11th International Conference on Vibration Problems
Z. Dimitrovová *et al.* (eds.)
Lisbon, Portugal, 9-12 September 2013

PREDICTION OF MATERIAL DAMPING IN TIMBER STRUCTURES

Nathalie Labonnote*[1], Anders Rönnquist[2], Kjell A. Malo[2]

[1]Sintef Building and Infrastructures, Trondheim, Norway
nathalie.labonnote@sintef.no

[2]Norwegian University of Science and Technology, Trondheim, Norway
{anders.ronnquist, kjell.malo}@ntnu.no

Keywords: damping, timber, human-induced vibrations, finite element analyses

Abstract. *Nowadays, more extensive use of wood in buildings is of sustainable interest. Key point for environmentally friendly timber structures, appropriate to urban ways of living, is the development of high-rise timber buildings. Serviceability issues are nowadays the main limitation to the complete development of tall timber buildings. Among them, excessive vibrations due to human activities (such as walking or dancing) or external excitation (such as wind, or road traffic) induce annoyance and other discomforts. Amplitude and duration have been recognized as the two most governing parameters when it comes to human sensitivity to vibration [1]. Damping has therefore a large beneficial influence since it decreases both the amplitude of steady-state oscillations as well as the duration of transient oscillations. Despite its substantial effects, damping is however rarely prescribed in design codes or standards, and is at best included under the form of a constant whose origins remain unclear. The common omission of damping in design criteria originates from the difficulty for the engineer to predict the damping characteristics of a floor during the design process.*

Damping is commonly divided into at least two categories: the material damping which refers to internal friction, and the structural damping which may arise from other sources such as friction in-between components and/or friction due to connectors. A first, yet conservative, step towards better prediction of damping in timber structures can therefore be accomplished by considering material damping as a lower boundary for total damping. To answer this challenge, this paper presents an innovative and efficient method for predicting material damping in timber structures. An application of this method is provided by describing a step-by-step procedure to predict material damping in a timber floor. The prediction of material damping of complex timber structures was derived via the implementation of the strain energy approach into finite element analyses. This rendered excellent results and accurate knowledge of the contribution to material damping from each member of the considered timber structure.

1 INTRODUCTION

Low damping is one of the primary causes of excessive human-induced floor vibration in buildings . Modern timber structures are prone to low fundamental frequencies due to the generalization of long-span architecture and "open-space" solutions. These low fundamental frequencies may unfortunately coincide with the frequency of walking excitation, rendering amplified dynamic response. However, compared to other building materials such as steel, timber exhibits a great advantage in the form of higher damping, which in general will decrease both the duration of transient vibrations and the amplitude of steady-state vibrations. In addition, higher damping in floors should ensure that vibrations are predominantly transient, and therefore more easily tolerated , since both duration and amplitude were largely recognized as influential parameters on the perception of vibration by human subjects .

When the response is damping controlled, there is a clear consensus about including damping in criteria for assessing the performance of *existing* floors. However, at present the omission of damping in design criteria originates from the difficulty for the designing engineer to predict the damping characteristics of a floor during the design process. This is especially relevant for wood structures where the damping characteristics to a large degree will depend on the workmanship and construction techniques . Although designers have accurate models and tools to predict strength and stiffness, the estimation and calculation of damping is usually more difficult due to a general lack of knowledge of the damping phenomena. The total damping: ξ_{tot}, is commonly divided into at least two categories:

- the material damping, ξ_{mat}, which refers to internal friction in the materials and
- the structural damping, ξ_{struct}, which may arise from other sources such as friction between components and/or friction due to connectors.

Hence:

$$\xi_{tot} = \xi_{mat} + \xi_{struct} \tag{1}$$

Structural damping ξ_{struct} is therefore partially dependent on the workmanship, whereas material damping ξ_{mat} is only dependent on the actual material properties. A first, yet conservative, step towards the better prediction of damping in timber structures can therefore be accomplished by considering material damping ξ_{mat} as a lower boundary for total damping ξ_{tot}. The great advantage in this formulation is that prediction models of material damping ξ_{mat} have been developed over the last few decades by means of the strain energy approach .

