

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ed a lower free vibration frequency than the non-damaged girders. Those date allowed to conclude on the need for their replacement or strengthening. The hypotheses on the use of dynamic testing for the evaluation of the strength properties of wood were first formulated in the papers published by the author [4], [5]. The author suggests recognizing the features of wood in the dynamic testing that yields clear results, instead of visual inspection or long-term testing used to date. Short dynamic tests are recommended for the selection of wood chosen for the building of elements of prestigious structures, also to detect damaged elements in the already constructed wooden structures.

Description of experimental testing

This paper describes the dynamic testing of beams made of two wood species: oak tree and pine tree. The testing was conducted on both dry and wet models. For formal reasons, this paper depicts the testing of models in the air-dried state of oak and pine wood. The plank models, of a 10×40 mm section, 1200 mm long, were prepared for the testing. Before the testing experiment, the planks were weighed in the air-dried state. The load at the end of the support was applied perpendicularly to the plane of the beam's lower rigidity (Fig. 2).

In order to eliminate the second-order vibration the mass of $m = 250.0$ g at the end of the support was introduced.

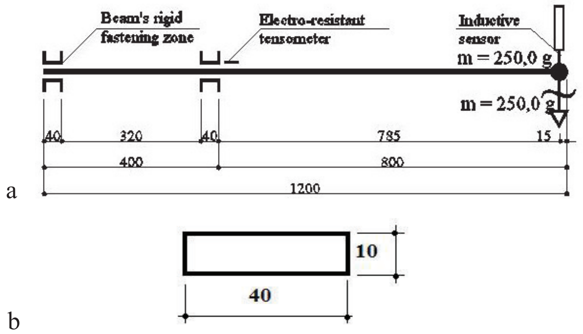

Fig. 2. Model of beams being tested: a) Schematic of a beam for dynamic testing, b) Section

Il. 2. Model testowanych belek: a) schemat belki do badań dynamicznych, b) przekrój

The frequency n and the damping ρ of free vibration coerced by the force $P = 250.0$ g suspended on a thread at the end of the support was tested. In all the cases the damped free vibration, regardless of the wood species, is well described by the function (1) pursuant to [3]:

$$y_t = y_0 e^{-\rho t} \cos\left(t\sqrt{\alpha^2 - \rho^2} + \varphi\right) \tag{1}$$

Specified below are the parameters of the vibrating movement measured on the models made of oak and pine wood planks, assessed according to the formulae as below:

– the vibration period T was measured in [s],

– vibration frequency: $n = 1/T$ [1/s] (2)

– the circular velocity of the damped free vibration was calculated from the formula: $\omega = 2\pi n$ (3)

– the dimensionless logarithmic damping decrement Δ was calculated from the formula:

$$\Delta = \ln\frac{A_0}{A_{n+1}} = \rho T \tag{4}$$

the damping coefficient ρ is:

$\rho = \Delta/T$ [1/s] (5)

Figures 3 and 4 show the exemplary charts of dampened free vibration of the plank models: oak wood plank and pine wood plank, during the first 10 s. For each grade of dry planks the following was calculated: The elastic rigidity K is measured using the vibration velocity ω and the damping ρ from the paper [1]:

$$\alpha^2 = \omega^2 + \rho^2 = K/m_{zr} \tag{6}$$

ω = free vibration frequency measured [radians],

ρ = free vibration damping measured,

α = specific vibration (non-damped) measured [radians],

$K_{ef} = m_{zr}\,\omega^2$ – effective rigidity of the beam, as measured on the model,

$y_0 = P/K_{ef}$ – immediate displacement under load $P = m_{zr}\,g$.

The circular velocity of non-damped free vibration, required to assess the rigidity of both dry and wet planks, was calculated from the formula pursuant to [1]:

$$\alpha = \sqrt{\omega^2 + \rho^2}\,[1/s] \tag{7}$$

where: ω – specific vibration, α – free vibration, ρ –vibration dampening.

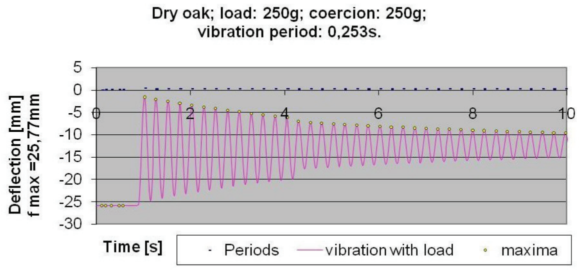

Fig. 3. Schematic diagram of the dry oak model vibration

Il. 3. Wykres drgań modelu z suchego dębu

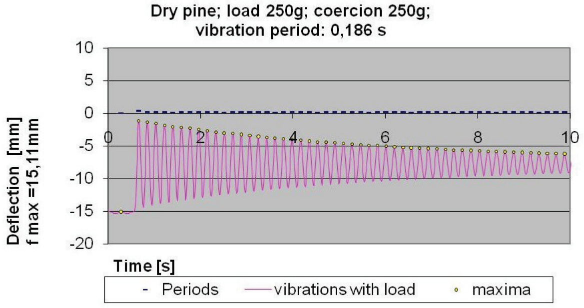

Fig. 4. Schematic diagram of the dry pine model vibration

Il. 4. Wykres drgań modelu z suchej sosny

Tab. 1. Parameters of the vibrating movement of the dry oak model loaded with a mass at the end

