Prediction model of the flanking transmission through a light-weight building construction utilizing fluid-structure interaction procedures

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Introduction

Lightweight constructions of timber material have got a number of advantages; it is cost effective and demands relatively shorter production duration. Countries like Sweden, Norway, Finland, Scotland, Canada and New Zealand with good forestry resources have shown an increased interest in research and development of lightweight building constructions.

One of the main drawbacks of lightweight structures is related to the sound transmission. The differences in weight, density and repartition they bring have repercussions on how the sound propagates in the rooms and in the structures themselves. This causes low frequency vibrations to propagate much easier in the structure. Also lateral sound transmission becomes an increasing nuisance. Without proper sound insulation, the tenant will not accept the building system, the system cannot meet the demands of the society (represented in the building codes), and the building system will not be used.

Flanking transmission through a number of T junctions in a floor construction causes many difficulties in acoustic design. A reliable prediction of the rate of diminution of average power along the transmission path, which is also referred to the acoustic attenuation, is hence an important part. The traditional statistic energy analysis, which is based on energy distribution, has its limitations in calculation of structure-borne sound attenuation due to a geometric change or to the structure damping due to material characteristics in the low frequency range. In the Fourier analysis of the flexure wave dispersive propagation solution, the floor construction is assumed to be a homogeneous and periodic plate with infinite length, so that the acoustic reflection from a geometrical or topological change can be neglected in the calculation [1, 2]. Hence it is impossible to obtain the rate of the acoustic transmission through an irregular floor structure in the low frequency range. Another disadvantage of the traditional acoustic modelling is that most methods do not take into account the complex material characteristics in the calculations, thus the damping effect is then not included in the final calculation results [3].

In the constructional wood beam, the sound wave travels 20%-30% faster along the fibre direction than perpendicular to the fibre direction. Rather than being a continuous plate, the floor structure contains an ensemble of a few plates with standard dimensions which are fastened to the wood beams by metal screw joints. . The topological change of the structure causes loss of the propagating kinetic energy. If the wooden beams in a floor construction are periodically distributed under the plates, the dispersive flexure wave and the longitudinal wave attenuation occurs in the immediate vicinity of the source. Flexure wave attenuation is the dominate factor and attenuation rate is stronger for the flexure waves than for the longitudinal waves [4]; most of the kinetic energy from the near field of flexure waves reflects back from the topological discontinuity, while the long field waves propagate towards another direction. Just a few beams away in the floor construction, the total propagation energy decreases dramatically and the longitudinal waves become important, as the flexure waves attenuate away.

A number of studies have been done to investigate the possibility to calculate the structure acoustic transmission through a light weight structure with numerical methods in the low frequency range [5, 6, 7, 8]. In the numerical models, the structure can be described with finite elements with specific material properties. The connection between different floor elements can be modeled with the help of the proper visco-elastic models.

However none of these articles have included the realistic material model for timber and the geometrical conditions of the light-weight floor structure. An earlier numerical investigation [12] has confirmed that an orthotropic wood model in the finite element simulations can improve the accuracy of the calculation results. The material models that have been used in this study are based on the orthotropic timber material models which have been used in fracture mechanic calculations [13, 14]. The dynamic behavior of the floor structures have been investigated with the Finite Element software MD Nastran 2006 r1. The special focus is on the material orthotropic characteristics and influence of the T junctions in the floor where there is a combined material and geometrical discontinuity.

Floor structure

The floor structure, partly represented by figure 1, is constituted by a regular succession of 11 beams of length 4.8m, which are placed parallel to each other. They support particle boards of dimensions 2.4 by 1.2m and 1.2 by 1.2m. The total dimension of the floor structure was 6 by 4.8m. We have in consequence an alignment of 5 plates in one direction, and 2 or 3 plates in the other direction, according to the pattern illustrated in the figure.

