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INFLUENCE OF MECHANICAL FASTENER SPACING ON ACOUSTIC PERFORMANCE IN TIMBER COMPOSITE PANELS

Aedan Callaghan[1], Wilson Byrick[2]

ABSTRACT: Mass timber construction is an increasingly common way of building taller and larger wood buildings utilizing renewable building materials with lower embodied carbon. With a lighter mass and higher flexibility relative to concrete, however, a mass timber panel provides relatively poor acoustic separation between adjacent spaces. This poor acoustic performance combined with the desire for exposed mass timber ceilings means that an additional subfloor layer decoupled by an acoustic interlayer, is often used to provide adequate separation between spaces within the building. In some structural systems, screw fasteners through the acoustic interlayer maybe required. This study investigates the deterioration of the airborne and structure borne sound transmission performance due to the addition of metal fasteners through interlayer 304.8 mm, 609.6 mm and 1219.2 mm on centre (o.c.). The change to both the airborne and structure borne sound transmission is directly related to the spacing of the fasteners, with the most significant decrease in performance noted between 200-4000 Hz. This data provides insight into the performance of composite timber floor systems requiring fasteners through the resilient interlayer and will assist with designing these systems with more certainty in regard to the sound transmission that will occur within the building.

KEYWORDS: Acoustics, Resilient Interlayer, Cross Laminated Timber

1 INTRODUCTION

Mass timber has rapidly gained popularity due to the lighter weight of buildings, faster speed of construction, and lower embodied carbon compared to concrete structures. The most common type of mass timber panel is cross laminated timber (CLT), where dimensional lumber is assembled in alternating directions perpendicular to the previous layer. The panels are then adhered with structural adhesive and pressed into panels, typically with an odd number of layers/plies (3-ply, 5-ply, 7-ply, etc.) [1].

However, with this lower mass and stiffness comes worse acoustic performance. A typical bare 3-Ply CLT at 104.8 mm thickness and having a mass of 53.66 kg/m^2 is measured as having a sound transmission class (STC) and impact insulation class (IIC) of 38 and 21 respectively [2]. To put this in context, the International Building Code (IBC) 2021 section 1206 requires STC 50 or higher and IIC 50 or higher to separate any living units with adjacent spaces [3]. This requires a robust assembly that can provide this 12-point improvement to STC and 29 point improvement to IIC.

To accommodate the desire for the mass timber ceiling to remain exposed, a resilient interlayer between the mass timber structural panel and an additional subfloor mass layer is the most common approach to improving the acoustics. This type of floating floor system can drastically improve both the airborne and structure borne acoustic performance of the timber floor panel. The resonance of floating floors (f_0) has been well studied and can be calculated based on spring stiffness (K_F), air stiffness (K_A) and mass sitting on the spring (m) as shown in equation (1) [4].

$$f_0 = \sqrt{\frac{K_A * K_F}{m}} \tag{1}$$

When the CLT or mass timber panel is designed as the full floor structural system, the additional topping can be fully decoupled and act as the mass layer needed for the floating floor. However, the use of timber composite floor systems can sometimes provide the most efficient structural system for a building and requires the timber and topping, typically normal concrete, to be mechanically connected to utilize the strength of both materials (timber typically in tension, concrete in compression) [1]. Given that a resilient interlayer is often the main form of added sound control to improve the acoustic performance, the addition of mechanical fasteners in this location will inhibit the overall acoustic performance. While many projects have utilized these composite systems with fasteners penetrating through the acoustic interlayer, little data is available to quantify the degradation on the airborne and structure borne sound

[1] Aedan Callaghan, Pliteq Inc, Canada, acallaghan@pliteq.com
[2] Wilson Byrick, Pliteq Inc, Canda, wbyrick@pliteq.com

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transmission of these composite panels compared to the fully decoupled floating floors.

Rigid or semi rigid penetrations through an acoustic isolation system are often referred to as a short circuit as they provide an unintended path for vibrations to travel and bypass the intended isolation system. Previous research on the effects of short-circuiting resilient channels with improper installation showed that the number of fasteners shorting out the resilient channels had a significant impact on performance [5]. Up to a 6dB decrease to the STC rating and 9 dB decrease to the IIC rating has been observed when the fasteners penetrating though the resilient channel into the joists were spaced at 609.6 mm o.c. by 406.4 mm o.c.