2 MATERIALS AND METHODS

2.1 Global method

The global method implements the strain theory approach via a finite element procedure. According to the strain theory approach, the material damping ξ_{mat} is expressed as a weighted arithmetic mean of the loss factors η_{ij}, where the weights are the strain energy components U_{ij}, so that:

$$\xi_{mat} = \frac{1}{2}\frac{\sum_{i,j}\eta_{ij}U_{ij}}{\sum_{i,j}U_{ij}} \tag{2}$$

The loss factors are obtained via calibration of models with respect to experimental results, as shown in Figure 1. The strain energy components are directly calculated within the finite-element procedure, as shown in Figure 2.

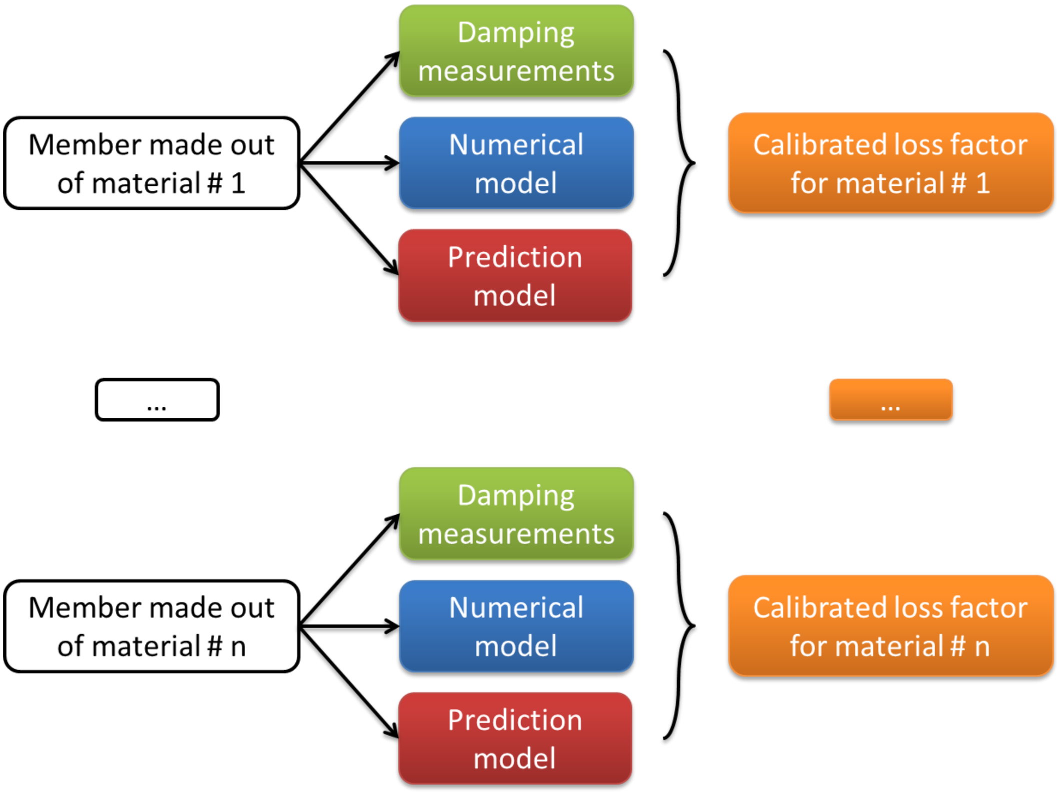

Figure 1: Global method for obtaining the loss factors.

