On the Influence of the Junctions on Wooden Buildings Structural-Acoustic Behaviour

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Summary
This paper aims to present an experimental test protocol used to analyze the vibro-acoustic behavior of a wooden lightweight structure under the influence of changes in its constructive parameters. The influence of these parameters are described using a shaker, a set of accelerometers and a wide-band microphone. The data collected are used to plot Frequency Response Functions (FRF) of both the accelerometers and the microphone, and also to experimentally rebuilt the mode shapes of the structure. The results of this work are coherent and confirmed that the experimental test protocol is functional and repeatable.

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1. Introduction

1.1. Context

The complexity and the huge diversity of wooden construction assemblies makes difficult the prediction of lightweight buildings vibro-acoustic properties. As a matter of fact, the acoustical behaviour of these structures can only be measured after building completion. The VIBRACOUBOIS project has been launched in 2011 to answer this problematic. It is coordinated by the innovative technology transfer center of the CRITT Bois (Epinal, France), in partnership with the LAUM (Acoustic Laboratory of the Maine University, le Mans, France) and several major industrial actors of the wooden construction sector in France. This project aims to understand and predict the vibro-acoustic phenomenons that take place in wooden lightweight structures by using both in-situ experimental results and a prediction tool based on the finite-elements method.

1.2. Building acoustics standards to extend

Because of their low density, lightweight structures are intrinsically more sensitive to vibrations and low frequency sounds. Therefore, as these structures become more and more popular, several research projects (Akulite, [1], for example) work on these new acoustic problematics. On the other side, European building acoustics standards, [2, 3], don't have the appropriate evaluation tools yet to measure low frequency noises in lightweight buildings. The frequency spectrum used in sound insulation between rooms needs to be extended. In fact, only the third octave bands between 100 Hz and 3150 Hz are taken into account, although we know that human beings can detect sounds at frequencies from 20 Hz. If needed, this frequency span can be extended from 50 Hz to 5000 hz, but with no obligation.

1.3. Modal behaviour

When running a modal analysis on any type of structure, we observe an augmentation of the modal density as the frequency increases. This work being focused on low frequencies, modal density is low and octave or third octave band filtering wastes a considerable amount of information like position, amplitude and damping of resonance peaks. Although it has been observed, [4, 5], that one wall in a room can be the source of vibro-acoustic disturbances when exposed to low frequency sounds. These phenomenons are not yet overcome in today's lightweight constructions, but they are the source of disturbances for inhabitants. To understand and to be capable of predict these phenomenons seems therefore important.

1.4. Test protocols to develop

Research about lightweight structures vibro-acoustic behaviour and evaluation of its influence on the acoustic properties of these buildings is still going on. This is why specific test protocols that evaluate the influence of important constructive parameters don't exist yet. This work is thus inspired by diverse methods, [6], materials, [7], and practical solutions, [4], brought by other research teams to get the most relevant results.

Figure 1. Full scale experimental mock up of VIBRA-COUBOIS project.

Figure 2. Plasterboard wall installation: insulating material positionning and plasterboard panel screwing.

1.5. Objectives of this paper

This work aims to present the study of an experimental mock up that will allow us to extract, with the help of a shaker, a set of accelerometers and a microphone, the vibro-acoustic properties of a lightweight structure under the influence of changes in constructive parameters. To achieve this goal, the collected data are used to plot Frequency Response Functions (FRF) of the accelerometers and the microphone, but also to experimentally rebuilt the mode shapes of the structure.

2. Test protocol description

2.1. Experimental mock up presentation

The experimental mock up (Figure 1) has been assembled in October 2014 in the CRITT Bois center in Epinal (France). It is the result of a partnership with the French wooden structures builder SOCOPA. The flexibility of this full scale mock up enables us to analyze the influence of various constructive parameters on the vibro-acoustic behaviour of the structure: joists orientation, floating floor, plasterboard wall, test load, etc... We only describe here the results of the measurements obtained before and after plasterboard wall installation (Figure 2).

2.2. The vibrating source

In this work the vibrating source is a shaker, [8, 9]. Firstly, compared to other modal analysis tools such as the impact hammer, the shaker has the major advantage to benefit from a perfect repetability. Secondly, it is able to excite the structure at very precise frequencies, which is impossible with the classical building acoustics tools such as the tapping machine, the bang machine, or the rubber impact ball. Finally, the vibrating energy injected by the shaker is high enough to get a satisfactory signal-to-noise ratio. In our case, the shaker is suspended above the floor with elastic tighteners to a wooden beam (cf Figure 3), avoiding any undesirable contact that could affect the vibro-acoustic response of the structure. A chirp signal is used to excite the structure, [7, 10], it follows an increasing logarithmic slope from 20 Hz to 220 Hz. This setting lasts longer on low frequencies than on high frequencies which increases the microphone and the accelerometers response functions precision.