Tab. 1. Parametry ruchu drgającego modelu z dębu suchego obciążonego masą na końcu

T_s	t_0	y_0	ρ_s	n_s	ω_s	φ	Δ_s
[s]	[s]	[mm]	[1/s]	[1/s]	[1/s]	[°]	
0.253	0.11067	25.77	0.1673	3.953	24.835	2.251	0.0423

Tab. 2. Parameters of the vibrating movement of the dry pine model loaded with a mass at the end

Tab. 2. Parametry ruchu drgającego modelu z sosny suchej obciążonego masą na końcu

T_s	t_0	y_0	ρ_s	n_s	ω_s	φ	Δ_s
[s]	[s]	[mm]	[1/s]	[1/s]	[1/s]	[°]	
0.186	0.5733	13.68	0.14	5.38	33.8	11.15	0.026

Table 1 specifies the parameters of the vibrating movement of the models made of oak wood, Table 2 specifies those for the model of pine wood, in the air dried condition.

Table 1 comprises the parameters of the vibrating movement as measured on the dry oak model, and assessed as follows:

– the vibration period measured is: $T_s = 0{,}253$ s,

– vibration frequency: $n_s = 1/T_s$

$T_s = 0{,}253$ s, $\rightarrow n_s = 3.953$ [1/s],

– the circular velocity of free vibration, as measured from the formula: $\omega_s = 2\pi n_s$ is: 24.835/s,

– the dimensionless logarithmic damping decrement of a dry plank Δ_s is: $\Delta_s = \rho_s\, T_s = 0.04233$

– the dimensional damping ρ_s is:

$$\rho_s = \Delta_s/T = 0.04233/0.253 = 0.1673 \tag{8}$$

Table 2 comprises the parameters of the vibrating movement as measured on the dry pine model, and assessed as follows:

– the vibration period measured is: $T_s = 0.186$ s,

– vibration frequency: $n_s = 1/T_s$

$T_s = 0.186$s, $\rightarrow n_s = 5.38$ [1/s],

– the circular velocity of free vibration, as measured from the formula: $\omega_s = 2\,\pi n_s$ is: 33.8/s,

– the dimensionless logarithmic damping decrement of a dry plank Δ_s is: $\Delta_s = \rho\, T = 0.026$

– the dimensional damping ρ_s is:

$$\rho_s = \Delta_s/T = 0.026/0.186 = 0.14 \tag{9}$$

Conclusions

The comparison of the formulation of the vibration of planks made of various wood species shows evident differences in the vibration period, damping, circular frequency and logarithmic damping decrement. The following conclusions were drawn on the basis of the testing performed:

1. There is a potential for drawing conclusions about the mechanical properties of the constructional wood basing on the dynamic testing.
2. The free damped vibration as shown in Figures 3 and 4 is well described with the function (1), regardless of the wood species.
3. Dry beams of a coniferous tree species, as represented by pine wood, have a lower period of specific vibration than beams made of deciduous trees, as represented by oak tree.
4. An oak wood beam has a significantly higher damping r of free vibration than that of pine wood, and a higher period of free vibration damped.
5. The dimensionless logarithmic decrement $\Delta = \rho\, T$ of free vibration damping of free beams made of deciduous trees is significantly higher than for those made of coniferous trees.
6. The conclusions drawn from the analysis of the experimental testing can be a basis for the dynamic diagnostics of wooden elements, both monumental and modern, for the use of qualifying them for replacement, repair or application in prestigious facilities.

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Parametry dynamiczne drgań swobodnych różnych gatunków drewna

W publikacji obliczono parametry ruchu drgającego belek z dwóch gatunków drewna: dębu i sosny w stanie powietrzno suchym. Pokazano, jak na podstawie częstotliwości drgań swobodnych oraz tłumienia drgań można dokonać wyboru gatunku drewna do budowy konstrukcji z drewna. Zaproponowano zastosowanie pomiaru drgań swobodnych do wyznaczania właściwości mechanicznych elementów.

Key words: wood, wooden constructions

Słowa kluczowe: drewno, konstrukcje drewniane