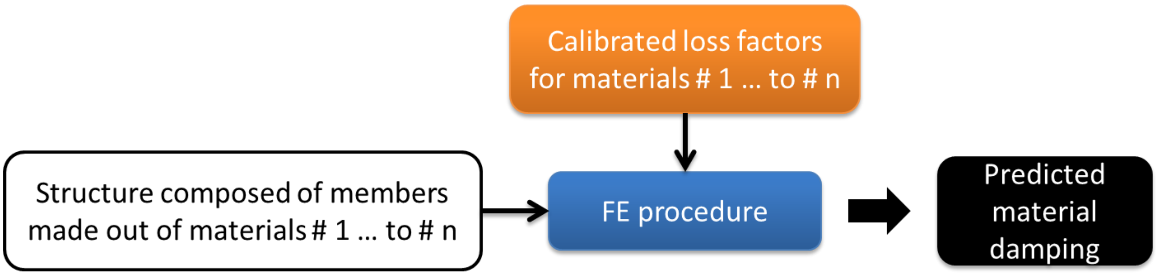

Figure 2: Global method for implementing the finite-element procedure

2.2 Materials

The previously described global method is applicable to any structure, composed of any type of members. However, for the sake of simplicity, this paper investigates the specific case of a timber floor made out of glulam beams (GB) and particleboards (PB) , as shown in Figure 3. The global method is applied to this specific case and is described step-by-step in the next sections. All steps are summarized in Table 1.

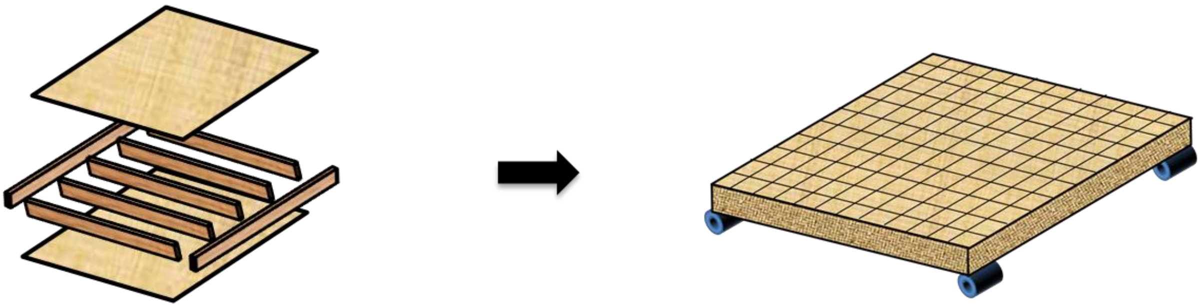

Figure 3: Considered layout for the timber floor.

2.3 Step 1: Experimental study

In the first step, dynamic properties of glulam beams and particle boards of structural dimensions are experimentally evaluated by the impact method. In addition, a well-defined statistical protocol to remove erroneous data is implemented in order to increase the reliability of the results.

2.4 Step 2: Analytical study

In a second step, prediction models are developed for timber beams and timber plates to predict material damping . Prediction models are derived from the strain energy approach, and input is based on loss factors η_{ij}, which are intrinsic properties of the considered materials, together with material properties and mode shape integrals, whose calculation can easily be implemented in most finite element codes.

2.5 Step 3a: Numerical study

In the third step, the commercial software Abaqus is used to build numerical models of GB and PB. GB are considered to be transversely isotropic, whereas PB are considered to be isotropic.

2.6 Step 3b: Numerical study

The mode shape integrals for GB and PB are then computed via a python procedure.

2.7 Step 4: Analytical study

In the fourth step, calibration of loss factors η_{ij} for GB and PB is performed by applying the prediction models (Step 2) to the previously obtained damping measurements for beams and plates (Step 1) and the previously computed mode shape integrals (Step 3b).

2.8 Step 5a: Numerical study

In the fifth step, the commercial software Abaqus is used to build a numerical model of a timber floor. The timber floor is composed of the same GB and PB as the ones studied in Step 1. Particleboard panels are modeled as two continuous plates over the whole surface of the floor, one on top and one at the bottom, using shell elements. Edge joists and joists are modeled using continuum elements.

