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THE EFFECT OF STATIC PRELOADING ON FLANKING SOUND TRANSMISSION THROUGH CROSS-LAMINATED TIMBER JUNCTIONS WITH RESILIENT ELEMENTS

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Abstract

The adoption of cross-laminated timber (CLT) as an engineered structural material in buildings is hindered by its poor acoustic performance. A critical factor is flanking sound, where vibrational energy is transmitted between two building components across a common junction. Resilient strips or pads can be added at the junction to decouple the panels and reduce flanking sound. While effective, the performance of these solutions depends largely on the type of junction that is being considered. The attenuation of flanking sound between two building components i and j is quantified by the vibration reduction index K_{ij}, which can be experimentally determined on-site or in a laboratory in accordance with ISO 10848. This work summarizes the findings of an experimental campaign on a horizontal X-junction made of CLT in a laboratory setting. Specific attention is paid to the effect of external static preloading, leading to added structural rigidity of the junction. In practice, this is the case for load-bearing walls supporting multiple floor levels. This effect is simulated by an external line load on the structure provided by a hydraulic press. In this study, multiple configurations are considered with and without resilient strips at varying external loads.

Keywords: *cross-laminated timber, flanking sound transmission, resilient interlayers, static preloading*

1. Introduction

While cross-laminated timber has gained popularity as a lightweight, carbon neutral alternative for traditional building materials, its acoustic performance is generally poor without special measures. One important factor is flanking sound transmission, where vibrational energy is transmitted between connected building components through a common junction. This phenomenon is quantified by the vibration reduction index K_{ij} between connected elements i and j. An effective solution for flanking sound is provided by resilient strips decoupling the connected panels. However, the direct influence of these strips on K_{ij} is difficult to predict, especially because the visco-elastic materials used in these strips typically exhibit a significant load dependency. As the load acting on a specific resilient strip in a building heavily depends on the floor level, it is important to take this loading variation into account when assessing the performance of the resilient strip. This work is part of a larger experimental campaign which aims to determine K_{ij} for CLT junctions with varying connection types and other boundary parameters. The main aim of this particular work is to study the effect of static preloads on K_{ij} for junctions with and without resilient strips. Section 2 describes the flanking setup used in the experimental campaign and the general test methodology. Section 3 presents K_{ij} results where the static preload and the presence of resilient strips are the main points of interest.

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2. Methodology

The experiments were conducted at a dedicated flanking setup in the Buildwise Acoustics Lab in Limelette, Belgium, as illustrated in Figures 1 and 2. The test object is a CLT X-junction consisting of two walls and a continuous floor, distributed into two zones width a span of 3.5 m and 3.9 m at the front- and backside of the wall, respectively. Each wall or floor element consists of two CLT panels with a width of 2.4 m, connected along a bolted lap joint. All CLT panels are 5-ply with a thickness of 100 mm and 140 mm for the walls and floor, respectively. Within the scope of this text, the floor panels are always

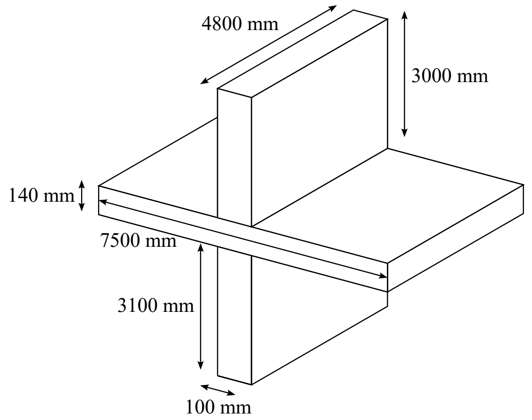

Figure 1: Dimensions of the CLT panels in the test X-junction.