This study aims to provide a similar understanding of short circuiting of the resilient interlayer in mass timber. The effect of these short circuits and the influence of spacing will be analyzed with 3 different spacings of 304.8 mm, 609.6 mm and 1219.2 mm on centre (o.c.) based on some common timber concrete composite designs [6].

2 THE ASSEMBLY

A 3-Ply CLT assembly with resilient interlayer and wood subfloor was assembled at Intertek ATI floor ceiling acoustical test chamber. The test chamber has a top opening of 3023 mm by 3632 mm with the exposed area in the receiving room below of 2896 mm by 3505 mm. A plan view of the assembly is shown in Figure 2. Intertek-ATI is accredited to perform ASTM E90 and E492 by the International Accreditation Service.

A cross section of the assembly is shown in Figure 2. In order to be able to add the self-tapping screws in an iterative fashion, a thinner 3-ply CLT was selected as the subfloor panel. A summary of the components in the assembly with thickness and weight are provided in Table 1.

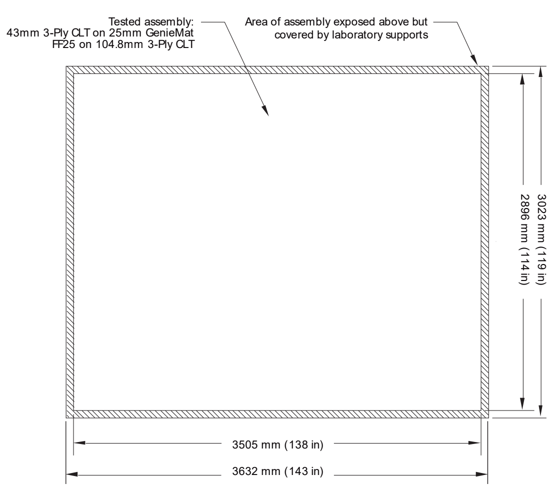

Figure 1: *Plan view of the tested assembly and lab chamber dimensions*

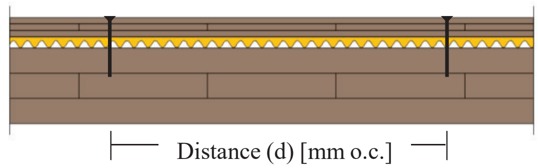

Figure 2: *Section view of the tested floor-ceiling assembly*

2.1 STRUCTURAL PANEL

A 3-ply cross laminated timber was used as the base structural panel for this testing. The panel measured at 104.8 mm thick panel with a mass of 53.66 kg/m^2.

2.2 RESILIENT INTERLAYER

A 25 mm recycled rebounded rubber elastomeric interlayer with a dimpled profile named GenieMat® FF25 was utilized as the decoupling material for this testing. It has an areal mass of 10.2 kg/m^2.

2.3 TOPPING

A thinner 3-ply CLT was used as the topping subfloor layer in this test series. It measured 44 mm in thickness with a mass of 23.43 kg/m2.

2.4 SELF-TAPPING SCREW

Fully threaded self-tapping screw with countersunk head 127 mm length were used for mechanically fastening the subfloor to the structural CLT and penetrate through the resilient interlayer.

Table 1: *Assembly component dimension and weights*

Component	Thickness (mm)	Mass (kg/m^2)
3-Ply CLT (Base)	104.8	53.66
GenieMat FF25	25	10.27
Thin 3-Ply CLT (subfloor)	44	23.43
Total	173.8	87.36

3 TEST PROCEDURES

The assembly was tested according to ASTM E90 and ASTM E492 with 3 different spacings of screws penetrating the resilient interlayer. These short circuits were created by fastening 9, 30 or 99 screws through the 44 mm subfloor panel and 25 mm GenieMat FF25 with 58 mm of embedment into the structural 3-Ply CLT panel. The assembly was tested with no short circuits. The first 9 screws were added at a 1219.2 mm o.c spacing. The assembly was then retested. The number of short circuits was increased to 30 at a 609.6 mm o.c. spacing and retested. Finally, the number of short circuits was

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increased to 99 with a 304.8 mm o.c. spacing. The locations of each short circuit are shown in Figure 3A-D.

