DIRECT IMPACT SOUND INSULATION OF CROSS LAMINATE TIMBER FLOORS WITH AND WITHOUT TOPPINGS

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ABSTRACT

Cross Laminated Timber (CLT), which is well suited for construction of tall buildings, is becoming a more popular construction material in North America. However, to ensure comfortable living conditions, sound insulation measures are necessary. The study presented here compares results of direct impact sound insulation of 5- and 7-ply CLT floors covered with different a concrete toppings on various interlayers. Improvements of up to 21dB in Weighted Normalized Impact Sound Pressure Level ($L_{n,w}$) were observed using a newly proposed reference floor for CLTs. Furthermore, the improvements of floor coverings on CLT floors are compared to those achieved on other types of construction, such as the reference concrete floor. The improvements of $L_{n,w}$ tend to be higher on the concrete floors than on the CLT floors tested. These and other findings will be presented.

Keywords: Impact Sound, Insulation, CLT, reference curve I-INCE Classification of Subjects: 51.4, 51.5

1. INTRODUCTION

A series of tests was conducted at the National Research Council of Canada on CLT floors, walls, and CLT building mockups to ensure newly developed design details will meet occupant satisfaction regarding fire, moisture, and airborne and impact sound insulation. Different linings (like floating floors, suspended ceilings and gypsum board wall linings) were applied to both sides of the CLT wall and floor specimens. This paper will focus on the effect of modifications made to the top side of the CLT floors – adding floor coverings - and their effect on sound insulation, more specifically on impact sound insulation.

After describing the measurement and analysis procedures, the obtained improvements achieved with floor coverings on CLT floors will be compared to those on concrete floors. As an important outcome of the study, a newly developed reference impact noise level spectrum for CLT floors will be introduced and used to quantify the impact noise improvement due to added floor coverings.

2. MEASUREMENT AND ANALYSIS PROCEDURE

2.1 Impact Sound Insulation

The normalized impact sound pressure level, L_n, was measured according to the test protocol in ISO 10140-3 [1] in the NRC Construction Floor Sound Transmission Facility. The facility consists of two structurally isolated rooms, one above the other, with a test opening that can accommodate a test frame with a 4.04 m wide and 4.96 m long floor specimen. The upper and lower rooms each have a volume of approximately 175 m^3. From the measured 1/3-octave normalized impact sound pressure levels (NISPL or L_n) the weighted normalized impact sound pressure level, $L_{n,w}$, a single number rating, is calculated according to ISO 717-2 [2]. A lower value of $L_{n,w}$ represents a higher impact sound insulation performance of the floor.

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2.2 Improvement of Impact Sound Insulation

The improvement of impact sound insulation due to a floor covering is also calculated according to the procedure in ISO 717-2. To do this, data sets of three floors are needed: the weighted and 1/3-octave band NISPL of the bare floor, of the floor with the floor covering of interest, and of a reference floor. The first two are obtained during the test. The reference floor values are generalized data that are listed for common floor types in standards and are necessary to be able to obtain comparable values of improvement that can be related between laboratories [2].

Generally, L_n and $L_{n,w}$ are used to describe the 1/3 octave band and weighted NISPL, respectively. However, in this paper, to better explain the procedure described in ISO 717-2, results of the bare and covered floor are distinguished using the following terminology.

Table 1: Terminology used for measured and reference floors with and without toppings

Covering		Measured	Reference
Without	NISPL (1/3 oct)	$L_{n,0}$	$L_{n,r,0}$
	Weighted (single number)	$L_{n,0,w}$	$L_{n,r,0,w}$
With	NISPL (1/3 oct)	$L_{n,c}$	$L_{n,r,c} = L_{n,r,0} - \Delta L_n$ $= L_{n,r,0} - (L_{n,0}-L_{n,c})$
	Weighted (single number)	$L_{n,c,w}$	$L_{n,r,c,w}$

After the measurements have been completed, the 1/3-octave band level differences between bare and covered floor are calculated to obtain the frequency dependent improvement $\Delta Ln = (L_{n,0}-L_{n,c})$. Next, this difference is subtracted from the bare reference curve ($L_{n,r,c} = L_{n,r,0} - \Delta L_n$) and weighted, to get $L_{n,r,c,w}$. Finally, the difference between the single number rating of the bare reference floor and of the simulated reference floor with covering is calculated to yield the improvement called ΔL_w in the standard. This single number value allows for a simple comparison of the impact sound insulation improvement of different floor coverings, measured in the same or different laboratories.