Figure 2: View of the CLT X-junction with floors covered with mineral wool packages.

connected to the lower wall with 4 partially threaded screws (Ø8 mm x 240 mm) with a spacing of 1000 mm. The upper wall is simply supported on the floor with no additional connectors, unless mentioned otherwise. The panels are partially supported by a steel frame structure. The CLT is vibration isolated from the frame structure with highly flexible resilient strips. The concrete floor slab at the bottom of the structure is vibration isolated from the rest of the building.

The aim of these experiments is to determine the vibration reduction index K_{ij} for all transmission paths between elements i and j across the X-junction. The measurements are carried out according to ISO 10848-1 [1]. Transient excitation is provided by hammer strikes at 4 well-separated positions for each partition. Similarly, velocity levels are measured with accelerometers at 4 positions satisfying required minimal distances between each other, the excitation positions and element edges as prescribed by ISO 10848. The velocity level difference $D_{\mathrm{v},ij}$ between elements is determined for a steady state excitation of 30 seconds at each excitation position. The structural reverberation time $T_{\mathrm{s},i}$ of each element i is estimated based on single hammer impacts for the same measurement and excitation positions as $D_{\mathrm{v},ij}$. The measurement formula for the vibration reduction index K_{ij} is given by [1].

$$K_{ij} := \frac{D_{\mathrm{v},ij} + D_{\mathrm{v},ji}}{2} + 10\log\left(\frac{L_{ij}}{a_{\mathrm{eq},i}a_{\mathrm{eq},j}}\right), \quad (1)$$

where

$$a_{\mathrm{eq},i} = \frac{2.2\pi^2 S_i}{c_0 T_{\mathrm{s},i}}\sqrt{\frac{f_{\mathrm{ref}}}{f}}, \quad (2)$$

for a reference frequency f_{ref}=1000 Hz, speed of sound c_0=343 m/s, centre band frequency f and surface area S_i of element i. The resulting vibration reduction indices are always presented in 1/3 octave bands with centre band frequencies from 100 to 3150 Hz. While K_{ij} is solely defined by structure-borne transmission through the junction, parasitic airborne sound between the panels through the room can also have an influence, leading to lower apparent K_{ij} values [2]. This is especially problematic if there is a low level of structure-borne transmission such that the airborne transmission is no longer negligible in comparison. In order to reduce this parasitic airborne contribution, the floors are shielded by mineral wool packages.

In this work, special attention is paid to the effect of static preloading on the structure. This is an important parameter as building junctions in practice are always subjected to a given preload due to the floor levels that are supported by the load-bearing walls. The contact between the CLT panels is imperfect in the unloaded case, especially for junctions with no rigid connectors such as screws or angle brackets. An external force can compress the junction, leading to a larger effective contact area between panels and added frictional forces. As a result, the vibration transmission between elements that are pushed together can be increased significantly in an effect similar to connection stiffening due to screws or other connectors. The effect of static loads in the form of concrete blocks with a weight of 346 kg each on a CLT L-junction has been studied by Pettoni Possenti et al. [3]. For a rigid junction, 3 concrete blocks led to a decrease of 6.7,dB for the aggregate K_{ij} value between 1250 and 5000 Hz. Mecking et al [4] also performed K_{ij} tests on a CLT L-junction with external line loads up to 20 kN/m, resulting in similar observations. For junctions with resilient elements such as strips or pads, static preloading also influences K_{ij} through the innate load dependency of these resilient materials. Nilsson et al. [5] studied variation in K_{ij} for CLT junctions with resilient strips at different floor levels of the same building. It was concluded increasing loads has a negative effect on the overall vertical sound insulation, including flanking sound. In the present work, a mobile hydraulic press is present at the top of the upper wall, which can exert static line loads up to approximately 80 kN/m on the CLT junction, corresponding to between 4 and 5 storeys.

