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The measurement of structure-borne noise for constructions of cross-laminated timber floors with lightweight timber framed interior walls

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ABSTRACT

The new four-room flanking facility at the National Research Council Canada has been used to measure the velocity level difference for junctions of cross-laminated timber floors and non-loadbearing lightweight timber walls. This combination of elements is typical of mass timber constructions in Canada, but neither velocity level difference data nor normalized level difference data for these types of constructions has been available for designers to estimate the apparent sound transmission loss of these constructions. The measurements in the flanking facility include different combinations of cross-laminated timber floors and lightweight timber walls as well as different floor and ceiling linings. The goal in part is to develop new empirical models for the velocity level difference as well as to develop guidance for refining the prediction method described in the standards, ISO 12354-1 and ISO 10848-1.

INTRODUCTION

Mass timber buildings have gained popularity in Canada since provincial building codes allowed for buildings of heights over ten stories. Furthermore, the adoption of mass timber buildings as a substitute or as a complement to concrete and steel could cut embodied emissions in buildings by as much as 25% [1]. Between 2013 and 2017, the Government of Canada invested \$5 million CAD through Natural Resources Canada's Tall Wood Building Demonstration Initiative to demonstrate the commercial viability of tall wood building construction [2].

A popular timber construction in Canada uses cross-laminated timber (CLT) elements for the exterior walls and the floors of a building, lightweight timber framed walls are used for the non-loadbearing interior walls. This hybrid construction is popular due to the familiarity and ease of building timber framed walls and the ease of running electrical, HVAC and plumbing through the wall cavities. However, the lack of acoustic data available that can be used to demonstrate compliance with the acoustic requirements of provincial, territorial or national building codes is a barrier to the use of these hybrid constructions. The lack of data often results in constructions that are overdesigned to ensure compliance with building code requirements, adding cost to the project.

The National Building Code of Canada [3] includes acoustic requirements based on the apparent sound transmission class (ASTC) rating. One method of demonstrating compliance with the acoustic requirements is to estimate the ASTC rating using the method described in the standard, ISO 12354-1 [4], but implemented using ASTM metrics as described in the Research Report RR-331 [5]. The calculation of the ASTC rating requires the knowledge of the structure-borne sound transmitted through the junctions between building elements in the form of the vibration reduction index (K_{ij}) for Type A elements such as concrete walls or floors or the normalized direction-average vibration level difference $(\overline{D_{v,ij,n}})$ for Type B elements such as timber or steel framed walls or floors. For hybrid constructions of Type A elements and Type B elements, a new metric called the standard direction-average velocity level difference $(\overline{D_{v,ij,s}})$ has been proposed [6]. While the standard, ISO 12354-1 includes an Annex of empirical data for the K_{ij} values for Type A elements, the calculations in the Annex are not applicable to the CLTs used in Canada nor to Type B elements such as the timber-framed lightweight walls. Therefore, the $\overline{D_{v,ij,s}}$ values must be determined experimentally from measurements made either in a dedicated laboratory facility or in the field as described in the standard, ISO 10848-1 [7].

FLANKING FACILITY

The National Research Council Canada (NRC) constructed a new four-room flanking facility in 2019 to replace the older eight-room and four-room facilities. The new four-room facility shown in Figure 1 was designed to be in full compliance with ISO 10848-1. It was also designed with material handling in mind and the open design allows for the construction and evaluation of heavy elements such as CLT or concrete floors and even exterior glass curtain walls. The four-room flanking facility is used for both the measurement of the velocity level difference using an electromagnetic shaker and accelerometers mounted on each element and for the measurement of the normalized flanking sound level difference $D_{n,f,ij}$ using loudspeakers and microphone arrays located in each room. An advantage of using the flanking facility for both sets of measurements is that shielding can be used according to ISO 10848-1 to measure the flanking sound level difference for each path. This allows for the comparison between flaking sound reduction index R_{ij} for each path calculated using the K_{ij} values and calculated using the $D_{n,f,ij}$ values.

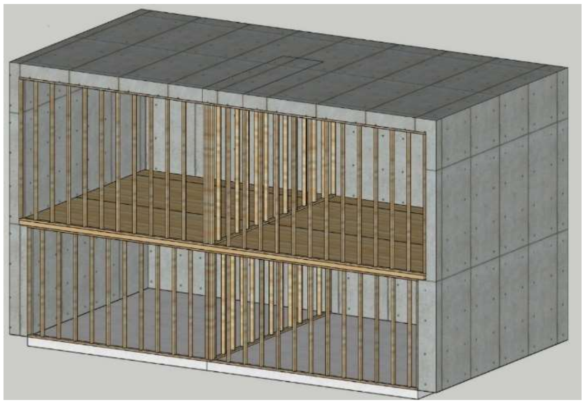

Figure 1: Model of the flanking facility

The first construction to be installed in the facility was a 140 mm thick 5-ply CLT floor with lightweight timber floors with timber framed walls. Several iterations of this construction have been evaluated to date with different interior wall constructions and different linings installed on the CLT floor and ceilings. Figure 2 shows the CLT ceiling and the lightweight walls in one of the lower rooms. Figure 3 shows the CLT floor and the lightweight walls in one of the upper rooms. The figure also shows the electromagnetic shaker suspended from the ceiling of the facility and attached to a lightweight wall.

