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Accurate Finite Element Modelling of Chipboard Single-Stud Floor Panels subjected to Dynamic Loads

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Abstract

In multi-storey buildings, the use of lightweight material has many advantages. The low weight, the low energy consumption and the sustainability of the material are some attractive benefits from using lightweight materials. Compared with heavier structures *i.e.* concrete the challenge in constructing a building compliant with building codes *vis-a-vis* the propagation of sound and vibrations within the structure is a challenge. Focusing on junctions in a multi-storey lightweight buildings, a modular finite element model is developed to be used for analyses of vibration transmission in lightweight buildings subjected to different types of loads.

Keywords: finite element method, junction, vibrations, buildings, multi-storey, lightweight, wood.

1 Introduction

Lightweight timber framed buildings have over the last decade, shown an increasing interest since it has several advantages compared to heavy concrete structures. There are, however, still disadvantages for timber framed structures where annoying vibrations and noise may be a problem and the most important source of vibrations in residential and office buildings is human walking[1]. In modern architecture there is a demand for open planning in both residential and office buildings that requires long span floor structures. Wood has high strength and stiffness in relation to its weight which makes it possible to build very long spans, especially with glue laminated timber. Slender floor constructions with long spans will have low resonance frequencies that, in combination with low damping, are easily excited by human activities like walking running and jumping. Since humans are sensitive to such vibrations the floors are often being regarded as annoying. Moreover, the vibrations may travel through the

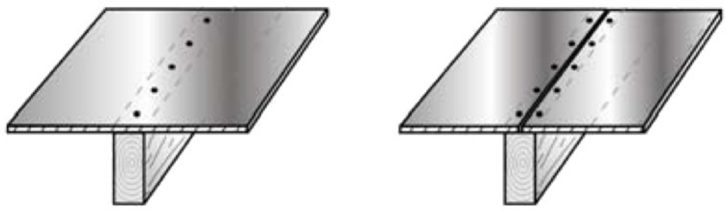

Figure 1: Types of T-connections investigated.

structure by flanking transmission into adjacent rooms both above and on the same floor that can cause audible noise[2] [3] [4]. The transmission of vibrations through junctions in lightweight buildings is dependent on the type of junction and of the materials used [5] [6] [7][8]

To analyse the global response of complete buildings, FE-models may be created by assembling models of floor and wall structures into large models of complete buildings. This paper is part of a larger project where FE-models of multi-storey lightweight buildings are developed for analyses of vibration transmission in lightweight buildings exposed to different types of loads. In order to reliably predict the dynamic performance of lightweight multi-storey buildings, knowledge of the behavior of the different types of junctions present in the structure is needed.

The main focus in this investigation is put on the mechanical description of the various connections that are present inside floors and at the junctions where floors and walls meet. At the floor/wall junctions a rubber foam material (Sylodyn) are often inserted to reduce noise and vibration transmission.

The present paper discuss the applicability of the finite element method in the simulation two types of screwed and glued junctions typically found inside lightweight wooden floors and the influence of Sylodyn when placed in junctions between floor, walls and ceilings is studied. For a more detailed investigations on the T-junctions and the Influence of Sylodyn in junctions see [11] and [12]

2 Influence of in-floor T-junctions

A lightweight wooden floor structure often consist of wood beams covered with chipboard. In such a floor two types of T-junctions may be distinguished; single plate chipboard junction and two plate chipboard junction, as shown in Figure 1. Experimental mock-ups as well as finite element models were made of the two T-junctions types. For both types, screwed as well as combined screwed and glued junctions were investigated. The dimensions of the mock-ups were 0.6 m $\times 0.6$ m.

The same structures were built twice with the difference that for the second set, glue was applied around the screws on the contact surfaces, summing up a total number of 4 mockups. The distance between the screws connecting the chipboard plates to the

	Beam		Board		Screw
E_1	$8.5\,10^9$Pa	E_t	$3\,10^9$Pa	E	$2.1\,10^{11}$Pa
$E_2 = E_3$	$3.5\,10^8$Pa	ν	0.3	ν	0.3
$\nu_{12} = \nu_{13}$	0.25	ρ	767kg/m^3	ρ	7800 kg/m^3
ν_{23}	0.3	d	0.055	d	0.02
$G_{12} = G_{13}$	$7\,10^8$Pa				
G_{23}	$5\,10^7$Pa				
ρ	432kg/m^3				
d	0.025				

Table 1: Properties of materials in the model.