3. Results and discussion

3.1. Bare junction

In what follows, multiple K_{ij} tests are described for the full X-junction, where the connection between the top wall and floor is adapted between configurations. In the first example, K_{ij} is determined for a reference junction where the top wall rests on the floor with no strip nor additional connectors. Figures 3 to 5 display the measured values for the various transmission paths across the X-junction for an increasing external line load with steps of approximately 6 kN/m. Without preload, the contact between the CLT panels is imperfect. By adding the preload, the contact area improves, leading to greater friction at the interface and more vibrational energy transmitted across the wall-floor interfaces. At every increment of the line load, K_{ij} decreases slightly until convergence is reached. In a prior test, the static line load for K_{ij} convergence was established to be between 10 and 12 kN/m. Note that the bottom corner path has lower K_{ij} values than the top corner path due to the higher self-weight of the structure acting on this wall-floor interface. When the external line load is sufficiently high, this difference is not significant as convergence is already attained. Notably, the overall frequency trend for K_{ij} changes depending on the preload. In the initial state without load, K_{ij} exhibits a logarithmic increase with frequency. At convergence, K_{ij} is more or less constant in the entire frequency range. This applies to the corner transmission paths as well as the wall-wall transmission paths. The main exception is the floor-floor transmission path which extends over one continuous floor, yielding very low K_{ij}. When preloading is supplied, the energy balance shifts such that there is more transmission across the other paths and less transmission across the floor. As a result, K_{floor} exhibits the opposite trend to the other transmission paths.

3.2. Junction with resilient interlayer

In the next example, a polyurethane foam interlayer with a thickness of 13 mm, width of 100 mm and maximum design load of 0.5 MPa is placed between the floor and upper wall. Similar experiments are conducted at external line loads corresponding to 0, 25 and 50% of the design load of the foam, approximately at 0, 12 and 24 kN/m. Figure 6 displays the measured K_{ij} for the top corner path and wall-wall path as well as $K_{ij,\max}$ for both paths. Other transmission paths only exhibit negligible changes relative to the reference junction without strip and are not displayed, therefore. The $K_{ij,\max}$ values are determined for a junction where the top wall is suspended multiple cm above the floor. As there is no structural contact, this case represents the highest apparent K_{ij}. The wall-wall path and top corner path have a very

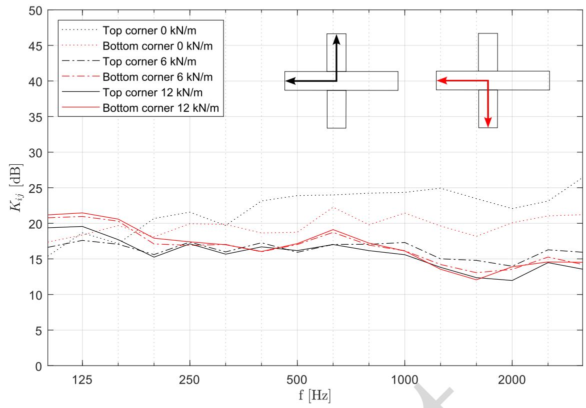

Figure 3: Vibration reduction indices for the top and bottom corner transmission paths for a varying static preload on a junction with no resilient strip.

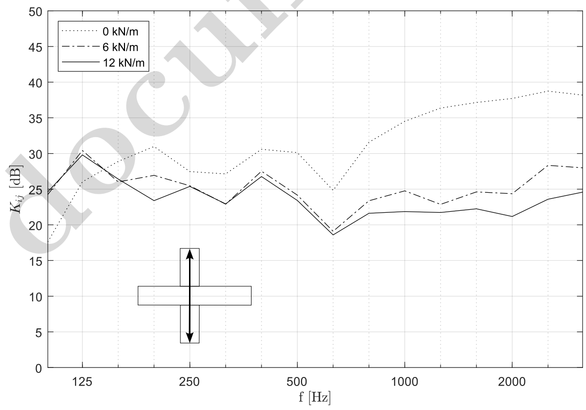

Figure 4: Vibration reduction indices for the wall-wall transmission path for a varying static preload on a junction with no resilient strip.