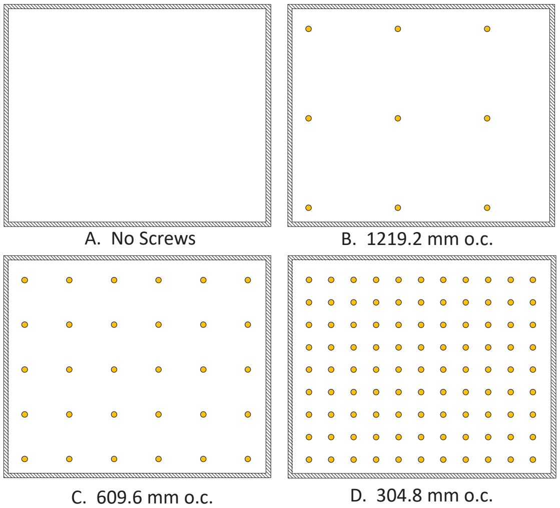

Figure 3: *Location of screws for the various configurations of short circuits. A: baseline case with no short circuits. B: 9 screws spaced 1219.2 mm o.c., C: 30 screws spaced 609.6 mm o.c., D: 99 screws spaced 304.9 mm o.c.*

4 RESULTS AND DISCUSSION

A summary of the STC and IIC single number ratings for each fastener spacing can be seen in Table 2. The STC rating decreased from 47 with no short circuits to 39 with screws at a 304.8 mm o.c. spacing. The IIC decreased from 41 with no short circuits to 35 with the screws at 304.8 mm o.c. for a total change of 6 IIC points. The HIIC was most affected by the increase in short circuits and decreased from 52 to 34 over the test series. Meanwhile the LIIC remained quite stable at 50-51 throughout all 4 tested assemblies.

Table 2: *Summary of STC and IIC performance*

Fastener Spacing (mm o.c.)	STC	IIC	HIIC	LIIC
None	47	41	52	50
1219.2	46	40	42	51
609.6	44	38	38	51
304.8	39	35	34	50

The 1/3 octave band frequency plots of transmission loss (TL) and normalized impact sound pressure levels (NISPL) for each test can be seen in Figure 4. While single number metrics are helpful for high level comparisons, the 1/3 octave band comparison provides further insight into the change in sound transmission at various screw spacings.

