COMPDYN 2011
3rd ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis, V. Plevris (eds.)
Corfu, Greece, 25–28 May 2011

EXPERIMENTAL INVESTIGATION ABOUT THE INFLUENCE OF THE USE OF GLUE IN JOINTS IN LIGHTWEIGHT STRUCTURES

J. Negreira Montero[1], A. Sjöström[2], and D. Bard[1]

[1] Lunds Tekniska Högskola – Division of Engineering Acoustics
BOX 118, 221 00 Lund, Sweden
Juan.Negreira_Montero@construction.lth.se
Delphine.Bard@construction.lth.se

[2] Lunds Tekniska Högskola – Division of Structural Mechanics
BOX 118, 221 00 Lund, Sweden
Anders.Sjostrom@construction.lth.se

Keywords: Lightweight, Joints, Glue.

Abstract. *Lightweight timber structures have many advantages, but high-demand acoustic quality is hard to achieve due to the relatively poor insulation through the junctions, especially in the low frequency range (20 Hz-200 Hz) where the weight (mass per unit of area) of a construction is an important parameter for the air-borne insulation properties [1]. Increasing the mass would improve the insulation but this would go against the main advantage of lightweight constructions. Impact sound from a walking person is the most common sound insulation problem for these kinds of structures, where the footsteps produce a high-degree of noise disturbance. Similar investigations of junctions have been done before [2]. The aim of this particular investigation, however, is to show how glue modifies the sound transmission through the joints in a wooden floor. Theory shows that coupling occurs in a joint either along a line or at individual points depending on the distance between the screws or nails with regard to the bending wavelength [3], [4]. When a viscous elastic material as glue is inserted in between the parts of the joint, the behavior will change and it is therefore important to be studied. To achieve this aim, two structures were built. The first one constituted of two squared plates of dimension 0.6 m x 0.6 m, each one of them fixed onto one beam 4.5 m wide and 22 cm high, by means of equidistant screws. A second set-up was built too, but this time only a single 1.2 m x 0.6 m plate was fixed onto the beam. The same structures were built again a second time, but this time glue was applied around the screws on the contact surfaces.*

1 INTRODUCTION

Lightweight timber structures have many advantages, but high-demand acoustic quality is hard to achieve due to the relatively poor insulation through the junctions, especially in the low frequency range (20 Hz-200 Hz) where the weight (mass per unit of area) of a construction is an important parameter for the air-borne insulation properties [1]. Increasing the mass would improve the insulation but this would go against the main advantage of lightweight constructions. Impact sound from a walking person is the most common sound insulation problem for these kinds of structures, where the footsteps produce a high-degree of noise disturbance. Similar investigations of junctions have been done before [2]. The aim of this particular investigation, however, is to show how glue modifies the sound transmission through the joints in a wooden floor. Theory shows that coupling occurs in a joint either along a line or at individual points depending on the distance between the screws or nails with regard to the bending wavelength [3], [4]. When a viscous elastic material as glue is inserted in between the parts of the joint, the behavior will change and it is therefore important to study this latter. To achieve this aim, two structures were built. The first one constituted of two squared plates of dimension 0.6 m x 0.6 m, each one of them fixed onto one beam 4.5 m wide and 22 cm high, by means of equidistant screws. A second set-up was built but this time only a single 1.2 m x 0.6 m plate was fixed onto the beam. The same structures were built a second time, but this time glue was applied around the screws on the contact surfaces**.**

2 TEST MODELS

2.1 Geometry

A total number of four mockups were built. The first one was constituted of two squared plates of dimension 0.6 m x 0.6 m, each one of them fixed onto one beam, 4.5 cm wide and 22 cm high, by means of equidistant screws. A second set-up was built this time consisting only of a single 1.2 m x 0.6 m plate fixed onto an identical beam. The same structures were built a second time, but this time glue was applied around the screws on the contact surfaces.