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, as stated before, realistic and can therefore be found in real timber lightweight structures. The thickness of the plates (chipboards) is 22 mm. Those properties were obtained from the manufacturers who provided the materials. The glue used was ordinary commercial PVAc glue commonly utilized in real constructions.

2.1 Finite element model

The model was implemented in in the commercial FEM package ABAQUS [9]. All the individual parts of the structure were modeled and assembled in the finite element model in order to resemble the real construction. The plate, the beam and the screws were modeled using a solid linear brick element with reduced integration and hourglass control. The glue was modeled using a cohesive 8-node linear three-dimensional element. The screws are manifested as square pins going through the plate and into the beam.

The structure was exposed to small loads and displacements only, meaning that all non-linear effects may be neglected and allowing the materials to be linear elastic with the properties shown in Table 1. The element mesh size was determined from a convergence analysis. The typical element size in the model was 4 mm resulting in a total of 937530 dofs. Having such a fine mesh enables us to resolve higher frequencies with greater accuracy in further studies. The model was fixed at two points along the z-axis towards the short edges on the bottom side of the beam.

First, a modal analysis was performed for the four different structures as discussed above. The eigenfrequencies for the identified modes is shown in table 2. The model was also used to perform a parameter study on the influence of the structural damping and the stiffness of the glue in the attenuation over the junction when subjected to an impact. In the prameter study, the values of the properties of the glue was varied. The modulus of elasticity was chosen as 250 MPa, 500 MPa or 1 GPa and the structural

Mode	single plate No Glue	Glue	dual Plate No Glue	Glue
1	27.859Hz	28.050Hz	12.572Hz	27.760Hz
2	41.002Hz	42.723Hz	39.005Hz	41.618Hz
3	68.236Hz	68.407Hz	46.566Hz	68.127Hz
4	68.538Hz	71.074Hz	58.999Hz	68.605Hz
5	117.33Hz	131.34Hz	94.822Hz	117.71Hz
6	139.45Hz	140.08Hz	106.77Hz	139.20Hz
7	147.46Hz	151.44Hz	144.82Hz	149.28Hz
8	149.02Hz	151.55Hz	147.70Hz	149.75Hz

Table 2: The first eight simulated eigenfrequencies

damping was selected as being 0.01, 0.015, 0.020, 0.025 or 0.030. All combinations where properties of the glue was analysed.

The evaluation points in the model were chosen so that they would correspond to the points of attachment of the accelerometers in the measurement setup and the evaluation points in the model. The attenuation was compared over four points on either side of the beam. To evaluate the attenuation over the discontinuity in the junction, the frequency response function was calculated for the case of dual plates glued together over the beam using a frequency sweep from 0 to 200 Hz.

2.2 Results of in-floor T-junction

The results of the analyses are presented in two sections, the modal analysis and the parameter estimation. The eigenmodes for the FE-model are presented in table 2 The measured eigenfrequencies was found to be consistently higher than the simulated ones, indicating that the model is not stiff enough. Some of the mode shapes for the measured and the simulated cases are shown in Figures 2, 3 and 4.

The parameter study performed in the FE-model indicates that the influence on the attenuation from the stiffness of the glue is the most dominant. In order to compare the two types of junctions, a frequency sweep was performed with a single continuous plate over the beam. Both glued and unglued cases were considered. In Figure 5 and in Figure 6 the difference in attenuation over the beam is shown for the dual and single plate cases. It can be noted that the difference in attenuation in the two plate case is much smaller than in the single plate case due to the discontinuity in the plate in the two plate case.

