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SERVICEABILITY CRITERIA FOR DESIGN OF TIMBER FLOORS

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Abstract: *This paper summarizes current regulations for comfort assessment of structural vibrations of timber floors in Europe and main design practices of timber floors on this aspect among the European countries. For building design, human activities are the most important internal sources of vibration in timber floors. The daily human activities such as walking, jumping or running on the floor may lead to an uncomfortable feeling to the users when magnitudes of the vibration are uncontrolled. Comparisons of vibration serviceability criteria for design of timber floors among the European countries were conducted and the recommendations on vibration serviceability design of timber floors are proposed.*

Key words: *timber floors, EC5, vibration, serviceability.*

1. Introduction

Timber is one of the most traditional materials used in buildings construction around the world. Its characteristics allow high degree of prefabrication, quick assembly, and immediate utilization. Wood has great fire resistance, and during the fire retains its characteristics, i.e. its mechanical properties do not change significantly due to high temperatures. Timber constructions are five times lighter than reinforced concrete, thus they are better capable of weathering seismic forces and stand out as material of choice for earthquake prone areas. Timber constructions have high energy efficiency.

Today the use of timber in multi-family houses is increasing and there is a need to develop better performing timber floors in order to increase the comfort of the residents. Floor vibration is significant problem for these structures. Because they are light and flexible, vibration is a source of discomfort in the use of this floor systems and its major cause are dynamic movements produced by human activities, such as walking.

Human perception of vibration is dependent on the frequency of vibration under consideration, and it is highly subjective to each individual and it is subject to a number of factors. Despite the individuality of each case, vibration is identified as one of the four main criteria groups for consideration under Serviceability Limit States (SLS) design, presented in Eurocode 5 (EC5) [1], with an emphasis being placed on vibration in floors.

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2. Serviceability Limit State of Vibration – EC5

Design rules for timber structures are specified in Eurocode 5. The section 7 of this code is devoted to the verification of the serviceability limit states, where the vibration problem is included. Installed machinery and human activities are considered as the two most important sources of excitation in timber-framed residential floors.

The rules presented in EC5 are applied to residential floors with fundamental frequency greater than 8 Hz, Eq. (1),

$$f_1 = \frac{\pi}{2L}\sqrt{\frac{(EI)_L}{m}} > 8 \text{ Hz} \tag{1}$$

where m is the mass per unit area in kg/m2, L is the floor span in m, and $(EI)_L$ is the equivalent plate bending stiffness of the floor about an axis perpendicular to the beam direction in Nm^2/m.

This limit was defined after several researches where it was concluded that floors with natural frequency with a lower value have a higher risk of resonance effects caused by walking, so they should be studied in a special investigation.

By testing over a hundred problematic floors, Murray [2] has concluded that their frequency is mostly between 5 to 8 Hz. It was recommended to avoid frequencies below 8 Hz because these cause discomfort to people, while human walk induces great displacements of floor structures with natural frequencies below 3 Hz.

The vibrations of timber floor structures caused by human action have been also experimentally researched by Chien & Richie [3], Bachmann & Ammann [4], Allen & Murray [5], Williams & Waldron [6] and Nor Hayati, Deam & Fragiacomo [7]. The Finite element method in the calculation of floor structure’s response to human action has first been introduced by Linden [8], Fragiacomo et al. [9], Hicks [10] Ebrahimpour & Sack [11].

The method defined by EC5 to verify the serviceability limit state of vibration consists in satisfying two requirements. The first requirement is related to the displacement caused by a static point load and should be limited by a parameter a, so that movements due to low-frequency components (f < 8 Hz), caused by walking, are suppressed, Eq. (2). Parameter a is the flexibility coefficient of the floor. Since the floors are considered to have natural frequencies higher than 8 Hz, these movements are semi-static in nature; hence the static criterion is adequate. Hence, the quotient between the maximum displacement (w), measured in mm, and the vertical point load that causes it (F), applied at any point of the floor and measured in kN, should be lower than the value of a parameter a.

$$\frac{w}{F} \le a \tag{2}$$

The second requirement, Eq. (3), limits the magnitude of the transient response due to the heel impact of a footstep. This impact excites higher frequency components and the timber floor response is governed by its stiffness, mass and damping. This dynamic criterion is translated to the limitation of the maximum initial value of the vertical floor vibration velocity (*v*), measured in m/s, caused by an ideal unit impulse (1 Ns) applied at the point of the floor giving maximum response by the combination between a parameter *b*, the floor fundamental frequency (f_1), in Hz, and its modal damping ratio (ξ).

$$v \le b^{(f_1 \xi - 1)} \tag{3}$$

For a rectangular floor with an overall dimension of *L*×*B*, simply supported along all four edges, the value of *v* may be taken as

$$v = \frac{4(0.4 + 0.6 n_{40})}{m\, B\, L + 200}\ (\mathrm{m/Ns^2}) \tag{4}$$

where *B* is the floor width in m, n_{40} is the number of first-order modes with natural frequencies up to 40 Hz, given as follows

$$n_{40} = \frac{B}{L}\left\{\left(\left(\frac{40}{f_1}\right)^2 - 1\right)\frac{(EI)_L}{(EI)_B}\right\}^{1/4} \tag{5}$$

and $(EI)_B$ is the equivalent plate bending stiffness of the floor about an axis parallel to the beam direction in Nm^2/m. ζ is the modal damping ratio, recommended as $\zeta = 0.01$.

The values for the parameters *a* and *b* are not specified in EC5. It is only presented a graphic with the recommended range of limiting values and the recommended relationship between the parameters, Figure 1.