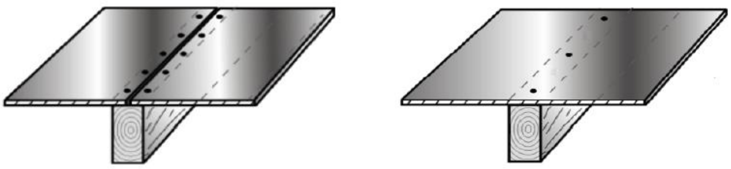


Figure 1: Set-ups.

The distance between the screws connecting the chipboard plates to the bearing beam, following the recommendations of manufacturers, was set to 25 cm in the case of a single plate and 12.5 cm in the case of two plates. The last screws were placed with a distance of 5 cm from the edges in both cases. Both types of connections are realistic and can therefore be found in real timber lightweight structures.

2.2 Materials

The properties of the materials used are listed in Table 1, where E is the Modulus of Elasticity, v the Poisson´s ratio, d the damping coefficient, ρ the mass density and G is the shear modulus.

Spruce Beam		Chipboard		Screws	
E_1	$8.5\cdot10^9$ Pa	E_t	$3\cdot10^9$ Pa	E	$2.1\cdot10^{11}$ Pa
E_2=E_3	$3.5\cdot10^8$ Pa	v	0.3	v	0.3
$v_{12}=v_{13}$	0.25	ρ	767 kg/m^3	ρ	7800 kg/m^3
v_{13}	0.3	d	0.055	d	0.02
G_{12}=G_{13}	$7\cdot10^8$ Pa				
G_{23}	$5\cdot10^7$ Pa				
ρ	432 kg/m^3				
d	0.025				

Table 1: Properties of the different materials used.

Those properties were obtained from the manufacturers who provided the materials. The glue used was ordinary commercial PVAc glue commonly used in real constructions.

3 WAVE PROPAGATION

3.1 Bending Waves

Bending waves are likely to be excited in bodies or structures where one or two dimensions are becoming small compared to the wavelength at an actual frequency, i.e. it is the dominant type of wave in construction elements (beams, plates…). If the plates of the floor structure are sufficiently thin, the shear wave propagation can be ignored and the acoustic wave propagation that leads to sound radiation are only the bending waves [5].

According to [7], the wave equation for a bending wave propagating along the x-axis has the following expression for the displacement η in the z-direction (orthogonal to the surface):

$$\eta(x,t) = [\eta_+ e^{(-ik_B x)} + \eta\_ e^{(ik_B x)} + \eta_{\eta-} e^{(-k_B x)} + \eta_{\eta+} e^{(k_B x)}]e^{i\omega t} \qquad (1)$$

where η_+, η_-, $\eta_{\eta-}$ and $\eta_{\eta+}$ are constants. While the first two terms within the brackets correspond to travelling waves (sinusoidal harmonic waves), the third and forth terms define the so-called evanescent waves (near field vibration waves which decrease exponentially in both the positive and negative directions of the x-axis). Since our excitation consists on short impacts, only evanescent waves will be considered.

4 MEASUREMENT PROCEDURE

In order to measure the vibrations as accurately as possible, the set-ups were hung from the ceiling, suspended to soft rubber springs. The resonance frequency of those springs was calculated beforehand assuring that it is sufficiently low and lower than the lowest eigenfrequency for the structure so that no effect from them is caught in the measurements.

The structure was excited with a hammer producing a sound impact. Nine different excitation points were considered. Dual-axis accelerometers *(iMEMS ADXL203* and *ADXL202E)* were fixed on the structure to record the vibrations. The acquisition software used was *Spectrum SBench 6.1*. The measurement disposition can be seen in Figure 2.