VELOCITY LEVEL DIFFERENCE MEASUREMENTS

The velocity level difference $D_{v,ij}$ for each flanking path in the facility, including higher order paths was measured in full compliance with ISO 10848-1. Six excitation positions and twenty-two measurement positions per element were used. ISO 10848-1 requires that the measurement positions be located within a defined area with a minimum of 0.5 m between measurement positions. The measurement positions were marked out on each element by drawing circles around each point to ensure the minimum distances between positions was maintained. Steel tabs were glued to the elements at each measurement position and the accelerometers were attached to the elements using magnets. An electromagnetic shaker, shown in Figure **4** was used as a source for all of the elements. In addition to the shaker, a tapping machine was used as a source for the floors.

Measuring twenty-two positions on both sides of eight elements simultaneously would be a challenge in terms of cost and organization and instead only two accelerometers were used per surface. A procedure was followed where the background surface velocity was measured followed by the measurement of the surface velocity with the source operating. The accelerometers were then moved to the next measurement positions and the procedure repeated. The structural reverberation time was also measured. This resulted in eleven sets of measurements per shaker position.

Figure 2: Photo from one of the lower rooms showing the CLT ceiling and the lightweight walls

Figure 3: Photo from one of the lower rooms showing the CLT ceiling and the lightweight walls

Figure 4: A 100 N shaker attached to the CLT ceiling. An impedance head attached to the stinger allows for the measurement of the mobility.

The velocity level difference was calculated for each set of measurement data according to:

$$D_{v,ij,m,q} = 10\log\left(\frac{v_{i,m,q}^2}{v_{j,m,q}^2}\right) \tag{1}$$

where $v_{i,m,n}^2$ is the squared velocity measured on element i at position q for shaker position m. The average velocity level difference from element i to element j for all of the shaker positions and the measurement positions is calculated according to:

$$D_{v,ij} = \frac{1}{MQ}\sum_{m=1}^{M}\sum_{q=1}^{Q} 10\log\left(\frac{v_{i,m,q}^2}{v_{j,m,q}^2}\right) \tag{2}$$

where M is the total number of excitation positions and Q is the total number of measurement positions on each element i and j. For example, for two shaker positions and two accelerometer positions per element:

$$\begin{aligned} D_{v,ij} &= \frac{1}{4}\Bigg[10\log\left(\frac{v_{i,1,1}^2}{v_{j,1,1}^2}\right) + \\ &10\log\left(\frac{v_{i,1,2}^2}{v_{j,1,2}^2}\right) + 10\log\left(\frac{v_{i,2,1}^2}{v_{j,2,1}^2}\right) + 10\log\left(\frac{v_{i,2,2}^2}{v_{j,2,2}^2}\right)\Bigg] \end{aligned} \tag{3}$$

It is important to note that two accelerometer positions per element is far too few and the number was only used for this example.

New guidance for the actual number of excitation and measurement positions is being developed based on measurement data for the next version of ISO 10848-1. A task group has been created as part of TC 43/SC 2/WG18 to review the standard with the goal of updating the measurements based on the experience gained with making the measurements over the past three decades as well as to make the standard easier to understand for new users.

RESULTS FROM THE MEASUREMENTS

The data which is being collected from the flanking facility will be made publicly available in the third edition of the research report, RR-335 [8] which is estimated to be in released 2027. The third edition will also include velocity level difference measurements from mock-junctions between CLT elements such as that shown in Figure 5. The mock junctions (both X and T junctions) were built to evaluate the velocity level difference when different fasteners between the elements were used both with and without resilient layers. Different fastener spacings are also being evaluated since this affects the velocity level difference. It is envisioned that the large data set for different combinations of elements and fasteners will allow for the development of empirical models for the prediction of the K_{ij} values for CLT elements.

The data will also be used for the refinement and transition to ASTM metrics of the equations used to estimate the apparent impact insulation class (AIIC) rating in buildings. While Canada currently lacks requirements for impact insulation in any of the provincial, territorial or national building codes, the NRC has been researching the appropriate metric to use in the requirements once they are introduced in the National Building Code of Canada. The research will be published in a companion report to RR-331.

Figure 5: A mock cross-junction between two CLT walls connected with brackets spaced 400 mm on center. The mock-junction is located in a new K_{ij} measurement area with an isolated floor. A layer of resilient material is located between the elements and the floor.

Lastly, the measurements in the flanking facility have provided the opportunity to evaluate proposed changes and additions to the ISO 10848-1 standard. For example, a difficulty with using the tapping machine as an excitation source is the loud airborne noise that it generates while operating. This airborne noise has the unattended consequence of inducing vibrations in all of the elements in the source room which is not insignificant. These additional airborne noise induced vibrations are then transmitted through the junctions to the elements in the receiving room. The influence of this parasitic noise is being evaluated by comparing the $D_{v,ij}$ measured between the floors and the other elements with the tapping machine and with the shaker. In addition, an insulated box was suspended over the tapping machine at a height of 15 mm from the floor to reduce the parasitic noise, but without mass loading the floor. The results of these tests will contribute to guidance for the reduction of parasitic noise.

Another aspect of the research is to evaluate different methods of shielding elements during the measurement of the normalized flanking sound level difference $D_{n,f,ij}$. For these measurements, Section 9 of the standard ISO 10848 recommends adding layers of gypsum board and fibrous material to all of the elements not included in the flanking path to be evaluated. However, for lightweight timber framed walls, it is important to avoid changing the transmission of structure-borne noise by directly fixing the shielding to the element or otherwise adding mass to the element. It is hoped that better guidance can be developed for the revised standard from the measurements in the flanking facility.

DISCUSSION AND CONCLUSIONS

The measurements being made in the new four-room flanking facility according to the standard, ISO 10848 are providing an abundance of data that will be made publicly available in research reports. The availability of the data will support the use of CLT and timber framed elements in buildings as a means to reduce embodied emissions in buildings. The data is also being used to support the proposed changes to the ISO 10848 standard to make it easier to use.

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