Geometric simplification of a wooden building connector in dynamic finite element model

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The characteristics of boundary conditions of a wood joist floor are critical in the dynamic behavior at low frequency. Furthermore, the properties of junctions between floor and wall are determinant in the vibrational energy transfer (flanking transmission). For this floor system, the junction between the wall and the joist frame is usually done by wood connectors which present a relatively complex form : folded sheet plate with nails or screws fixing). The aim of this study is to replace the complete model of the connector by an equivalent element in term of transfer functions. The identification of the equivalent parameters is build jointly by numeric analysis and experimental study. In the vibro-acoustic domain, this simplified model reduces the number of vertices, and the resolution time of CAD model building. This simplified structural model can thus be coupled to the acoustics of the adjacent rooms.

1 Introduction

In wooden buildings, the junction between the joists and beams is usually performed with wood connectors for reasons of speed of assembly and ease of implementation. The mechanical characterization of building assemblies are mainly designed in the static domain, to estimate resistance to failure. In the dynamic domain, we have few information about the stiffness and damping factor of this assembly. These data are needed to determine the boundary conditions of joist floor as they influence the vibrational behavior.

Figure 1: Wooden joist floor with wood connectors

These works contributes to PhD thesis to predict the sound insulation of wooden joist floors.

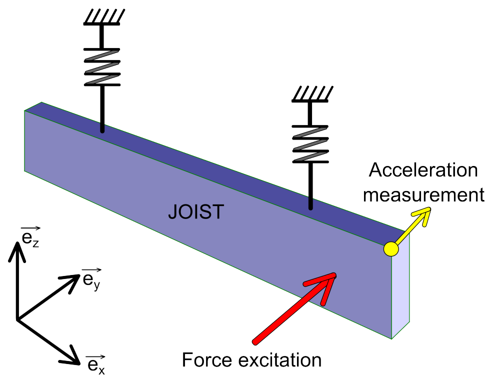
2 Experimental and numerical model of joist

To investigate the vibrational behavior of the assembly with elements having a transverse isotropic behavior of stiffeness matrix and a mass and rigidity variability, it is necessary to identify the elastic constants of wood samples. At first, we used modal analysis applied on a wooden joist (cf. Fig. 3) to obtain the frequency response of the system. After selecting the eigenvalues of bending modes associated to y axis, we determine the damping factor (η) and the longitudinal modulus ($E_{L,\vec{e_x}}$) of joist with Bernoulli model.

Geometry and mass properties of the tested sample:

- Dimensions : $L_x = 4.5$, $l_y = 0.06$, $h_z = 0.22$ [m]
- $\rho = 460$ [kg/m^3]

Figure 2: Sketch of experimental test of wooden joist



2.1 Determination of elastic constants of wood joist

2.1.1 First approach : Bernoulli model

Various articles [3, 4] on the evaluation of stiffeness properties on wood material has already been made. The techniques used involve either the longitudinal vibrations or to the transverse vibrations. For the case of bending vibrations, there are several models : Bernouilli, Rayleigh or Timoshenko model. The simplified Bernoulli model presents the following hypothesis :

- $L_x \gg l_y, h_z$
- shear and influence of support are ignored

For deflection along the direction y, (v_y), the equation of motion, by this simplified model, can be written as fonction of elastic modulus along x-axis, E_x , moment of inertia of the cross-section about z-axis, $I_{G,z}$, mass density, ρ , and the surface of section, S :

$$E_X I_{Gz} \frac{\partial^4 v_y}{\partial x^4} + \rho S \frac{\partial^2 v_y}{\partial t^2} = 0 \tag{1}$$

The resolution of the Eq. 1 leads to the following results in calculating the elastic modulus, E_x as function of frequency by :

$$E_X = 4\pi^2 \frac{\rho S L_x^4}{I_{Gz} X_n} f_n^2 \tag{2}$$

with :

$$\sqrt[4]{X_n} = (2n+1)\frac{\pi}{2} \qquad n = 1, 2, 3, ... \tag{3}$$

From the first 5 eigenvalues determined on the frequency response (cf. Fig. 3), we calculated the values of the elastic modulus associated to an eiguenvalue (n).

Table 1: Eigenvalues and damping factor for the first 5 bending modes along y-axis

n	$f_{b,y}(n)$ [Hz]	$\eta(f_{b,y}(n))$	E_x [GPa]
1	16.9	0.6 %	14.3
2	45.2	0.6%	13.3
3	88.7	0.5%	13.3
4	144.8	0.9%	13.0
5	212.1	1.0%	12.5