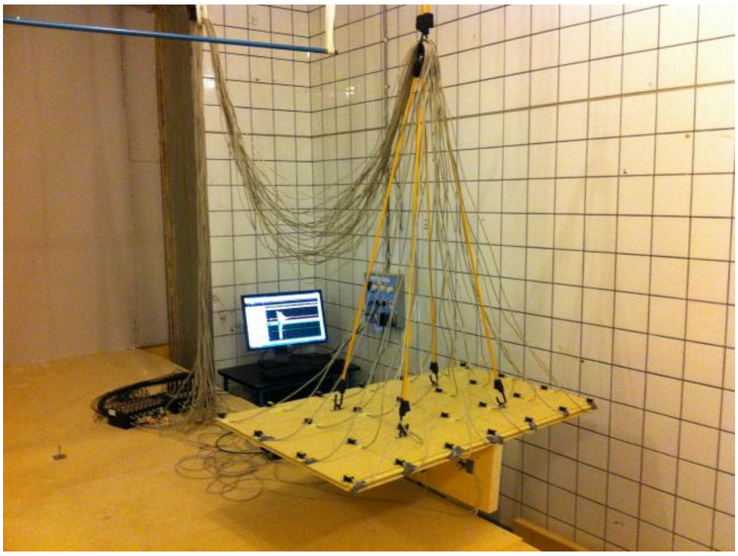


Figure 2: Measurement disposition.

The overall transmission rate in the floor structure depends on discontinuities present in the structure in addition to other factors such as the location of the internal stiffness, the dimension of the standard chipboard plates used in the construction, the thickness of the beam and the distance between the screws [5].