However, since the improvement is different depending on the type of base floor used in the test, different groups of reference floors are specified in the test standards. Currently, three reference curves exist in ISO 717-2 and ISO 10140-5 [3] for four different types of floors: one heavy concrete, and three lightweight (C1,2, & C3) wooden joist floors. The ISO nomenclature for these three reference curves and their corresponding single number ratings can be seen in Table 2 below.

Table 2: Difference between terminologies used in ISO standards and this paper to describe impact metrics

Publication		Heavy	Light C1,2	Light C3	CLT	Measured
ISO 717-2 ISO 10140-5	NISPL (1/3 oct)	$L_{n,r,0}$	$L_{n,t,r,0}$	$L_{n,t,r,0}$		
	Single Number	ΔL_w	$\Delta L_{t,1,w}$ $\Delta L_{t,2,w}$	$\Delta L_{t,3,w}$		
This paper	NISPL (1/3 oct)	$L_{n,r,0}$(H)	$L_{n,r,0}$(L1,2)	$L_{n,r,0}$(L3)	$L_{n,r,0}$(CLT)	
	Single Number	$\Delta L_{n,w}$(H)	$\Delta L_{n,w}$(L1,2)	$\Delta L_{n,w}$(L3)	$\Delta L_{n,w}$(CLT)	$\Delta L_{n,w}$(Meas)

The table also shows that no reference curve exists in the standards for CLT or similar solid lightweight floors. A proposed CLT reference curve will be presented later together with some results after introducing the specimens. The main purpose of this table is to introduce the descriptors used in this paper for more clarity, and to introduce the new metric under the “Measured” column, which is simply the difference between the weighted single number rating of the measured bare and measured covered floors ($\Delta L_{n,w}(Meas) = L_{n,0,w} - L_{n,c,w}$). This metric is most relevant for comparing covering improvements measured in the same lab and on the same base floor.

3. SPECIMEN DESCRIPTION

The CLT and concrete assemblies considered in this study are referenced by a series of short codes identifying the elements from the top to the bottom layer. The number following each short code is the thickness of the layer in mm. For example, CON38_RESL9_CON200 indicates a 38 mm concrete topping installed on a 9 mm resilient interlayer on top of a 200 mm concrete slab. The four base floor assemblies that are investigated in this paper are:

— CLT5: 5 ply - 175 mm thick; area density = 90 kg/m^2
— CLT7: 7 ply - 245 mm thick; area density = 130 kg/m^2
— CON150: 150 mm thick; area density = 375 kg/m^2
— CON200: 200 mm thick; area density = 500 kg/m^2

with one floor covering:

— CON38: 38 mm thick; area density = 100 kg/m^2

installed on selected different resilient mats (mostly on the CLT5 floor):

— None: no mat
— RESL8: 8 mm thick shredded rubber with 4 mm dimples
— RESL9: 9 mm thick closed-cell foam
— RESL13: 13 mm thick rubber nuggets on plastic foil
— RESL17: 17 mm thick shredded rubber with 8 mm dimples
— WFB11: 11 mm thick wood fiber board
— FELT19: 19 mm thick felt

4. RESULTS

Three comparisons are made in this section. The first is between the different bare assemblies (see Figure 1). The second is between the 38 mm concrete topping (CON38) on the RES9 resilient interlayer on the concrete and on the CLT base assemblies. The third is with various resilient interlayer mats only on the CLT5 floors.