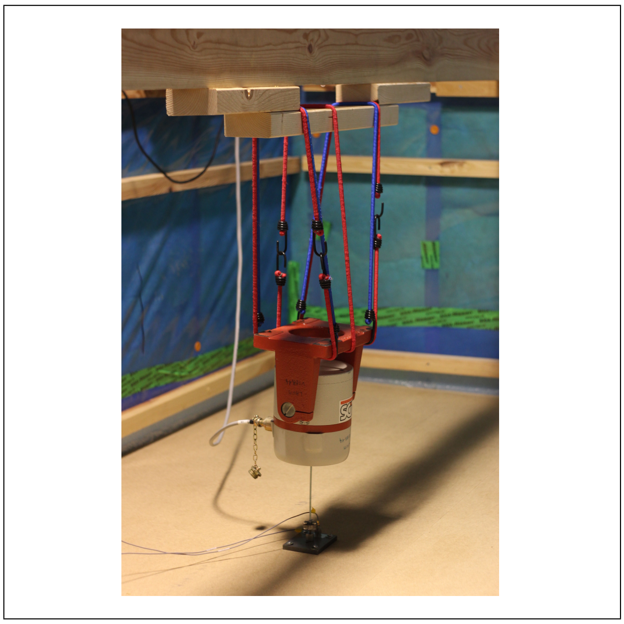

Figure 3. Experimental setting of the shaker used as a vibrating source to excite the floor.

2.3. Sensors positionning

In order to get a simple and wide topography of the studied wall, the accelerometers are distributed on the whole wall in a regular grid configuration. In this work, 16 accelerometers are distributed in 4 rows and 4 columns (Figure 4) which allows to detect mode shapes of the wall with precision until about 60 Hz. Furthermore, in order to observe the influence of the wall vibrations on the acoustic pressure field in the

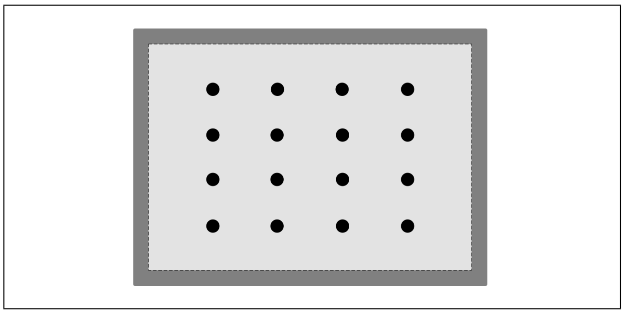

Figure 4. Regular grid distribution of the accelerometers on a wall.

room, a wideband microphone is also used. It is placed in a cavity corner in order to detect low frequency sounds.

3. Experimental vibro-acoustic analysis: case of a plasterboard wall installation

3.1. Introduction

A considerable amount of tests have been carried out since the mock up completion. These tests enabled us to upgrade the experimental protocol, but also to analyze the influence of various constructive parameters on the vibro-acoustic behaviour of the structure. This paper being only focused on the plasterboard wall case, the results of all these tests won't be described here. Additional results will be presented during the oral presentation though.

3.2. Accelerometers FRF: extraction of a wall eigenmodes

The data collected by the accelerometers placed on the tested wall and those collected by the force sensor on the shaker rod are used to calculate the FRF of each measurement channel. A global average using all accelerometers FRFs is then calculated and plotted (Figure 5), which shows the global vibratory response of the studied wall.

On Figure 5, the global average of all accelerometers FRFs before plasterboard wall installation (blue) and after plasterboard wall installation (green) is plotted. Firstly, we observe numerous resonance peaks on both curves. These peaks resolution is high in low frequencies ($\leq$ 80 Hz), but they spread out as frequency increases. We can also notice that the presence of the plasterboard considerably reduces the amplitude of the global vibratory response of the wall between 100 Hz and 170 Hz. On the other side, the presence of the plasterboard seems to increase the vibratory response beyond 170 Hz while smoothing it.

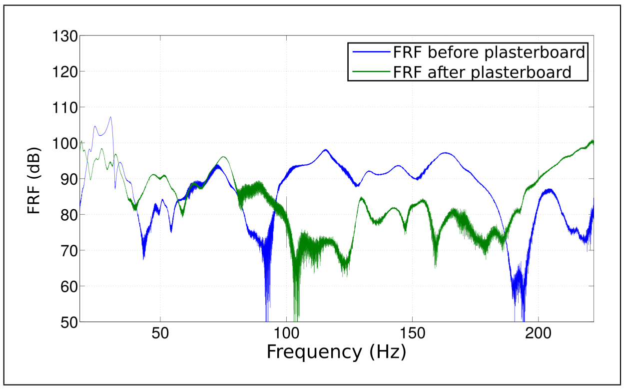

Figure 5. Global average of all accelerometers FRFs before plasterboard wall installation (blue) and after plasterboard wall installation (green).

3.3. Eigenmodes rebuilding

When isolating one eigenfrequency, with the help of the sensors FRFs, we can calculate the displacements amplitudes at that specific frequency using the data collected by each accelerometer. The combination of this information with the precise accelerometers coordinates on the wall enables us to plot on a 3D chart the spatial topography of the corresponding eigenmode (Figure 6).

3.4. Microphone FRF: first try of resetting between theory and experiment

The vibrating energy injected by the shaker in the floor is high enough to run a modal analysis on the walls below, but in the same time it is high enough to generate in the cavity below a characteristic pressure field measurable with a wideband microphone. The results of these measurements are plotted on Figure 7.