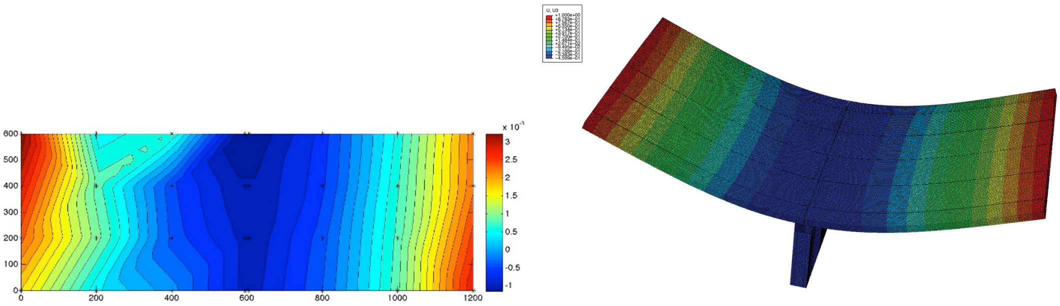

Figure 2: First eigenmode, left: measured, right: simulated

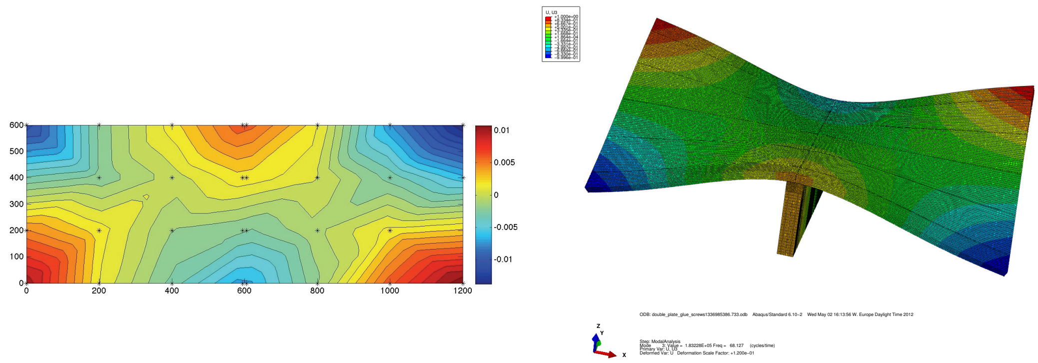

Figure 3: Third eigenmode, left: measured, right: simulated

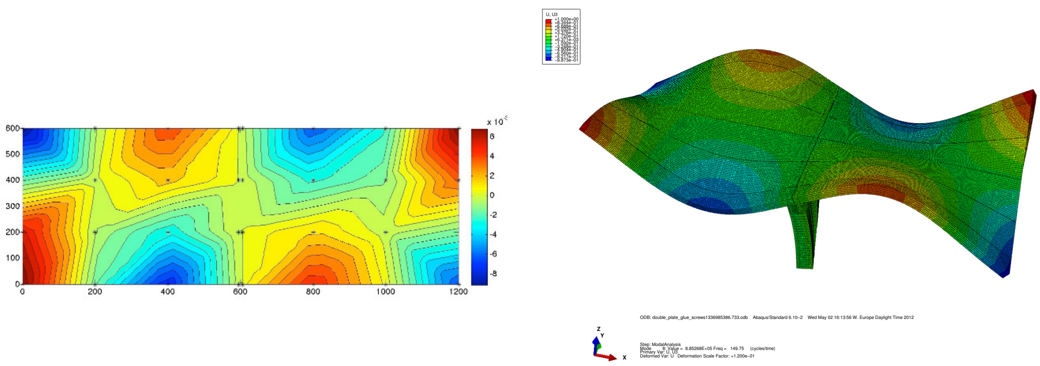

Figure 4: Eigenmodes, left: 6th measured, right: 7th simulated

3 Vibration transmission through an elastic layer

In this investigation, the influence of Sylodyn when placed in junctions between floor, walls and ceilings was studied. Several types of floors and ceilings as well as different placements and properties of the Sylodyn were analysed.

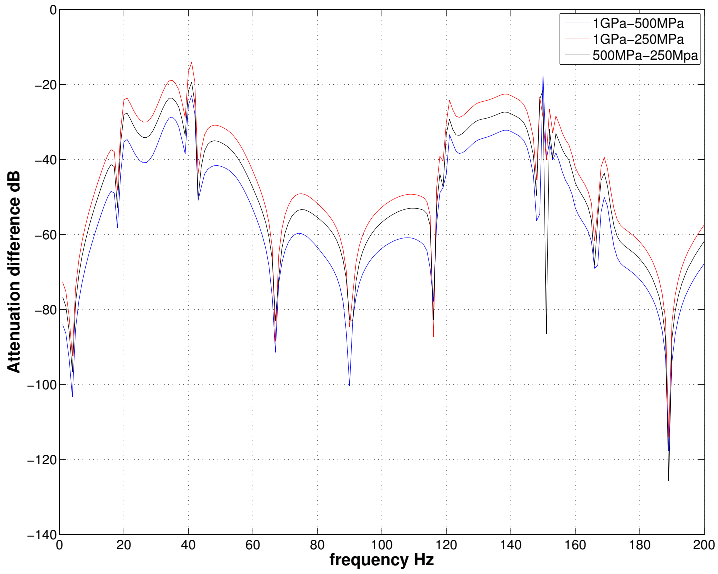

Figure 5: Attenuation differences dual plate cases 0 to 200 Hz

3.1 Problem Description

In this investigation, a standard volume of a room was considered. Its inner dimensions were 3.6 m width, 6 m long and the height was 3 m. In Figure 7, an example of an elastomer installed as a damper in a wall is shown.