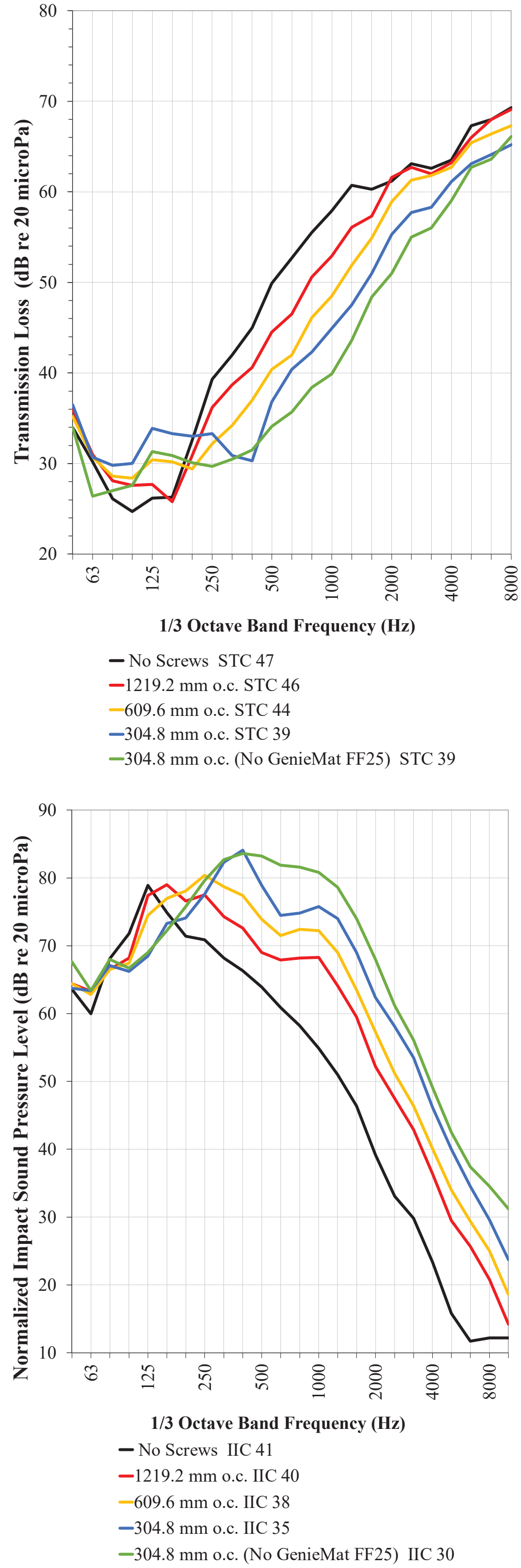

Figure 4: *Transmission loss (Top) and Normalized Impact Sound Pressure Level (Bottom) results of the tested assembly with various screw spacings*

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The data shows a relatively consistent shift to the curves with each sequential addition of more screws and reduced spacing. The TLs in the 250-2000Hz range all display a similar slope with an offset in the curves. Table 3 shows the change in TLs across that frequency range for each screw spacing. When the change in each sequential halving of screw spacing is compared, the decreases in TLs were 4 dB, 3.8 dB and 3.4 dB respectively with each increase in fasteners.

Table 3: *Change to TL at each screw spacing from 250-2000Hz*

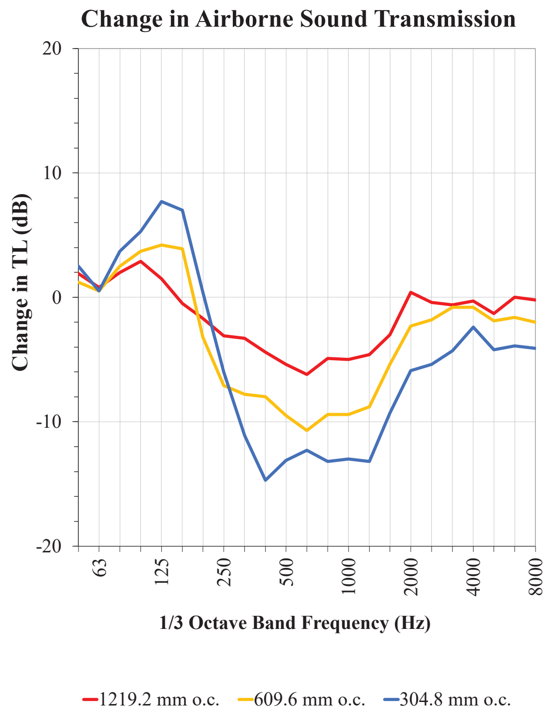
	Change to TL (relative to no screws)		
1/3 Octave Band (Hz)	1219.2 mm o.c. (dB)	609.6 mm o.c. (dB)	304.8 mm o.c. (dB)
250	-3.1	-7.1	-6.0
315	-3.3	-7.8	-11.1
400	-4.4	-8.0	-14.7
500	-5.4	-9.5	-13.1
630	-6.2	-10.7	-12.3
800	-4.9	-9.4	-13.2
1000	-5.0	-9.4	-13.0
1250	-4.6	-8.8	-13.2
1600	-3.0	-5.4	-9.3
2000	0.4	-2.3	-5.9
Average	-4.0 dB	-7.8 dB	-11.2 dB

When comparing the change in NISPL across the tests, the area with the most consistent shift of the curve appears to be the same frequency range of 250-2000Hz. This data can be seen in Table 4 and shows the average increase to NISPL for each spacing. Across the selected frequency range, the shift is greatest with an average increase in NISPL of 9.4 dB in going from no screw to the 1219.2 mm o.c. spacing with the relative change then 4.2 dB and 3.8 dB respectively for each addition of screws.