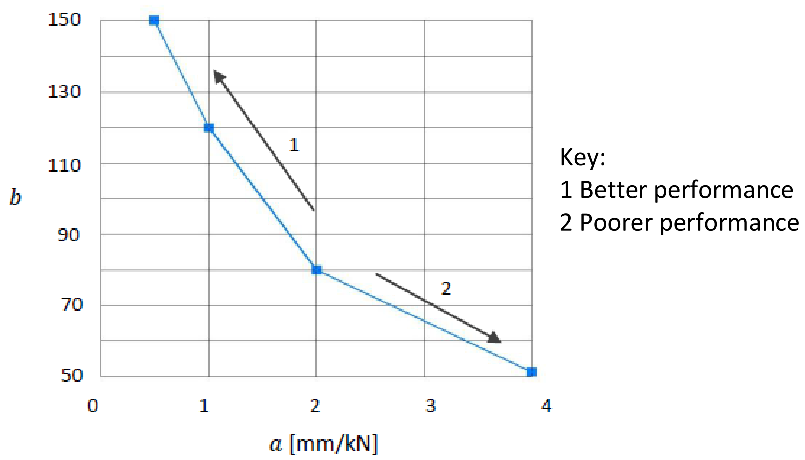

Fig. 1. *Recommended range and relationship between a and b [1]*

If the value of flexibility coefficient, a (mm/kN) is below 2, the floor shows better performance, otherwise, it belongs to poorer performance category.

These requirements should be applied assuming that the floor is unloaded, i.e., only the mass corresponding to the self-weight of the floor and other permanent actions should be considered. It is also pointed out that more information about this parameter choice should be included in the National Annex.

3. Material and Methods

The methods for determining these parameters and the corresponding design limits proposed in the National Annexes of the European countries vary largely from country to country due to different design methods, fabrication procedures and construction techniques. To identify those differences a comparative analysis for timber floor in domestic property with clear span of 3.7 m was carried out, Figure 2.

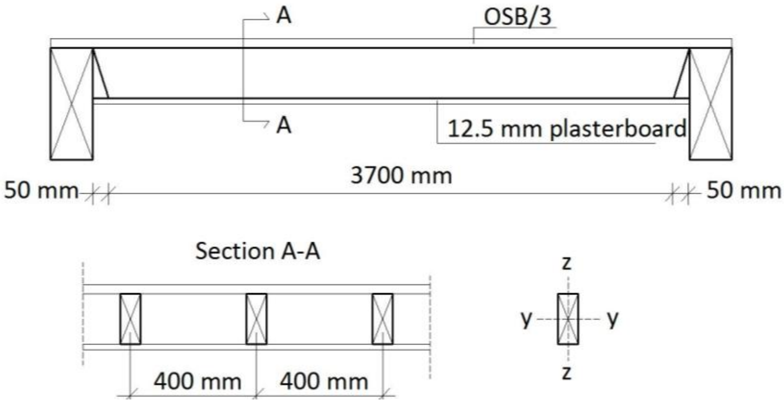

Fig. 2. *Geometric characteristics of timber floor*

The structure comprises 47 mm by 200 mm deep sawn timber joists at 400 mm c/c, strength class C18, and functions in service class 1 conditions. The flooring is 180 mm thick OSB/3 boarding and is nailed to the joists. Although the floor structure is finished on its underside with plasterboard, no increase in the flexural stiffness of the floor will be allowed for this. The floor width is 4.0 m and the floor mass, based on permanent loading only, is 35 kg/m^2. Timber and OSB stiffness properties are 9 and 4.93 kN/mm^2, respectively.

4. Results and Discussion

The floor fundamental frequency and necessary requirements stated in Eq. (2 and 3) are calculated according the National Annexes (NAs) to EN 1995-1-1. The results are shown in Table 1 and 2. Also the corresponding limiting values are given.

The floor fundamental frequency, the maximum displacement and limit a Table 1

Country	f_1 [Hz]	*w* [mm/kN]	Limit *a* [mm/kN]
France [12]	15.85	**1.47***	**1.3***
Belgium [13]	15.85	1.47	1.5
Italy [14]	15.85	**1.47***	**1.0***
Ireland [15]	15.85	1.47	1.8
Sweden [16]	15.85	1.47	1.5
Netherlands [17]	15.85	**1.47***	**1.0***
United Kingdom [18]	15.85	1.47	1.8

* indicates that the design fails

Unit impulse velocity v and limit $b^{(f_1\xi-1)}$ Table 2

Country	*v* [m/Ns^2]	*ζ* [%]	Limit *b*	$b^{(f_1\xi-1)}$ [m/Ns^2]
France [12]	**0.02***	1	108	**0.019***
Belgium [13]	0.02	1	100	0.02
Italy [14]	**0.02***	1	120	**0.018***
Ireland [15]	0.02	1	101.36	0.02
Sweden [16]	0.02	1	100	0.02
Netherlands [17]	**0.02***	1	120	**0.018***
United Kingdom [18]	0.02	2	88	0.046

* indicates that the design fails

5. Conclusions

Eurocode 5 Part 1-1 has provided structural engineers for design of timber floors with three vibrational serviceability design criteria, with respect to the fundamental frequency, unit point load deflection and unit impulse velocity response, respectively. The differences in the design limit in the National Annexes (NAs) to EN 1995-1-1 in the Europe remain large between the countries. In general, United Kingdom is more generous than other countries while France, Italy and the Netherlands are stricter. From all of the above, it can be concluded that it is necessary to harmonize the corresponding limits and damping ratio in NAs of European countries in order to avoid this difference in results for the same floor constructions.

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