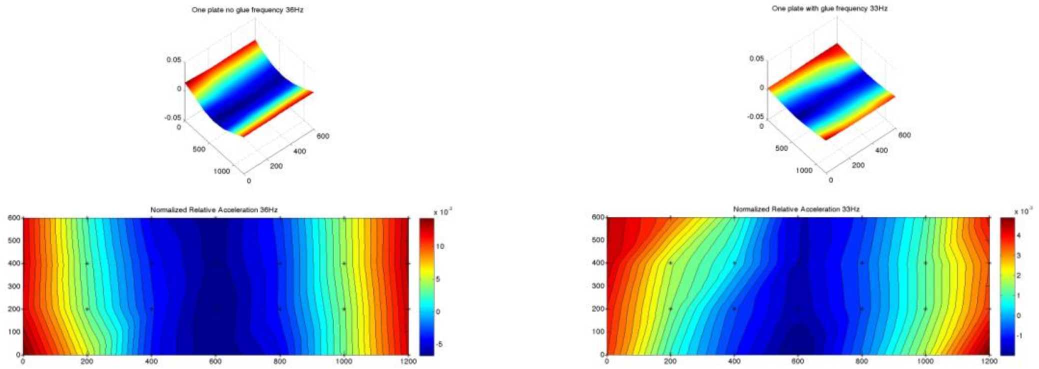
5 RESULTS

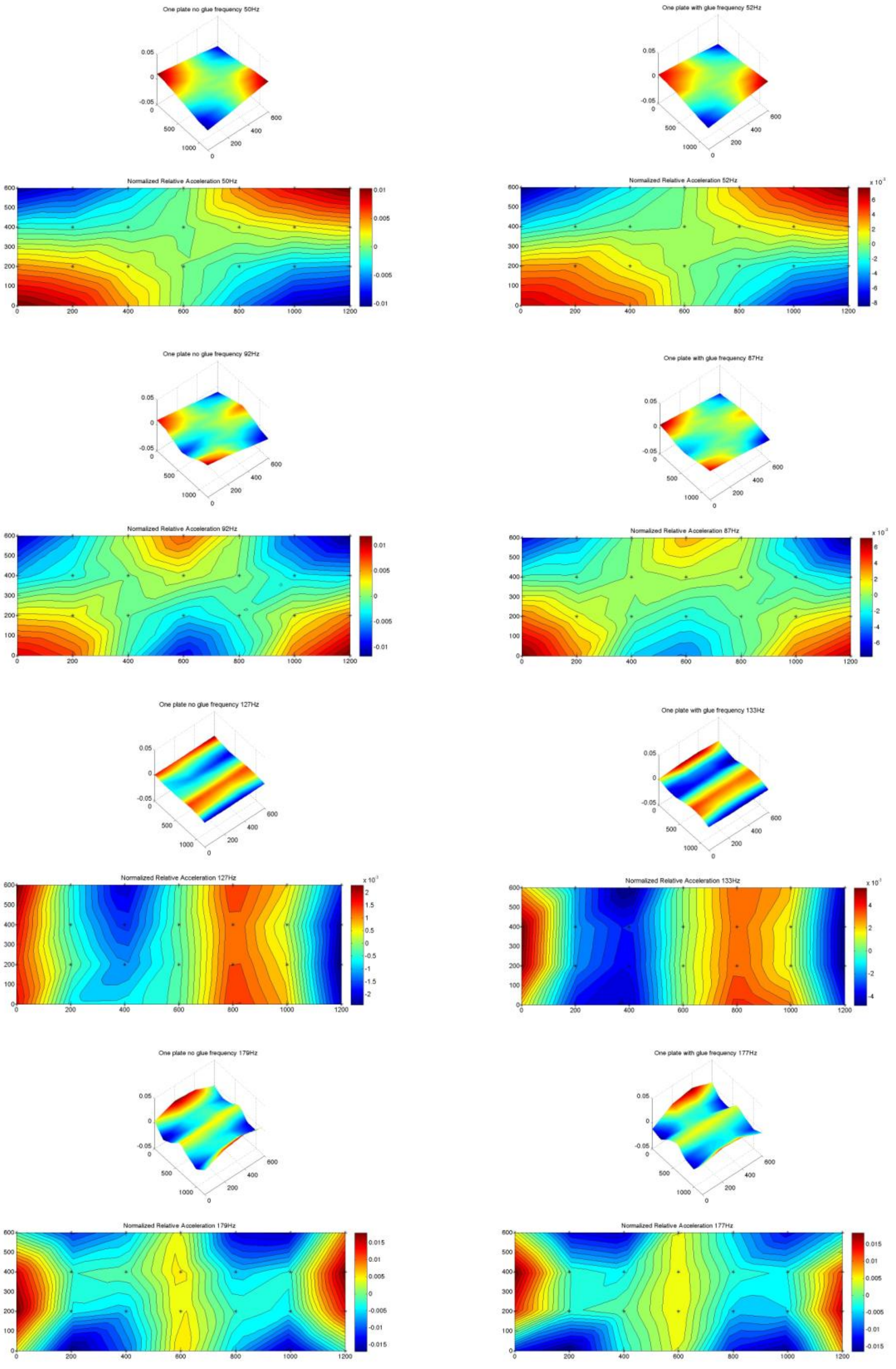
In order to present the results in a general fashion, the data acquired by the accelerometers was scaled with the force applied. As previously mentioned, the structure was excited at nine different locations. As a modal analysis is to be performed, it is not desired that the results are influenced by the excitation point. Thus, an average was carried out over all the excitation points according to [6].

In order to compare the behavior of both set-ups, the modal analysis previously mentioned was used to investigate the influence of the use of glue in the junctions.

5.1 Single-plate Set-up

In Figure 3, the normalized relative acceleration plots corresponding to different eigenmodes are presented. In the left column, the non-glue case is shown while the right column corresponds to the glued case.