Table 4: *Change to NISPL at each screw spacing from 250-2000Hz*

	Change to NISPL (relative to no screws)		
1/3 Octave Band (Hz)	1219.2 mm o.c. (dB)	609.6 mm o.c. (dB)	304.8 mm o.c. (dB)
250	6.6	9.5	6.7
315	6.1	10.5	14.1
400	6.3	11.1	17.8
500	5.1	10.0	15.0
630	7.0	10.6	13.6
800	10.0	14.2	16.6
1000	13.4	17.3	20.9
1250	13.1	18.0	23.0
1600	13.1	17.1	22.6
2000	13.0	18.1	23.2
Average	9.4 dB	13.6 dB	17.4 dB

To better understand the trends across all 1/3 octave bands, the change to TL and NISPL for the 3 different screw spacings (relative to new screws) are plotted in Figure 5.



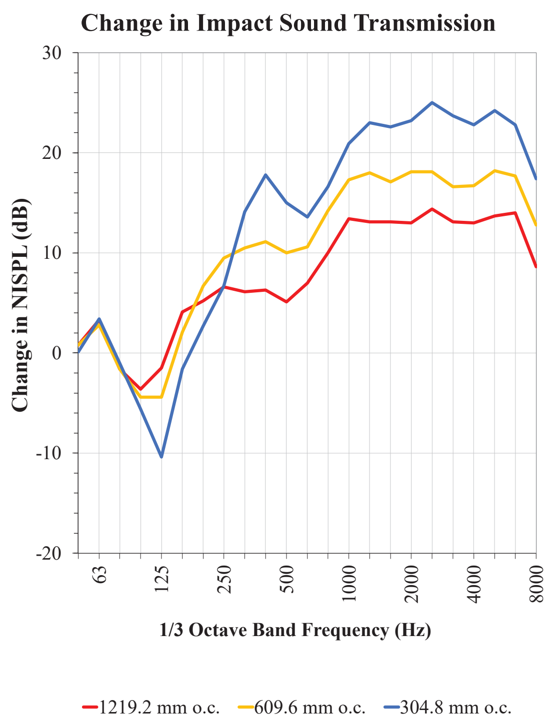


Figure 5: *Change in TL (Top) and NISPL (Bottom) across the 1/3 octave band frequencies.*

When looking at the change in performance in Figure 5, at mid and high frequencies, there is an increase in both airborne and impact sound transmission correlating to the addition of the fasteners through the GenieMat FF25 interlayer. This is in line with the expectation for rigid fasteners acting as short circuits. However, the change across both the TL and NISPL data show an inversion near 200 Hz. In both cases, some improvement from the addition of more fasteners is observed at the low frequencies below 200 Hz. There are no signs of error in the lab testing or issues with background noise at those frequencies, so the improvement is believed to be real. This low frequency range is considered the stiffness-controlled region so the addition of screws stiffening the overall assembly is likely contributing to this improvement.

To evaluate the role of stiffness, the GenieMat FF25 was removed, and the topping panel was reinstalled with fasteners returned at their 304.8 mm spacing. This showed similar low frequency NISPL behaviour, indicating this is fully due to the stiffening effect. However, the TL performance was worse without the resilient interlayer. The resilience and damping properties of the GenieMat FF25 may also be contributing by creating a constrained layer damping system.

Since higher frequency impact sound (400 Hz and up) is more easily rolled off simply by adding a finish floor on a thin recycled rubber underlayment like in concrete construction, a timber composite system that can improve the low frequency impact performance without requiring the addition of concrete could have major benefits. Further research is needed to determine what role the damping properties play and quantify the impact of stiffness compared to a constrained layer damping effect. A prefabricated timber panel. A timber composite system that does not rely on a high embodied carbon material such as concrete would offer a more sustainable system and could allow for further offsite fabrication with the full cassette ready for installation on site. Additionally, a composite panel system that does not incorporate poured concrete is fully de-constructable allowing for all components to be separated, reused and recycled.

5 CONCLUSIONS

The addition of screws penetrating through a resilient interlayer has a significant impact on the acoustic performance and must be considered for adequate STC and IIC performance. Up to a 25 dB increase in NISPL and up to a 14 dB decrease in TL were observed in comparing an assembly with no fasteners through the resilient interlayer to one with screws at 304.8 mm o.c. While very significant to the final performance, the fastener spacing is correlated to a gradual impact on airborne and impact sound transmission and can be taken into consideration during design of the structural system.

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