4.1 Bare assemblies and reference curves

Both CLT curves and both concrete curves follow the same trend, whereby the concrete floors throughout most of the frequency range have a lower NISPL, indicating better performance. Within one type of construction (CLT or concrete), the heavier floor has the lower $L_{n,w}$, meaning higher impact insulation performance. The reference curve for the concrete floors is according to ISO 717-2, whereby the CLT reference curve is defined in this paper to start off with a slope of 6dB/oct until 500Hz (mass law), where it reaches a plateau at 84dB and drops of after 1kHz at 9dB/oct followed by 15dB/oct after 2kHz.

The shapes of the reference curves match quite well the shape of the corresponding measured curves. However, for the concrete case the measurement curves slope much steeper in the lower frequency range than the corresponding heavy concrete reference curve.

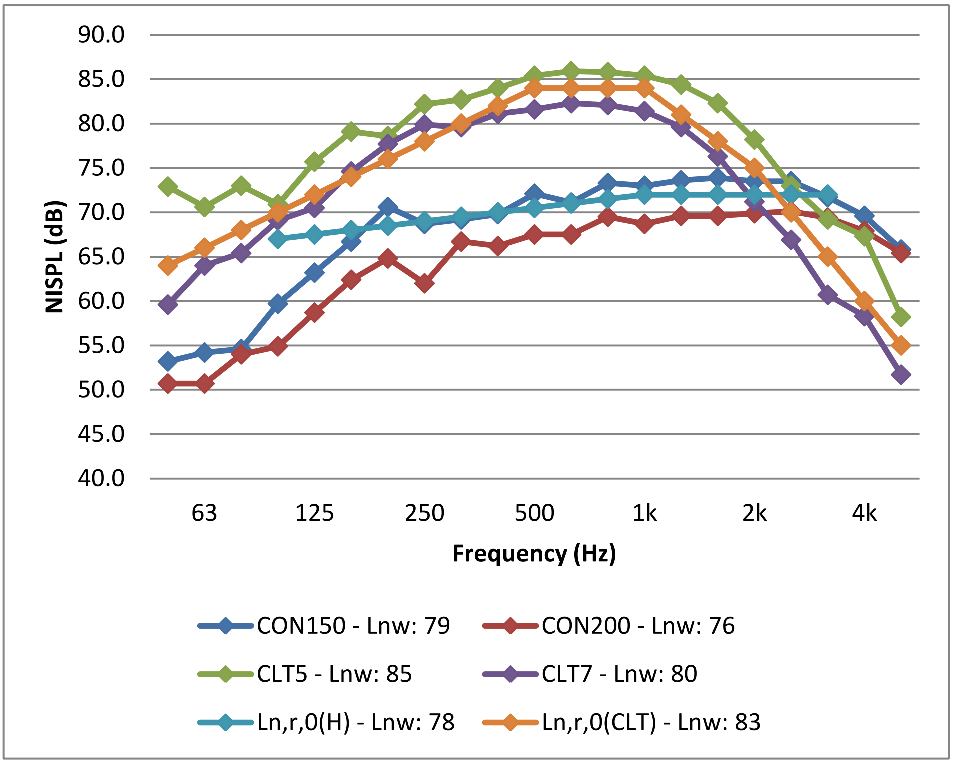

Figure 1 – Measured NISPL of bare CLT and concrete floors, and ISO reference curve for heavy concrete floors and preliminary NRC reference floor for CLTs

4.2 One topping on different base assemblies

The improvement due to adding a 38 mm concrete floor covering on a 9 mm resilient interlayer mat to the CLT and concrete base floor is presented in Figure 2.