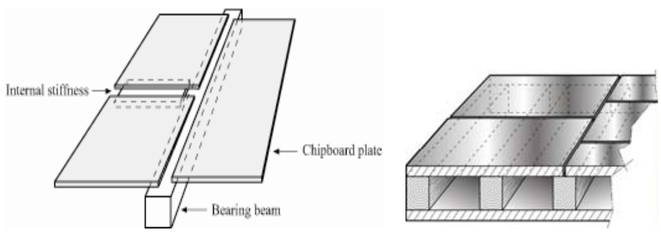

Figure 1.-Floor structure,

Finite elements model

The overall transmission rate in the floor structure depends on a number of factors, among others the location of the internal stiffness, the dimension of the standard chipboard plates that uses in the construction, the thickness of the bearing beam and the distance between each screw. A simple illustration of a floor structure mesh can be found in Figure 2.

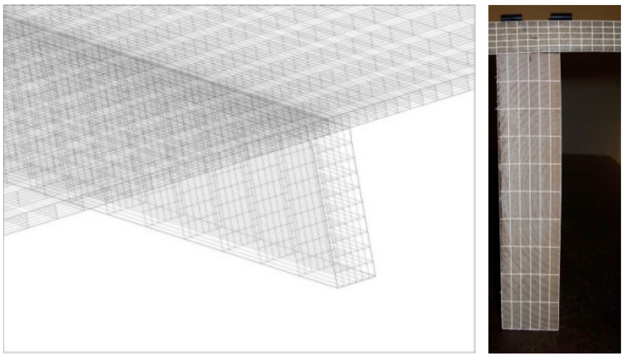

Figure 2.- Illustration of the finite element mesh of a beam and a chipboard.

The vibration reduction level of the structure can be calculated with help of modal frequency response points. During the simulation, the frequency spectrum of the impact is between 15Hz to 500 Hz. The excitation is asserted on the upper bay side of the floor structure. The distance between the excitation location and the observation location is 1.45 meter in the propagation direction. Results from eight nodes in the vicinity of the response positions also on the upper bay-side are collected and a mean average response function was obtained. The computational results have been compared with the experimental measurements from a previews article [12]. Figure 3 shows the comparison between the average attenuation rates per meter on the third octave band in the low frequency range.

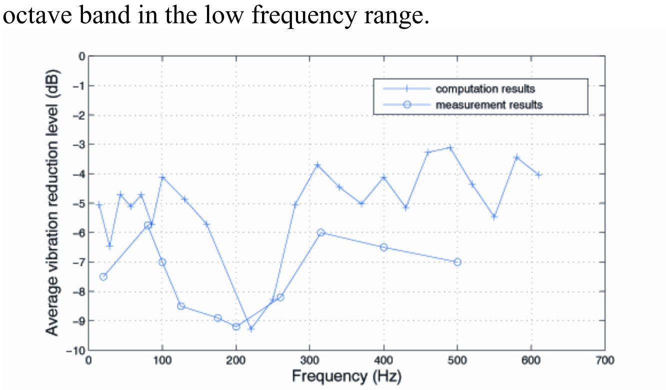

Figure 3.- average vibration reduction level per unite length of the whole floor structure.

The reference velocity vr for both the computational results and the measurement results of the average attenuation rate per unit length is the indicated reference velocity according the ISO 140- 1. Both graphs have captured a maximum around 200 Hz on the Fourier domain. The computed frequency response value has nevertheless a lower average attenuation rate, this depends likely on the simple material damping model in the simulations, also on the production uncertainties of the structure during the measurement performance. The comparison graph shows that the agreement between the experimental measurements and the computational output is sufficiently good.

Summary and conclusions

Finite Element analysis of lightweight wood floor elements has been conducted and compared to experimental measurements.

The finite element based method is an appropriate method to calculate the velocity reduction rate for a complicated floor structure with advanced material models. The structure acoustic attenuation rate depends highly on the material model in the finite element simulations. The implementation of the local internal stiffness, the discrete screw joint and the constitutive orthotropic material models of the floor elements can improve the simulation results compare with the measurement results.

To include the torsional wave, an appropriate visco-elastic coupling between the beam and the plate is needed. The damping coefficient can be calculated with the help of results from the scattering matrix. In this fashion, the energy dissipation due to contacts between the bearing beams and the chipboard plates can be included. To calculate the sound transmission from one room with such a floor to the other, a fluid structure interaction model can be used to calculate the pressure difference between the excitation room and the receiving room, the vibration pattern also can give a foundation for the actual radiation of the sound from one room to the adjacent room.

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