Two different placements of the Sylodyn were analysed as shown in Figure 8. One hereafter denoted as Case A, where the Sylodyn is placed in between the top and the bottom part of the walls and the floor and ceiling on the side of the vertical partitions. The second, Case B, where the Sylodyn is positioned underneath the floor and on top of the wall below. In this case, the upper wall is resting on the floor whereas the ceiling is fitted into the cavity left by the walls.

In both Case A and B, the beams comprising the floor and the ceiling were considered to be placed along the shorter dimension, i.e. widthwise. Furthermore, for Case A, the difference in flanking transmission was also investigated when considering the beams oriented in the lengthwise direction. A parameter study by varying the material properties for the Sylodyn was also carried out. Finally, an analysis of the junction without Sylodyn was performed for comparison.

3.2 Finite Element Model

Modelling a junction to represent all the phenomena involved and thus its real behaviour is a very complicated task. The main objective of this investigation is to study the effects of different placements of the Sylodyn on the flanking transmission. Hence,

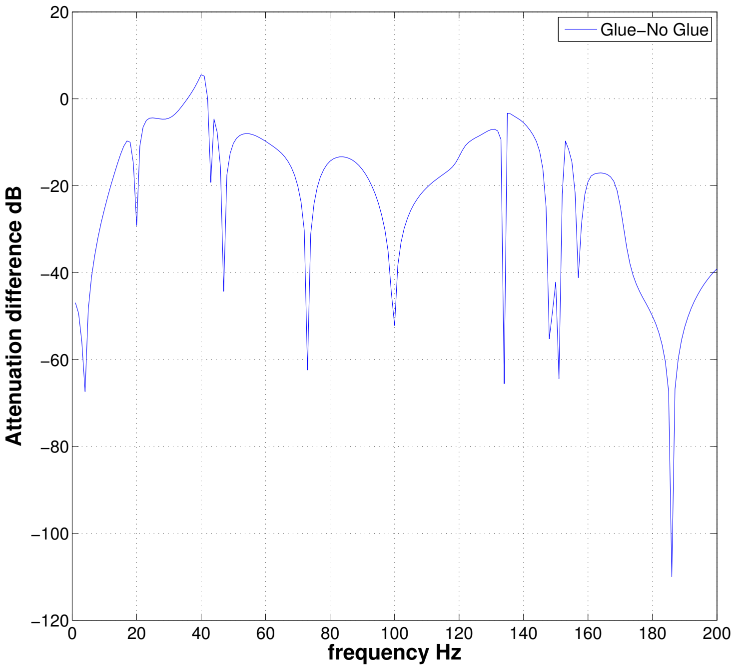

Figure 6: Attenuation differences, single plate cases 0 to 200 Hz

the relative differences between the modelled results are of greater importance than the absolute correlation between the model and existing measurements. By doing so, one gains knowledge on the behaviour of the structure by investigating the parameters influencing the response and therefore enabling to eventually create a more refined model. With such a model, one could correlate simulatetd with experimental results.

As shown in Figure 7, the construction elements are composed of different materials, i.e. plasterboards, parquet, massive wood, etc. For this first investigation, only the load bearing wood structure and the Sylodyn was considered. This simplification will not disrupt the relative differences between the different cases studied. Furthermore, only negligible vibrations were expected to be transmitted through the insulation but were taken into account by slightly increasing the damping of the other materials.

The structure was only exposed to loads and displacements of low magnitude. Therefore, all non-linear effects was neglected and the materials were modelled as linear elastic.

The elastomer introduced in the model to reduce the noise and vibration transmission was Sylodyn NE, a mixed cellular polyurethane dampening material developed by Getzner Werkstoffe GmbH. These viscoelastic construction elements are aligned in the path of propagation of the vibrations. Sylodyn may be used in many different ways, e.g., covering the whole surface, in stripes or in block shapes. In this study, it was modelled as squared blocks with dimensions 100 mm x 100 mm x 25 mm. The

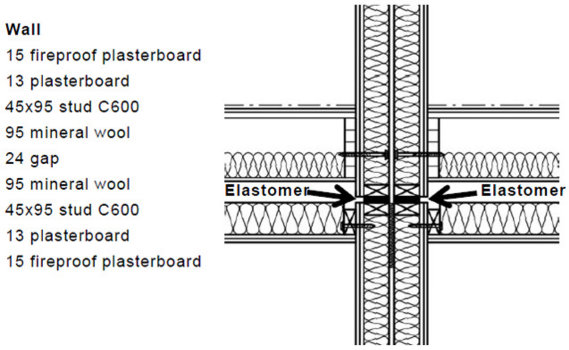

Figure 7: Separating wall junction with elastomer.

distance c/c (centre-to-centre) between two blocks in the junction was set to 400 mm.