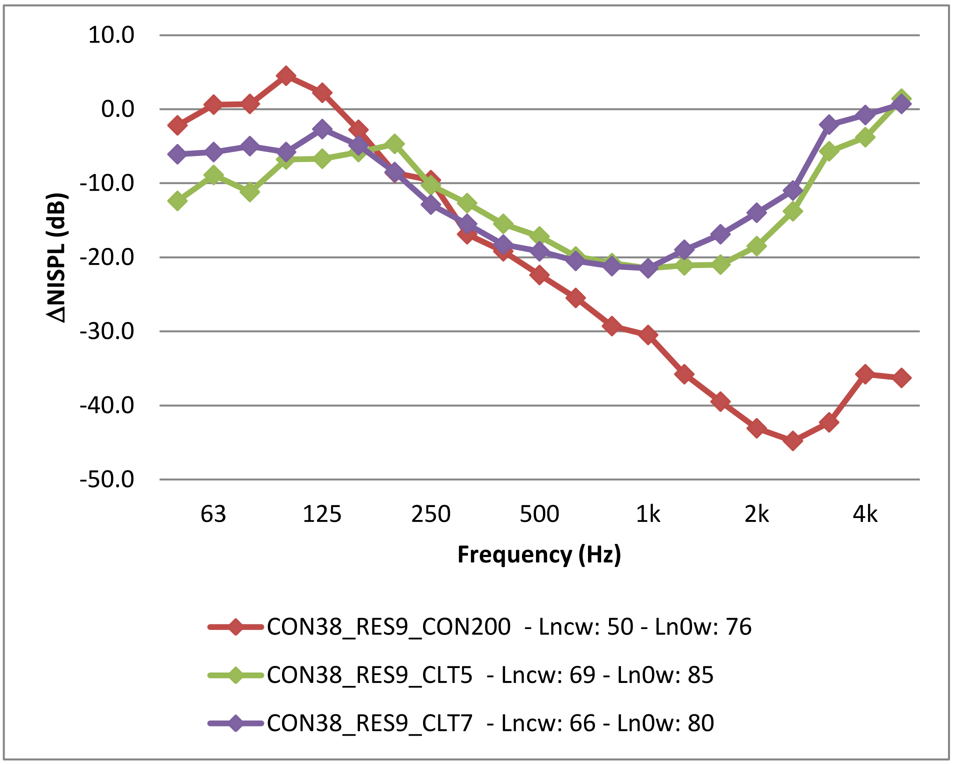

Figure 2 – Improvement of NISPL due to adding CON38_RES9 on the CON200, CTL5 and CLT7 floors

At the low frequencies, around 50Hz, where only the relative mass increase affects the results, the most improvement can be found for the lightest base assembly (CLT5), and the least improvement for the heaviest base assembly (CON200). A slight worsening can be observed for the CON200 case around 125Hz, which stems from a resonance created by the mass of the covering (CON38) and low stiffness of the resilient interlayer (RES9). This resonance is not as pronounced for the CLT floors, probably because the CLT base floors are less stiff than the concrete ones, which leads to less compression of the resilient layer needed to cause a distinct resonance. Above the resonance there is a great improvement due to the topping that is very similar for both CLT floors. The improvement on the concrete floor continues to much higher frequencies than for the CLT floors. The decrease of improvement for the CLT floor is most probably due to the increase of power injected into the concrete topping relative to the power injected into the bare CLT floor, due to impedance matching of the hammers and the surface of the bare CLT assemblies.

The single number ratings below in Table 3 show the same improvements using the reference curve technique explained above. The table also highlights how important the choice of the correct reference curve is for calculating the single number improvement $\Delta L_{n,w}$ by comparing the results using all four reference curves and the measured improvement difference, $\Delta L_{n,w}$(Meas) for the three floor assemblies from Figure 2.

Table 3: Single number improvements calculated with different reference floors. “Diff” column is difference between $\Delta L_{n,w}$(Meas) highlighted in blue and $\Delta L_{n,w}$ using “correct” reference curve highlighted green.