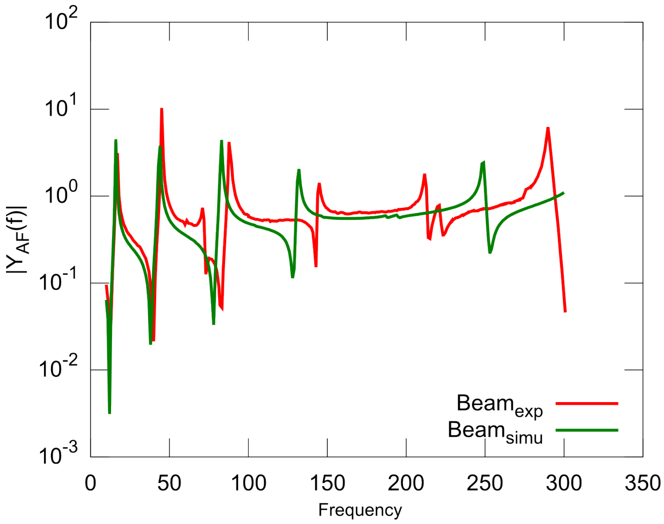
Table 2: Differences of eigenvalue between simulation and experiment for the 5 first bending modes along y-axis

n	$f_{b,y,exp}(n)$ [Hz]	$f_{b,y,simu}(n)$ [Hz]	$\delta f(n)$ [%]
1	16.9	16.1	4.7 %
2	45.2	43.6	3.5 %
3	88.7	82.8	6.6 %
4	144.8	131.5	9.2 %
5	212.1	194.7	8.2 %

2.1.2 Second approach : numerical model

We choosed to compare the response frequency obtained with the experimental test, with a numerical model with FEM analysis. The constants integrated in the FEM model are based on the value E_x calculed in the precedent section and with [1, 2] to extrapolate the other constants. In Fig. 3, we compare the frequency response obtain in th experiment and in the numerical simulation.

Figure 3: Frequency response of the sample by simulation and experiment



In the Tab. 2, we observe a good concordance between the eigenvalues calculated by the FEM simulation and the experiment study. The difference $\delta f(n)$ on the eigenvalues increase with frequency. On the FEM model, the stiffeness matrix is a constant matrix, but the visco-elastic behaviour of wood materials increase the longitudinal elastic modulus with increasing frequency.

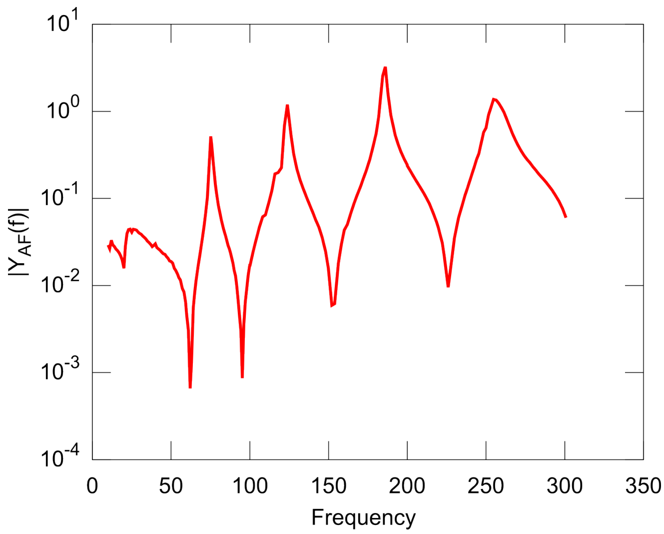
3 Experimental and numerical model of global system

To simplify the geometry of the wood connector, we choose to start with a parallelepiped form of this assembly. The section of the assembly is the same as the joist and the dimension along x-axis is the same as the dimension of l_y. The stiffeness matrix of the connector is base on a orthotropic material. The linear and angular rigidity of the connector could be different for the 3 spatial directions.

On the Fig. 4 and with the case of Fig. 5, the harmonic excitation generates only bending modes along y-axis and torsional modes along x-axis. Other experimental studies on this assembly with differents direction forces and acceleration measurement are necessary to resolve the problem. To obtain the matrix stiffness of wood connector, the resolution is based on the variation of eigenvalues depending on elastics constants.

We present the results of this part during the presentation.

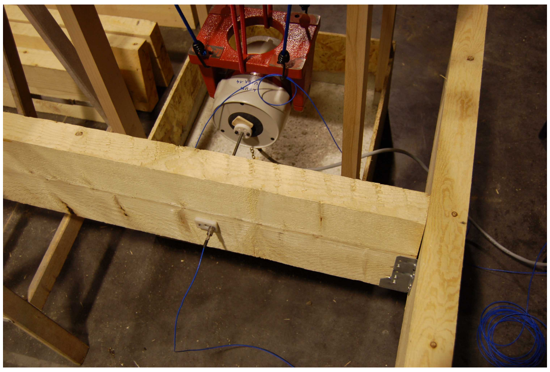
Figure 4: Frequency response of the joist-wood connector-beam system



4 Conclusion

In this paper, we present a method to determine the elastic modulus along the length of the joist. We compare it with a simplified analytic model of a beam (Bernoulli) and validate this approximation with a FEM analysis. On the second time, we explain the method to determine the stiffness matrix of the wood connector from the frequency responses of the global assembly. The results of this study will be integrated in a vibro-acoustics problem of wooden floor joist.

Figure 5: One position of sensor and forced excitation for bending modes along y-axis applied on the complete system



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