One plate no glue frequency 50Hz
One plate with glue frequency 52Hz
Normalized Relative Acceleration 50Hz
Normalized Relative Acceleration 52Hz
One plate no glue frequency 92Hz
One plate with glue frequency 87Hz
Normalized Relative Acceleration 92Hz
Normalized Relative Acceleration 87Hz
One plate no glue frequency 127Hz
One plate with glue frequency 133Hz
Normalized Relative Acceleration 127Hz
Normalized Relative Acceleration 133Hz
One plate no glue frequency 179Hz
One plate with glue frequency 177Hz
Normalized Relative Acceleration 179Hz
Normalized Relative Acceleration 177Hz

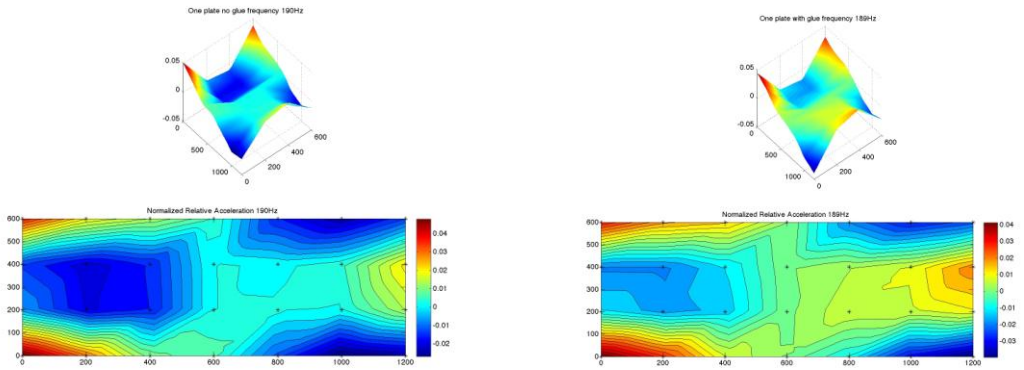


Figure 3: Comparison of modes of vibration. In the left hand side, six modes for the single non-glued plate are presented while the correspondent modes for the plate with glue are listed in the right column.

It can be observed that the glue does not have that much of an influence in the modal shapes or the frequencies they occur at, since their values are quite similar in both cases. Just a slight damping effect can be observed.

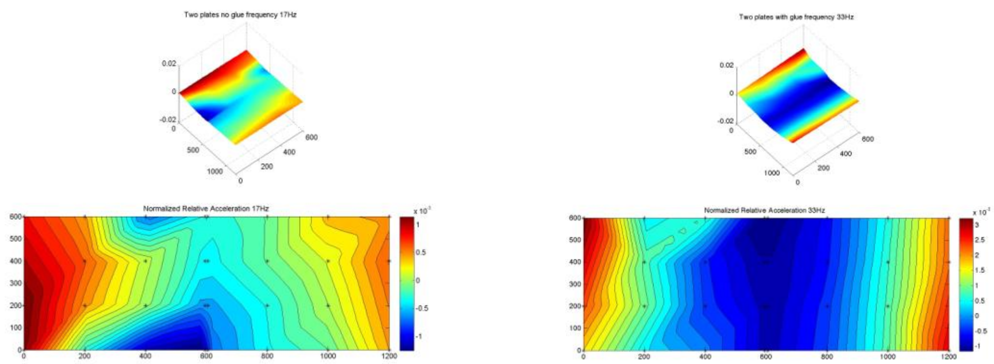
All the modes can be easily identified. The influence of the glue is visible in a reduction of the frequencies for the eigenmodes, especially for the frequencies within the higher part of the observed frequency range, particularly for the torsional modes (f_3, and f_6). Note that the magnitudes of the accelerations are quite low due to the scaling with the force and the fact that the hammer blows were quite soft. Table 2 summarizes the eigenfrequencies.