2.9 Step 5b: Numerical study

A python procedure is implemented in Abaqus to calculate the strain energy components U_{ij}. Strain energy components are calculated for each element, and then summed over members: edge joist, joists, top plate and bottom plates.

2.10 Step 6: Final result

In the sixth step, the predicted material damping ξ_{mat} is finally calculated from the calibrated loss factors (Step 4) and the calculated strain energy components (Step 5b) as outlined in Eq. (3).

Input	Step #	Output
GB specimens + PB specimens well defined experimental protocol	Step 1	fundamental frequencies modal damping
strain energy theory	Step 2	prediction model for beams and plates
Finite element theory	Step 3a	numerical model for GB and PB
numerical model for GB and PB Python procedure	Step 3b	mode shape integrals for GB and PB
prediction models for beams and plates mode shape integrals for GB and PB modal damping for GB and PB	Step 4	calibrated loss factors for GB and PB
Finite element theory	Step 5a	numerical model for timber floor
numerical model for timber floor Python procedure	Step 5b	strain energy components
calibrated loss factors for GB and PB strain energy components	Step 6	material damping of timber floor

Table 1: Sequential procedure.

3 RESULTS AND CONCLUSIONS

- An accurate estimation of the contribution to material damping from each member of the considered timber structure is obtained. Figure 3 and Figure 4 show for example that top and bottom plates induce larger material damping than joists or edge joists.
- There is no doubt that the development of environmentally- and user-friendly timber buildings relies on an enhanced knowledge on damping phenomena . To answer this challenge, an innovative and efficient method for predicting material damping in timber structures was developed. An application of this method is provided by describing a step-by-step procedure to predict material damping in a timber floor.
- The procedure is easy to implement in most commercial finite-element softwares, and renders excellent results. In addition, this procedure can be applied to any type of timber structure made out of timber beams and timber panels, as long as the damping properties of the beams and panels can be accurately determined experimentally.
- This study is expected to help establishing more precise design rules or standards dealing with comfort properties, with the global motivation of setting a basis for the development of new high-rise timber building solutions.

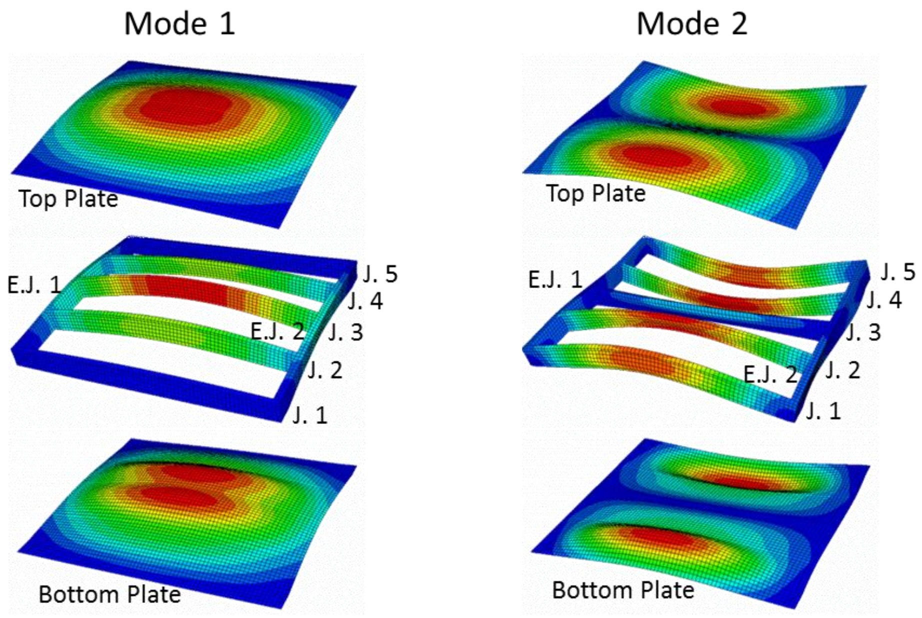

Figure 4: Different deformations types for each floor member (J. = Joist, E.J. = Edge Joist).