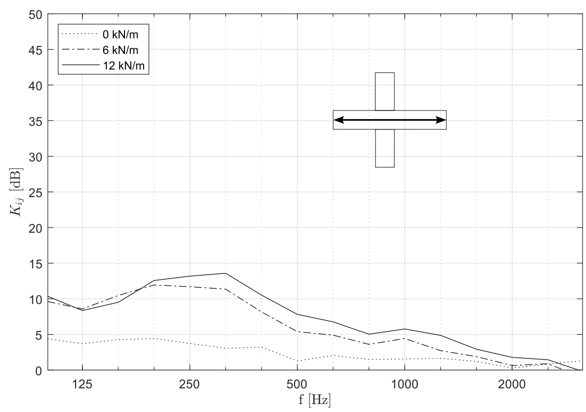

Figure 5: Vibration reduction indices for the floor-floor transmission path for a varying static preload on a junction with no resilient strip.

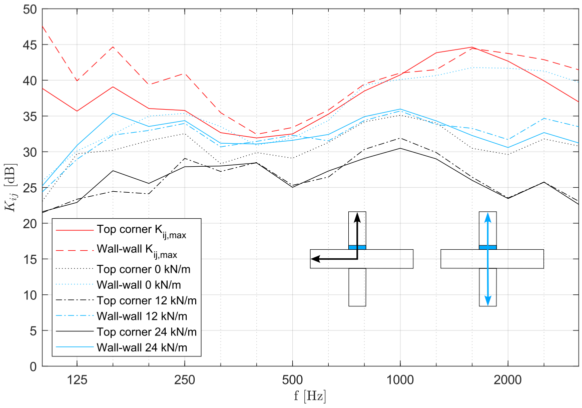

Figure 6: Vibration reduction indices for the top corner and wall-wall transmission paths for a varying static preload on a junction with a polyurethane foam strip.

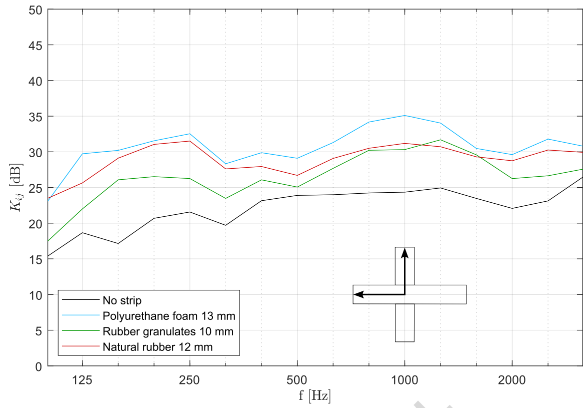

Figure 7: Vibration reduction indices for the top corner transmission path for no static preload on a junction with varying resilient strips.

similar frequency trend, with K_{wall} at a higher level than K_{corner} as is also the case for the reference junction. Notably, there is a dip around 2000 Hz and peaks around 1000 Hz and 2500 Hz in the K_{ij} curve. These phenomena correspond to shear resonances and anti-resonances of the strip, leading to local minima and maxima, respectively. Only the wall-wall path for a configuration without static preload does not follow this trend. A potential explanation for this is that the values are limited due to parasitic airborne sound transmission. Despite the mineral wool shielding $K_{ij,\text{max}}$ is only slightly higher in the frequency range with these resonances. Due to the proximity to this upper limit, the true strip behavior with resonances may not be observable unless parasitic airborne sound is reduced further. This is also the case around 400 Hz. Each lower K_{ij} curve for transmission paths across the strip does display these dips and peaks because they are sufficiently low to avoid the upper limit imposed by parasitic transmission. Similar to the reference junction, increasing the static preload lowers K_{ij}, especially at higher frequencies, due to the improved contact area at the junction, added friction and stiffening of the resilient material. Typically, it requires higher preloads for junctions with resilient strips to reach convergence as these materials allow for more elastic deformation than timber. In this case, the results at 25% and 50% are already very close together. By adding the resilient strip, regardless of the static preload, K_{ij} is increased 5 to 15 dB relative to the reference junction, depending on the frequency band.