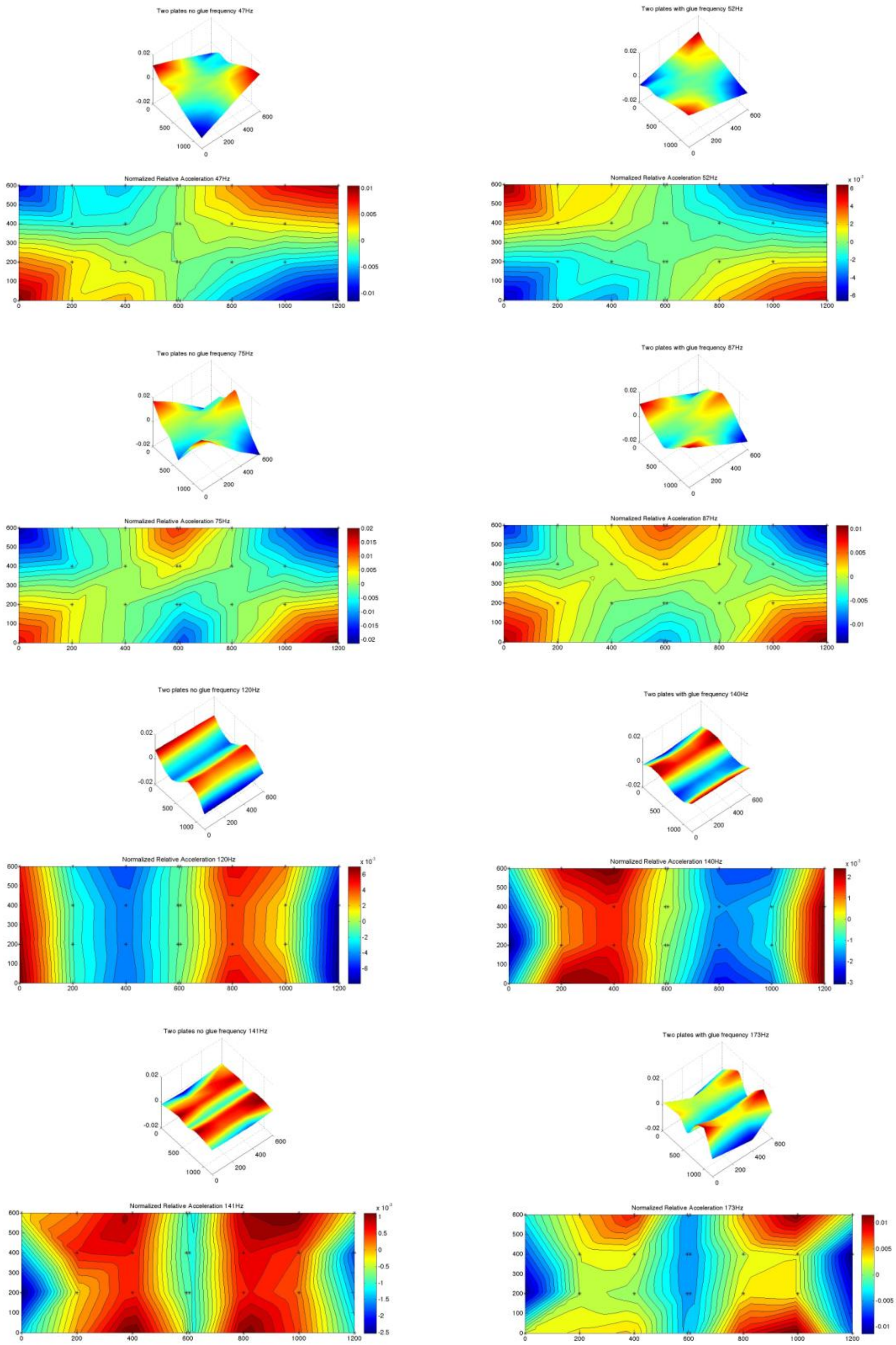
One plate no glue		One plate with glue	
f_1	36 Hz	f_1	33 Hz
f_2	50 Hz	f_2	52 Hz
f_3	92 Hz	f_3	87 Hz
f_4	127 Hz	f_4	133 Hz
f_5	179 Hz	f_5	177 Hz
f_6	190 Hz	f_6	189 Hz

Table 2: Eigenfrequencies for the single plate case.

5.2 Two plates Set-up

In Figure 4, the normalized relative acceleration plots corresponding to different eigenmodes are presented. In the left column, the non-glue case is shown while the right column corresponds to the glued case.