In Figure 9, the load-deflection curve under compression loads for a block of Sylodyn is shown. This curve, as all the material properties, is dependent on a parameter called shape factor; a geometric measure for the shape of the elastomeric bearing. It is defined as the ratio of the loaded area and the sum of the area of the perimeter surfaces. It has an influence on the deflection and the static load limit respectively. It can be observed that in the lower load ranges, there is a linear relationship between compression and deformation. After the linear load range, the curve moves on a degressive path, i.e. the material reacts to additional static and dynamic loads in a particularly soft manner, thus allowing for highly effective vibration isolation. For loads and deformation exceeding the degressive range, the deflection curve is progressive. The material becomes stiffer and therefore the vibration isolation is reduced. This material is not affected by overload as it recovers almost completely after load removal. Furthermore, as all elastomers, Sylodyn reacts to dynamic loads more stiffly than to static loads.

Poisson's ratio can only be stated with adequate precision for materials that are loaded in the linear range. It was set to 0.44, whilst the loss factor considered was 0.204. Due to this assumption (Hooke's law applies), the preload on the Sylodyn due to the walls resting on top of the blocks will not have an influence on the results. The

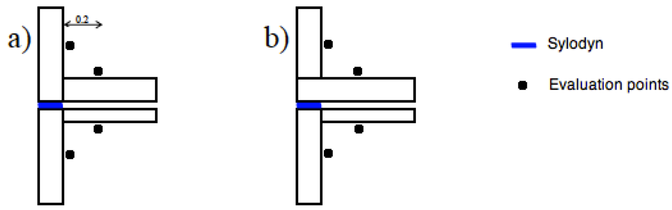

Figure 8: Two Sylodyn positions; a) installed between the walls, b) installed between floor and wall.

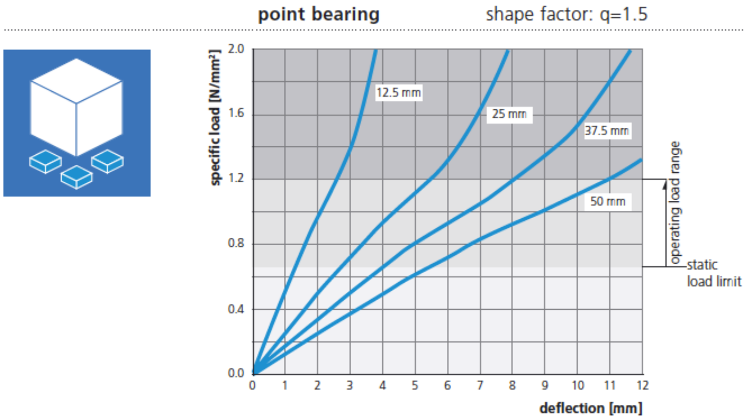

Figure 9: Load-deflection curves for Sylodyn.

Wood		Sylodyn	
E_1	900 MPa	E	3 (varied)
E_2	500 MPa	ν	0.44
E_3	12.5 GPa	ρ	750 kg/m^3
ν_{12}	0.558	η	0.1
ν_{13}	0.038		
ν_{23}	0.015		
G_{12}	40 MPa		
G_{13}	700 MPa		
G_{23}	700 MPa		
ρ	550 kg/m^3		
d	0.03		

Table 3: Material properties.

other material used in the model was wood. It is an anisotropic material, implying different material properties in different directions. The material properties are listed in Table 3. Damping was modelled as Rayleigh damping with the damping ratio set to 3%.

Initial calculations, i.e. convergence analyses, were carried out on single beams with different lengths and on plates with different dimensions in order to establish an appropriate mesh size that provides adequate results with low computational cost. The FE-model thus contained approximately 2 millions degrees of freedom. 8-node brick elements with reduced integration were used throughout the model.

The connections between the parts in the model determine most of the torsional rigidity and influence the behaviour of the whole structure. In this study, the interactions between parts were modelled with tie constraints (full coupling). This creates stiff connections and it is closest to the real structure, where the elements are rigidly constructed using glue and screws.