Topping	**Base**	**$\Delta L_{n,w}$ (H)**	**$\Delta L_{n,w}$ (L12)**	**$\Delta L_{n,w}$ (L3)**	**$\Delta L_{n,w}$ (CLT)**	**$\Delta L_{n,w}$ (Meas)**	**Diff**
CON38_RESL9_	CON200	21	5	11	20	26	5
CON38_RESL9_	CLT5	14	9	12	17	16	-1
CON38_RESL9_	CLT7	10	8	12	16	14	-2

The ranking of the single number improvements on the different floors shows the topping performs best on CON200, followed by CLT5, and finally, CLT7, except when using the lightweight reference curves. Using the lightweight reference curves obviously makes no sense, but demonstrates that the improvements and ranking of the floors can get totally mixed up. In both cases using the lightweight reference curves the CON200 floor shows the least improvement. For L3 there is no significant difference between the three floors. Using the lightweight reference curve for the heavy concrete and CLT floors is quite extreme and an unfair challenge, but it highlights how important the correct shape of the curve is, and that if it is off, the ranking of the floor covering improvement could change.

The column highlighted in blue, $\Delta L_{n,w}$(Meas), shows the number that might be most interesting, when making comparisons within the same lab. Note that for the CON200 floor these improvements differ from the standard improvements $\Delta L_{n,w}$(H) by 5 dB. This is probably due to the discrepancies mentioned earlier between the measured concrete bare and concrete reference curves at the low frequencies. The suggested CTL reference curve has more similarities to the measured curves, which is why the difference between the deltas is only -2 dB. However, before testing the suggested CLT curve in other labs, a statement of its relevance cannot be judged, as it was designed around data measured in this same lab.

To put the proposed CLT reference curve under more testing, the improvement of different toppings is compared below in Table 4. The toppings tested show improvements ranging from 6 to 22 dB whereby FELT19 as an underlay performs best. The worst underlay besides placing the topping directly on the floor with a 7 dB improvement, was RES8 with 14 dB improvement. This table also shows that there is only a difference of up to 1 dB when comparing the single number improvements using the CLT reference curve, $\Delta L_{n,w}$(CLT), and the measured differences, $\Delta L_{n,w}$(Meas). This is a sign that the developed CLT reference curve works quite well in this laboratory under the conditions tested.

Table 4: Single number improvements of different toppings on CLT5 calculated using CLT reference floor ($\Delta L_{n,w}(CLT) = L_{n,r,0,w} - L_{n,r,w}$) and using difference of measured single numbers ($\Delta L_{n,w}(Meas) = L_{n,0,w} - L_{n,c,w}$)

Topping	$\Delta L_{n,w}$ (CLT)	$\Delta L_{n,w}$ (Meas)	Diff	$L_{n,r,0,w}$	$L_{n,r,w}$	$L_{n,0,w}$	$L_{n,c,w}$
CON38_RES9	17	16	-1	83	66	85	69
CON38_WFB11	15	14	-1	83	68	85	71
CON38_RESL8	14	13	-1	83	69	85	72
CON38_RESL17	20	19	-1	83	63	85	66
CON38_RESL13	21	21	0	83	62	85	64
CON38_None	7	6	-1	83	76	85	79
CON38_FELT19	22	21	-1	83	61	85	64

5. SUMMARY AND CONCLUSIONS

Firstly, comparisons were made of a 38 mm concrete floor covering on 9 mm resilient close cell foam mat on a CLT5, CLT7 and 200 mm concrete floors. The results showed that although the mass-spring resonance of the topping was most predominant in the case of the concrete floor, the topping achieved the highest improvement on the concrete floor. Furthermore, it was shown that the ranking of the improvement of floor toppings is highly dependent on the shape of the reference curve, which is why a CLT reference curve, currently not available in any standards, was developed.

The CLT reference curve, based on the measurements conducted, seems to work quite well for the lab and floor used for its development. However to ensure it is reliable it should be tested in a round robin series at multiple labs with multiple floors and floor coverings and tuned again thereafter.

Seeing that the heavy concrete reference curve delivered weighted improvements that were quite different from those calculated through weighted NISPL differences (with and without floor covering), suggests that it might need revision, too. These discrepancies are most probably due to the overestimation of the reference curve at the low frequencies. For such an undertaking, other lab data will need to be consolidated also.

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