Two plates no glue frequency 47Hz
Normalized Relative Acceleration 47Hz
Two plates with glue frequency 52Hz
Normalized Relative Acceleration 52Hz
Two plates no glue frequency 75Hz
Normalized Relative Acceleration 75Hz
Two plates with glue frequency 87Hz
Normalized Relative Acceleration 87Hz
Two plates no glue frequency 120Hz
Normalized Relative Acceleration 120Hz
Two plates with glue frequency 140Hz
Normalized Relative Acceleration 140Hz
Two plates no glue frequency 141Hz
Normalized Relative Acceleration 141Hz
Two plates with glue frequency 173Hz
Normalized Relative Acceleration 173Hz

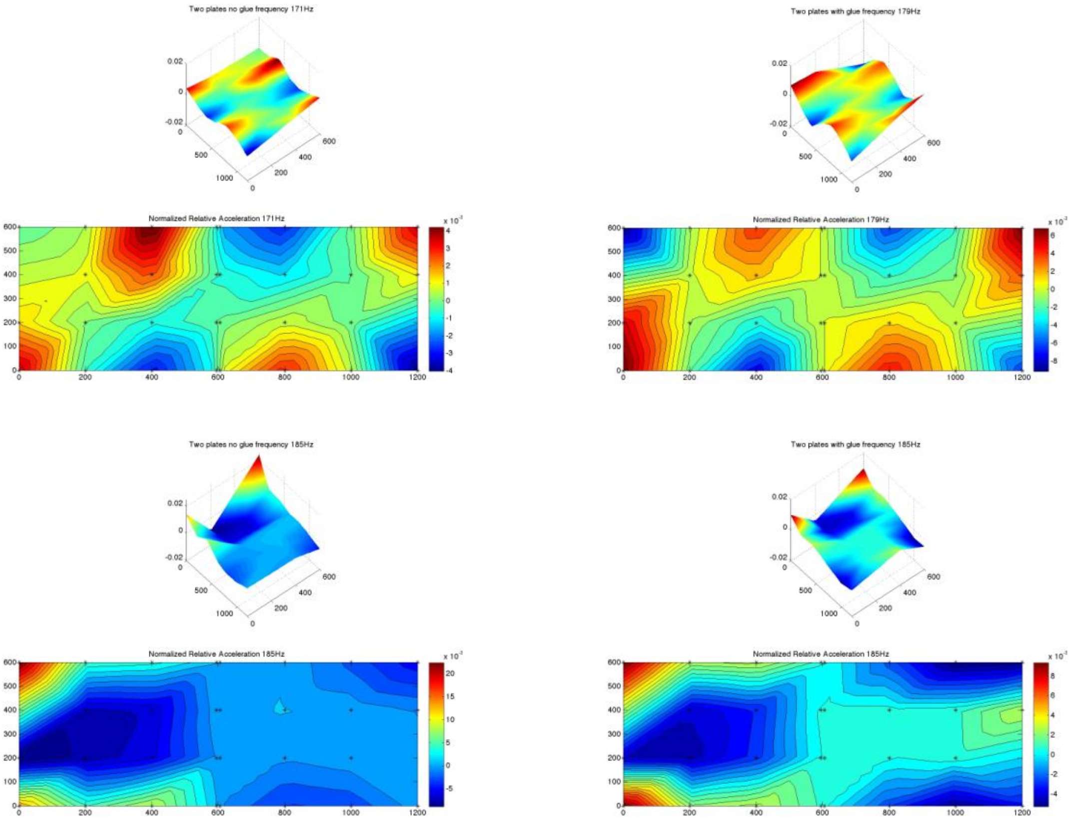


Figure 4: Comparison of modes of vibration. In the left hand side, seven modes for the single non-glued plate are presented while the modes for the plate with glue are listed in the right column.