The load considered was a 5 N harmonic concentrated force located at the middle of the room. A frequency sweep from 10 to 100 Hz in steps of 1 Hz was carried out. Fixed boundary conditions were applied at the free end of the walls. The different models for all studied cases is shown in Figures 10 - 12. The blocks of Sylodyn are shown in grey colour, the floor in blue, the ceiling in red, the inner walls in yellow and the outer walls in green. Apartment separating walls (inner walls) were considered along the long edge of the room, whereas facade walls (outer walls) along the shorter sides.

3.3 Results

The following results show the performance of the junctions regarding the flanking transmission by means of plots ”acceleration versus frequency”. Furthermore, the transmission from the source, located on the middle of the floor, to the ceiling underneath through the inner wall junction was investigated, i.e. the vertical transmission from the floor to the ceiling through the long side of the room. The frequency dependent acceleration was evaluated at 6 nodes along the floor, walls and ceiling, all placed 0.2 m from the junction. Likewise, the acceleration magnitudes were also evaluated on top and bottom of the Sylodyn blocks. An average acceleration for the 6 nodes was carried out and plotted for the different elements composing the junction. In Figure 3 the evaluation points are shown.

Case A, beams oriented widthwise

In Figure 10, one can observe that the Sylodyn blocks (grey) are placed between the partitions whereas the floor and the ceiling are fitted into the space created by the walls, see Figure 3. The beams are oriented widthwise. As shown in Figure 13, the maximum acceleration magnitudes occur between 35 and 60 Hz. One can also identify that Sylodyn dissipates nearly all vibrations, i.e. dampens vibrations, as the acceleration levels evaluated on the ceiling and the wall underneath are very low.

Case A, beams oriented lengthwise

This case is comparable with the previous case, although the beams in the floor and ceiling are now placed lengthwise, see Figure 11. The peak acceleration magnitudes existent on the floor are higher than in the previous case, probably due to the change of the orientation in the load bearing beams of the horizontal partitions. Likewise, the shape of the plots is also changed as seen in Figure 14. In this case, the acceleration peaks occur between 25 and 50 Hz as well as between 80 and 95 Hz approximately. However, the acceleration magnitudes on the ceiling and wall underneath are still very low, depicting the efficiency of the Sylodyn when dissipating the energy of the vibrations.

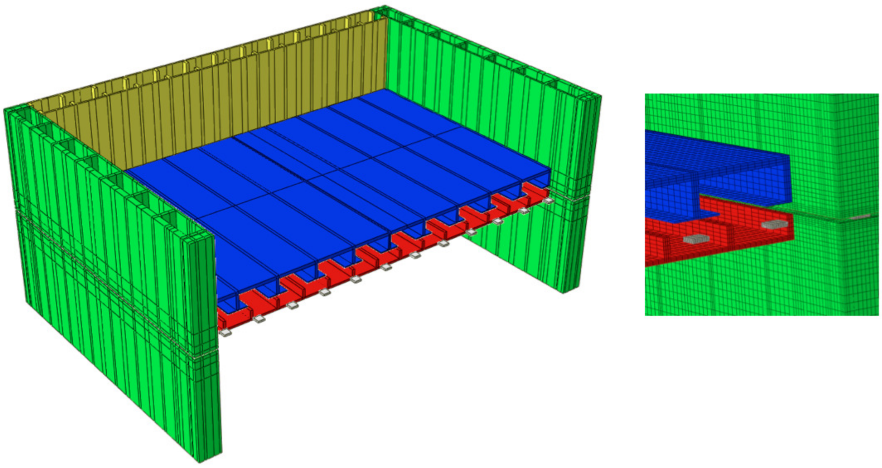

Figure 10: Case A: the beams being oriented widthwise.

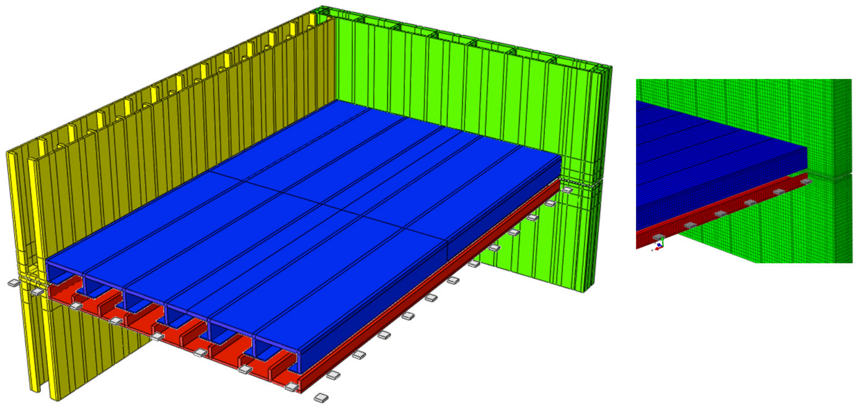

Figure 11: Case A: the beams being oriented lengthwise.