On this graph, the vertical dotted lines symbolize the theoritical position of the resonance modes (between 0 Hz and 150 Hz) for a rigid walls-parallelepipedic room. Now, we know that when the cavity dimensions are close to the excitation signal wavelength (usually at low frequencies), the resonance modes that prevail are the cavity modes. Looking at Figure 7, we observe that the resonance peaks at 41 Hz (green curve) and 66 Hz (blue curve) are quite close from the two first theoritical cavity modes (dotted line). The resonance peaks that we observe at 25 Hz and 30 Hz are most probably the first resonance mode of the floor.

It is usefull to mention that cavity dimensions used in the theoritical resonance modes calculation had to be simplified due to the fact that the joists are exposed in the cavity. This simplification and uncertainties about the geometry of the cavity explains the small gap we observe between the theoritical resonance peaks (at 41 Hz and 66 Hz) and those

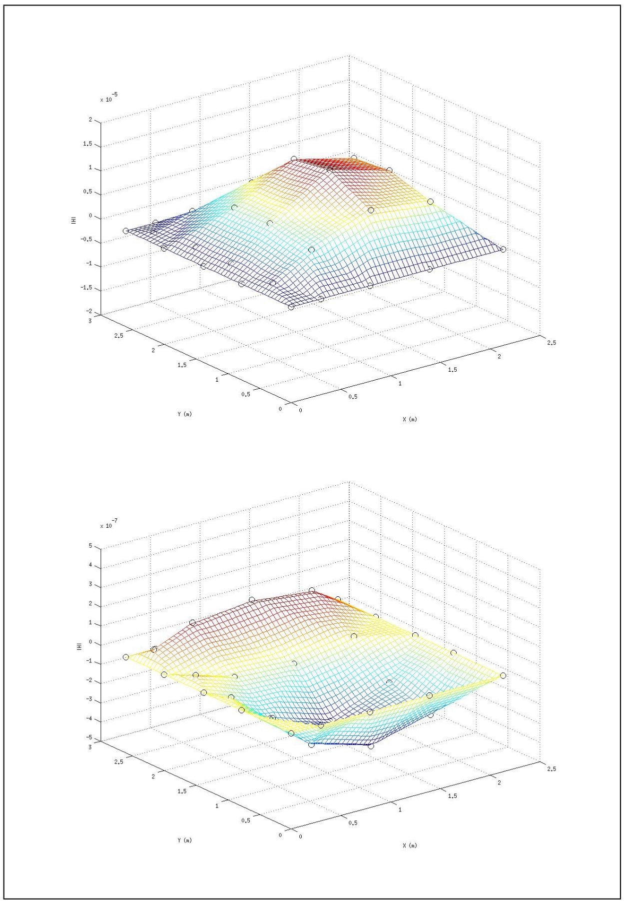

Figure 6. 3D chart showing accelerometers displacements amplitudes on a wall at fixed eigenfrequencies (f = 39 Hz and f = 58 Hz here).

measured experimentally.

If we look closer to the theoritical resonance peak at 66 Hz, we observe that only the blue curve (before installation of the plasterboard wall) shows a resonance close to that peak. The explanation comes from the cavity mode type excited at this frequency. In fact, it is the first vertical axial mode (0,0,1) in accordance with the height of the room (2.6 m). This height being reduced by approximately 30 cm after the installation of the plasterboard wall (Figure 2), the theoritical resonance frequency of this eigenmode increases from 66 Hz to 74 Hz, which explains the gap we observe on Figure 7 between the peaks on the blue and the green curve. These observations confirms that experimental results are coherent.

4. CONCLUSIONS

The results of this work confirmed that the experimental test protocol used to analyze the vibro-acoustic behavior of a wooden lightweight structure is functional and repeatable. The influence of changes in constructive parameters can simply be described using a shaker, a set of accelerometers and a wideband

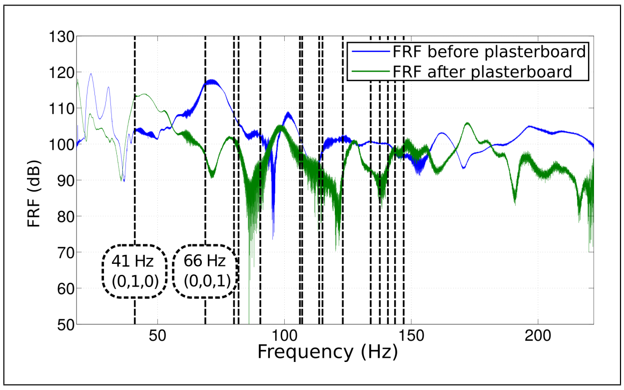

Figure 7. Microphone FRF before plasterboard wall installation (blue) and after plasterboard wall installation (green). The vertical dotted lines symbolize the theoritical position of the resonance modes (between 0 Hz and 150 Hz).

microphone. Complementary tests evaluating the influence of other constructive parameters will be done during the next few months. Finally, the results of all these measurements will feed a numerical prediction model currently in development.

Acknowledgement

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