The non-glued case is, as expected in advance, softer and thus the eigenfrequencies are lower than in the glued case for the correspondent mode (see Table 3). Again, the magnitudes of the accelerations are quite low due to the scaling with the force and the fact that the hammer blows were quite soft. Likewise, the modal shapes can be also easily identified. Table 3 summarizes the eigenfrequencies for each case.

Two plates no glue		Two plates with glue	
f_1	17 Hz	f_1	33 Hz
f_2	47 Hz	f_2	52 Hz
f_3	75 Hz	f_3	87 Hz
f_4	120 Hz	f_4	140 Hz
f_5	141 Hz	f_5	173 Hz
f_6	171 Hz	f_6	179 Hz
f_7	185 Hz	f_7	185 Hz

Table 3: Eigenfrequencies for the two-plate case.

Table 4 compares both glued cases. Note the similarity between them due to the use of glue, which seems to force the two plates to behave as a single plate.

One plate with glue		Two plates with glue	
f_1	33 Hz	f_1	33 Hz
f_2	52 Hz	f_2	52 Hz
f_3	87 Hz	f_3	87 Hz
f_4	133 Hz	f_4	140 Hz
f_5	177 Hz	f_5	173 Hz
	Not found	f_6	179 Hz
f_6	189 Hz	f_7	185 Hz

Table 4: Eigenfrequencies for the glued cases.

6 CONCLUSIONS

In this study, the influence of the use of glue in lightweight junctions has been investigated through measurements on set-ups. The conclusions that can be made are:

- It can be observed that in the single plate case, the glue did not have much of an influence. The slight differences observed may be due to the anisotropy of the spruce beam and its different properties in the different set-ups. This can be the result of, for instance, knots or also because of the damping properties of the glue.
- In the two-plate case it was noticed that the glue plays an important role since it stiffens the junction by pulling both plates together. Due to that, the non-glued case is, as expected, much softer and its eigenfrequencies therefore lower.
- It has been shown that the glue plays a double role within the joints. In the vertical layer when keeping together both plates it acts as a stiffener while in the horizontal layer (on top of the beam) it acts as a dampener. Further work is needed to study both behaviors of the glue.
- The previous conclusion can be validated comparing both cases with glue (Table 4). Note the similarities between both of them. The glue in the vertical layer (two-plate case) stiffens the junction letting them behave almost as a single plate glued onto a beam (the eigenfrequencies in both cases are almost identical).
- Further investigations about the double role of the glue are needed in order to obtain a better understanding of its behavior. Moreover, accurate models for simulation may be developed as a prediction tool for comparison. Likewise, the types of junctions studied could also be identified within a larger real structure and compared with the set-ups studied by similar measurement techniques.

REFERENCES

[1] L. Cremer, M. Heckl, B. A. T. Petersson. *Structure borne-sound*. 3rd Edition. Springer-Verlag. Berlin. ISBN 3-540-22696-6.

[2] D. Bard, L.G. Sjökvist. Sound Transmission through a complete wood cross junction in a light-weight building. *Internoise, 37th International Congress and Exposition on Noise Control Engineering*, Shanghai, China, October 26-28, 2008.

[3] R. J. M. Craik, R. S. Smith. Sound transmission through light-weight parallel plates, part II: structure borne sound. *Applied Acoustics*. 2000; 61(2):247-69.

[4] L. Galbrun, Vibration transmission through plate/beam structures typical of light-weight buildings: Applicability and limitations of fundamental theories, *Applied Acoustics*. 2010; 71:587-596.

[5] D. Bard, J. Sonnerup, G. Sandberg. A finite element solution of structure-borne sound attenuation for a light-weight timber floor. *Building Acoustics*. 2008. 15(2):137-151.

[6] SIS (1997). SS-ISO 2631-1. *Vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements.* Swedish Standards Institution.

[7] C. Hopkins, *Sound Insulation*, Elsevier, ISBN 978-0-7506-6526-1 (2007).