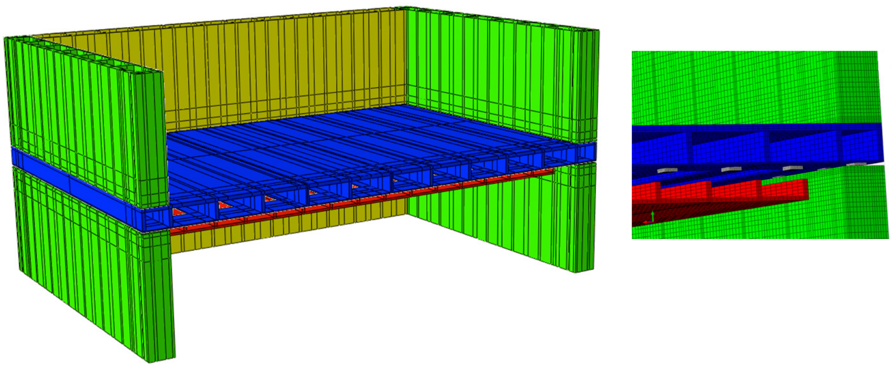

Figure 12: Case B: the beams being oriented widthwise.

Case B, beams oriented widthwise

In Figure 12 the changed placement for the Sylodyn is shown. The walls on the upper floor now rest on the floor itself, being the Sylodyn in contact with the floor and the walls in the floor underneath. The ceiling is, as in the other cases, fitted into the cavity left by the vertical partitions. The shape of the plots resembles the ones in case A widthwise but with smaller acceleration magnitudes almost over all the frequency range as shown in Figure 15. This shows a priori a better performance of the junction regarding flanking transmission, although a more extensive study is needed to confirm this. As in the other cases, the Sylodyn performs very well when reducing the transmitted vibrations.

The modulus of elasticity of the Sylodyn was also varied in order to investigate its influence on the response of the structure. For case A with the beams of the floor and the ceiling along the widthwise direction was considered for this purpose. The initial value of the modulus of elasticity, i.e. 3 MPa was varied and set to 6 MPa and 9 MPa respectively. It was observed that the variation on the acceleration magnitude when increasing the value of the modulus of elasticity had a small influence on the results.

The performance of the junction without Sylodyn was also investigated. Thus, all contacts were wood-wood connections. The performance of case A with beams placed widthwise was compared in both cases. It is apparent that the acceleration magnitudes evaluated at the bottom room without the Sylodyn are much higher, which indicates the advantages of using the Sylodyn as a vibration insulator in the junction.

4 Conclusions

In the study of the T-junctions, the influence of the use of glue in lightweight junctions was investigated through measurements on various junctions and compared to finite element simulations. It was observed in the measurements [10] that in the single plate case, the glue did not have much of an influence in the lower frequencies. The slight differences observed in the measurements between the glued and non-glued case for a single plate may be due to the anisotropy of the spruce beam and its different properties in the different set-ups and not of the glue itself. 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, letting the two plates act as a single plate when adhesive is used. This was observed when comparing the modes for the measured cases. The same applies for the simulation as shown in table 2.

The parameter study undertaken in the glue showed that the type of glue does not influence to a great extent the response of the structure at least not when considering the structural damping in the glue. As expected, it was observed that the attenuation is much higher when a discontinuity is present then in the case of a continuous plate when calculating the attenuation from the simulated frequency sweeps. It can be con-

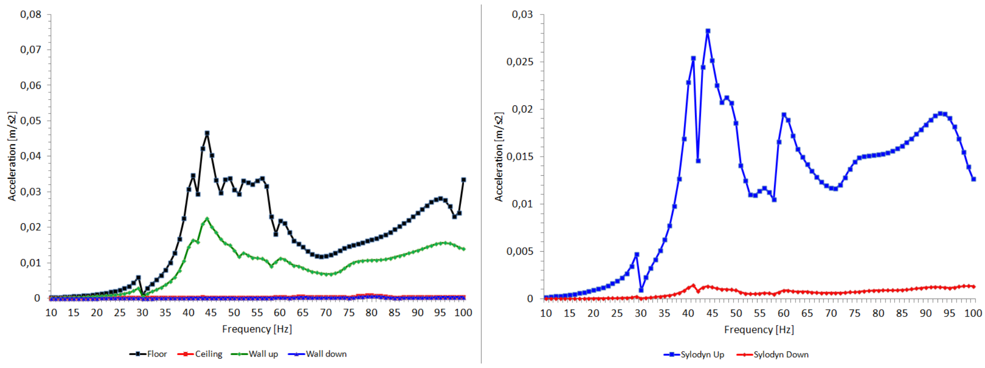

Figure 13: Case A widthwise. Acceleration magnitudes evaluated on the floor, ceiling, upper and bottom walls (left) and top and bottom of Sylodyn (right).