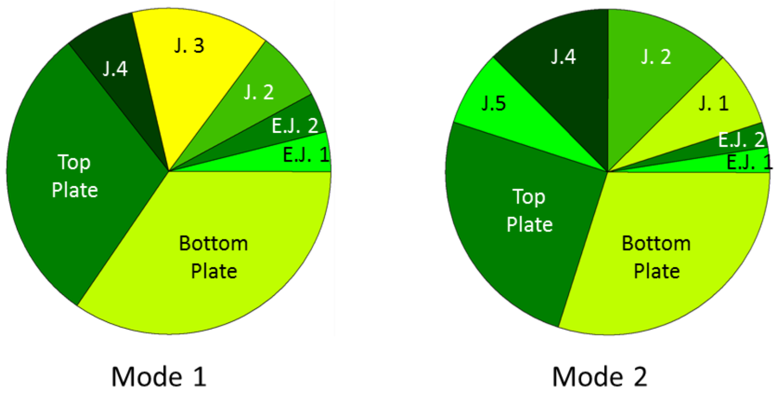

Figure 5: Contribution to material damping from floor members (J. = Joist, E.J. = Edge Joist).

REFERENCES

[1] I. Saidi, N. Haritos, E. F. Gad and J. L. Wilson, Floor vibrations due to human excitation: damping perspective. Proceedings of *Earthquake Engineering in Australia*, Canberra, Australia, 2006.

[2] R. E. Kalkert, J. D. Dolan and F. E. Woeste, The current status of analysis and design for annoying wooden floor vibrations. *Wood and Fiber Science*, **25**, 305-314, 1993.

[3] N. Alves, N. Roitman and C. Magluta, Dynamic response under human movements. *Materials and Structures*, **32**, 31-37, 1999.

[4] I. Smith and Y. H. Chui, Design of lightweight wooden floors to avoid human discomfort. *Canadian Journal of Civil Engineering*, **15**, 254-262, 1988.

[5] J. D. Dolan, T. M. Murray, J. R. Johnson, D. Runte and B. C. Shue, Preventing annoying wood floor vibrations. *Journal of Structural Engineering New York, N.Y.*, **125**, 19-24, 1999.

[6] E. E. Ungar and E. M. Kerwin, Jr., Loss factors of viscoelastic systems in terms of energy concepts. *Journal of the Acoustical Society of America*, **34**, 954-957, 1962.

[7] R. D. Adams and D. G. C. Bacon, Measurement of the flexural damping capacity and dynamic Young's modulus of metals and reinforced plastics. *Journal of Physics D (Applied Physics)*, **6**, 27-41, 1973.

[8] European Committee for Standardization, *NS - EN 1194 - Timber structures - Glued laminated timber - Strength classes and determination of characteristic values,* Brussels, 1999.

[9] European Committee for Standardization, *NS-EN 12369-1 Wood-based panels - Characteristic values for structural design - Part 1: OSB, particleboards and fibreboards,* Brussels, 2001.

[10] N. Labonnote, A. Rønnquist and K. A. Malo, Experimental Evaluations of Material Damping in Timber Beams. *Wood Science and Technology*, **47**, 1033 - 1050, 2013.

[11] N. Labonnote, A. Rønnquist and K. A. Malo, Semi-analytical prediction and experimental evaluation of material damping in wood panels. *Holzforschung*, **67**, 333 - 343, 2013.

[12] N. Labonnote, A. Rønnquist and K. A. Malo, Modified hysteretic damping model applied to Timoshenko timber beams. *Computers & Structures*, **121**, 22-31, 2013.

[13] N. Labonnote, *Damping in Timber Structures* [PhD]. Trondheim, Norwegian University of Science and Technology, 2012.