In the final example, several configurations with varying resilient strips are compared. Next to the reference junction and polyurethane foam strip from the previous example, the strips consist of a filled vulcanized natural rubber (2 strips with a thickness of 6 mm each, design load of 0.8 MPa) and a resin-bonded recycled granulate rubber (1 strip with a thickness of 10 mm, design load of 0.6 MPa). Figures 7 and 8 display the comparison of K_{ij} for the top corner path of each configuration for the cases of no static preload and a preload at 75% of the prescribed design load, such that convergence of K_{ij} is reached. For the wall-wall transmission path, similar conclusions apply and results are therefore omitted from this paper. For the unloaded case, all resilient strips result in significant improvements relative to the reference junction with no strip. The polyurethane foam has the best performance followed by the natural rubber. All resilient materials showcase a similar trend with high-frequency dips and peaks due to (anti-)resonances, although the corresponding frequencies may shift due to the different material stiffness and thickness. Similarly, a high internal damping of the interlayer can limit their amplitude. In the case with a high external load, all curves show a similar downward shift as the compression of the strip allows for more efficient vibration transmission. Especially the rubber strips exhibit a strong decrease of K_{ij}, while for the polyurethane foam this effect is more limited. Considering the resilient strips are used in practice at a similar static preload due to the upper floor levels supported on the wall, the polyurethane foam strips may be the most efficient to reach a sufficiently high K_{ij}.

4. Conclusions

This paper gives an overview of an experimental campaign of flanking sound transmission measurements an a CLT X-junction. The vibration reduction index K_{ij} was determined for configurations where the top wall is either directly supported on the floor or resilient strips of various materials are placed in between. An additional parameter is the static preload of the junction supplied by a hydraulic press exerting a line load on the top wall. For the reference junction without a resilient strip, this external force leads to a larger contact surface area between walls and floors and increased junction stiffness and, therefore,

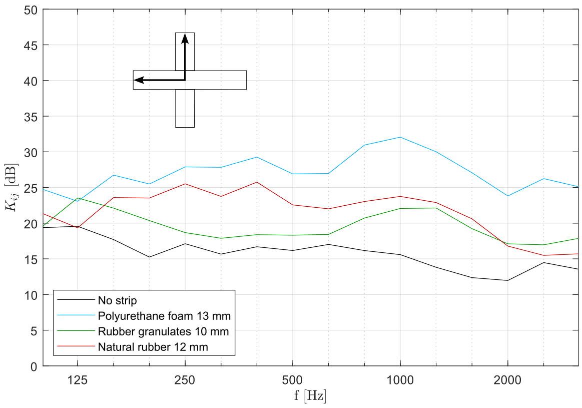

Figure 8: Vibration reduction indices for the top corner transmission path for a static preload of 75% of the strip design load on a junction with varying resilient strips.

more efficient vibration transmission for any paths across these interfaces. The measured K_{ij} values converge for a line load approximately at 12 kN/m when no additional friction can be added to the interface. When a resilient strip is added, additional load dependency comes into play: that of the stiffness of the interlayer material. The highest K_{ij} values were obtained with a polyurethane foam strip for experiments both with and without static preload. Both the natural rubber and recycled rubber granulate strips still improve upon the reference junction. Especially the natural rubber layer performs only slightly worse than the polyurethane foam. However, the performance of both rubber layers decreases to a high extent when a preload is present. As a result, the polyurethane foam strips are the most effective overall to improve K_{ij} from this material selection. The static preload acting on the junction should be considered in the experimental determination of K_{ij} due to its presence in building junctions with upper floor levels and due to its strong influence on the measured values.

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