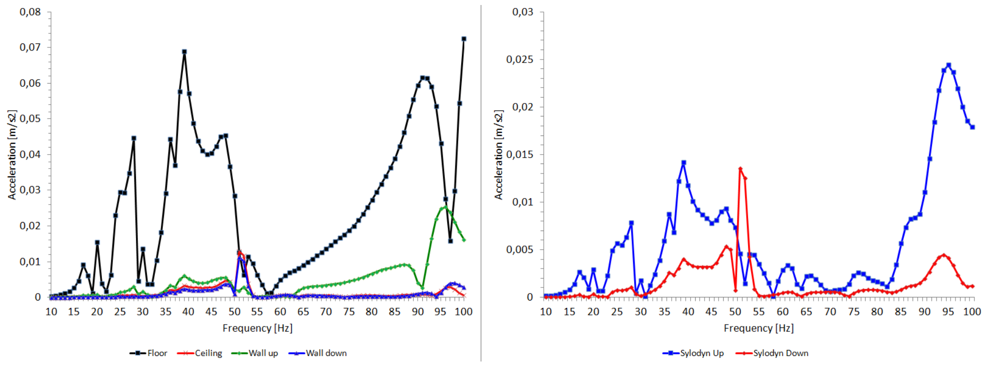

Figure 14: Case A lengthwise. Acceleration magnitudes evaluated on the floor, ceiling, upper and bottom walls (left) and top and bottom of Sylodyn (right).

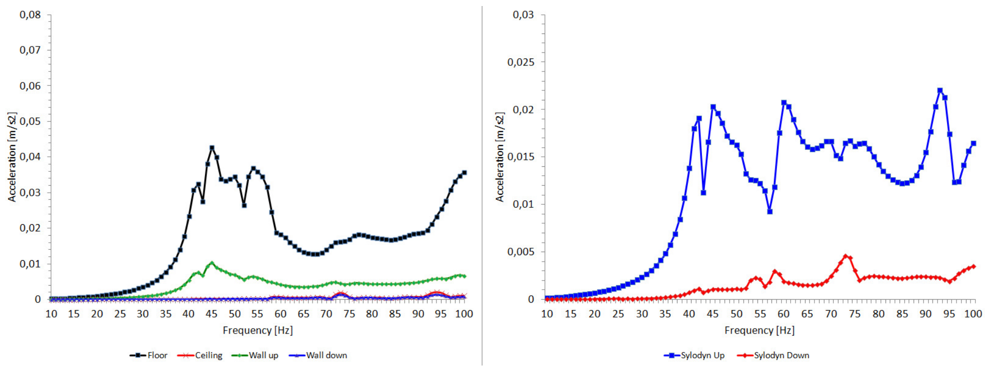

Figure 15: Case B widthwise. Acceleration magnitudes evaluated on the floor, ceiling, upper and bottom walls (left) and top and bottom of Sylodyn (right).

cluded that the differences in attenuation are not a consequence of the properties of the glue, particularly the structural damping. But rather a consequence of the type of junction.

An extensive investigation regarding the flanking transmission when introducing

Sylodyn in a lightweight junction was also carried out. It was shown that regardless of the orientation of the load bearing beams in the floor and ceiling or the placement of the Sylodyn, the reduction of acceleration magnitudes within the blocks of Sylodyn is very effective.

It was also portrayed by a parameter study that a variation in the modulus of elasticity of the Sylodyn does not greatly influence the vibration transmission through the junction. Likewise, it was shown that case B for the placement of the Sylodyn may perform better than case A, although a more extensive study is needed in order to confirm this fact.

In addition, the performance of a junction with Sylodyn was compared to the same junction without Sylodyn, i.e. wood-wood connections all over. It was observed that the vibrations transmitted are much higher in the latter than in the former case. Hence, the advantages of using Sylodyn for this type of junction were proved.

Insight into the performance of the junction regarding flanking transmission has been gained. Ultimately, this will eventually allow the creation of more refined models in order to correlate experimental and simulation results, which could be used as a prediction tool during the design phase of the structures. In these advanced models, more realistic boundary conditions as well as the real materials for the partitions may be considered.

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